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1935 Index—Electrical Engineering and Transactions

This multientry annual reference index covers comprehensively the entire text content of the 12 issues of ELECTRICAL ENGINEERING published during 1935 and of the identical content of the 1935 A.I.E.E. TRANSACTIONS, volume 54.

Discussions have received particular attention and a special effort has been made to provide effective correlation between references to technical papers and to all published discussions of those papers. In this connection it is of importance to note that discussions of many technical papers published during the latter half of 1934 were published in the early part of 1935, and hence appear in this current index. Likewise, many discussions of the later 1935 papers will be published early in 1936, and consequently will not be found among the references contained in this current index.

For convenience in use, this index is subdivided into the following general divisions:

1. Technical subjects.
2. Authors, including the writers of discussions.
3. News items pertaining to Institute activities.
4. News items of a general nature.
5. Biographical (personal and obituary) items.

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Preface

This, the fifty-fourth volume of the TRANSACTIONS of the American Institute of Electrical Engineers, contains the entire text content of the 12 monthly issues of ELECTRICAL ENGINEERING published during 1935. This is the second in a new series of annual volumes initiated under the Institute's unified publication plan which became effective January 1, 1934.

Discussions of technical papers, printed in ELECTRICAL ENGINEERING from month to month as they become available, are thoroughly correlated in the comprehensive multi-entry annual reference index which begins on page 1426 of this volume. A reference to any of the several subject entries for any technical paper will lead directly to any discussion on that paper that may have been published during 1935. In this connection it is of importance to note: first, that, of 1934 papers, this volume contains all discussions published after December 1934; second, that, likewise, the discussion of many of the later 1935 papers will appear in the 1936 TRANSACTIONS by virtue of publication in ELECTRICAL ENGINEERING subsequent to January 1, 1936.

Errata

1. Page 117, equations 3a and 3b should read:

$$E_0 \frac{(4\pi h_1 h_2)}{\lambda d} \sqrt{1 + \frac{\epsilon^2 (h_1 + h_2)^2 \lambda^2}{(\epsilon - 1) 4\pi^2 h_1^2 h_2^2}} \tag{3a}$$

$$E_0 \left(\frac{4\pi h_1 h_2}{\lambda d}\right) \sqrt{1 + \frac{(h_1 + h_2)^2 \lambda^2}{(\epsilon - 1) 4\pi^2 h_1^2 h_2^2}} \tag{3b}$$

2. Page 168, figure 8, center oscillogram, lower curve trace should be designated "Load Voltage" and center curve trace should be designated "Tube Voltage."

3. Page 978, equation 2 should read:

$$i = E_{max} \frac{2}{\pi} \left[\frac{1}{R} - \frac{2}{3} \frac{1}{\sqrt{R^2 + (2\omega L)^2}} \cos\left(2\omega t - \tan^{-1} \frac{2\omega L}{R}\right) - \dots \right.$$

$$\left. - \frac{2}{n^2 - 1} \frac{1}{\sqrt{R^2 + (n\omega L)^2}} \cos\left(n\omega t - \tan^{-1} \frac{n\omega L}{R}\right) \dots \right] \tag{2}$$

4. Page 1144, second column, line 40, 45 degree should be 90 degree.

5. Page 1145, first column, line 7, 0.046 should be 0.026.

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Photo by Wendell Mc Rae

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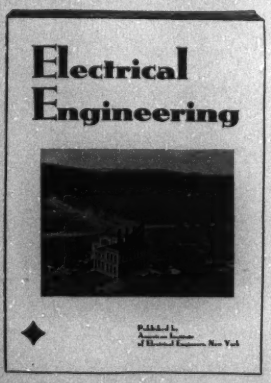

FOR the convenience of those readers wishing to preserve their copies of ELECTRICAL ENGINEERING for the year 1934, the Institute is prepared to perform this service at cost ($4.00 plus foreign postage).

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X Rays—What Should We Know About Them?

By GEORGE L. CLARK, Fellow Am. Phys. Soc.
University of Illinois, Urbana

Most engineers are familiar with some of the more common uses of X rays, and many have had occasion to apply them in their daily work; to many, however, the picture of this versatile tool and its numerous applications is quite incomplete. The latter will find this article particularly interesting and instructive. The nature of these rays, the mechanism of their production, and the fundamental principles underlying their many applications in medicine, physics, chemistry, biology, and industry are outlined briefly. Perhaps the most striking application is the determination of the ultimate fine structure of materials from the results of diffraction analysis, in which the X rays provide a supermicroscopic vision of matter. This is the thirteenth and concluding article of the "Science Series for Engineers" developed under auspices of the A.I.E.E. committee on education.

EVERY LAYMAN has come to the realization that the X ray department is an essential part of the equipment of every modern hospital or clinic. He also knows that the medical applications of these rays, discovered just 39 years ago, are classified as diagnosis and as therapy. He probably has seen the bones of his own hand held between the X ray tube and a fluoroscopic screen. He may have been a patient for whom broken bones were set, internal tumors discovered, foreign bodies exactly located and extracted without guess work, tuberculosis indicated or disproved, or a host of other ailments diagnosed from X ray films. He should be familiar with the fact that cancer and other pathological conditions are treated successfully by X rays or gamma rays from radium.

Again the layman may have heard that biologists have been producing all sorts of peculiar changes in fruit flies by X raying eggs; that physicists have been utilizing these same rays to explore the architecture of atoms; that chemists have been unfolding the building plan of crystals in some marvelous way with these rays; that all the welds in Boulder Dam construction are being subjected to some kind of an X ray test in the interest of soundness and permanence; that some of the greatest industries have X ray research laboratories in no way concerned with medical problems; but unless the layman has had special training, the nature of these rays, the mechanism of their production and measurement, and the fundamental principles of this versatile agency in medicine, physics, chemistry, biology, and industry may remain a mystery, and the full power and possibilities of the scientific tool unrealized.

So one may ask, first of all: What are these rays, designated originally by the letter "X" because of their mysterious nature, and sometimes by the name of the great German physicist who accidentally discovered them in 1895—Röntgen rays? They are invisible and have no electrical or magnetic properties whatever; and yet when they impinge upon certain chemicals and minerals these substances glow with a visible light. They blacken a photographic film just as light does. In passing through air or any other gas, they "electrify" or ionize the gas so that an electric current will flow between charged plates through the gas. Crystals such as rock salt reflect X rays at certain definite angles. Measurement also shows that under very special conditions they may be reflected from mirrors, refracted or bent very slightly in passing from air into a solid, diffracted by passing across lines ruled very closely together on glass, and polarized. Some of these latter properties immediately suggest light, for ordinary white light certainly can be reflected from mirrors, spread out into a spectrum or rainbow of colors by a prism or ruled grating, bent in passing from air into water or glass, and polarized. However, there are some marked differences apparently between light and X rays. The latter have the power of penetrating matter that is entirely opaque to ordinary light. This can be proved by placing the hand between the X ray tube and a photographic film or a fluorescent screen made of some chemical substances, such as zinc silicate, calcium tungstate, or barium platinocyanide, which glow under the action of X rays. The bones of the hand can be seen clearly outlined in finest detail. These rays have passed through the hand, but much more easily through soft tissue than through dense bones. In other words, a far greater absorption of the rays takes place in the bones than in the flesh, with the result that in the path of the bones less blackening of the film or brightening of the screen occurs than for adjacent areas, and a shadowgraph is produced. By virtue of this highly penetrative quality of X rays, the interior of the body or of any object can be examined easily without in any way cutting open or damaging the body or the object.

So one may conclude that X rays are like ordinary light in many respects, but differ at least in the property of penetration. Strangely enough, as these comparison are extended, it is found that at least a part of the cosmic rays permeating all space (which have been mentioned frequently in newspapers), the gamma rays from radium, X rays, ultra-violet light, visible light, infra-red or heat rays, and even radio waves, all have fundamental similarities. They

differ only in wave length. Light is to be considered as some kind of wave motion of electromagnetic origin since many of its properties can be explained only upon such a basis. Now yellow light can be shown to have a wave length a little less than 6,000 Ångström units, that is, 0.00006 centimeter (one Ångström unit is equal to 10^{-8} centimeter). X rays

Courtesy General Electric X-Ray Corp.

Fig. 1. Conventional type of modern Coolidge X ray tube

are just like light except that their wave lengths are very much shorter. Medical science ordinarily is interested in X rays with wave lengths of 0.1 to 1 Ångström unit, although shorter and longer waves have been measured and can be produced by the X ray machine. X rays are penetrating because of those short wave lengths; the shorter, the thicker will be the object through which the rays may penetrate. The cosmic rays, which man thus far cannot produce, probably penetrate 18 feet of lead or more.

The possibilities of future development are illustrated by the recent achievement of 2 Germans, Lange and Brasch, in producing X rays from a tube at 3,000,000 volts with a minimum wave length of only 0.004 Ångström unit. One such tube could produce rays of an intensity corresponding to that from a million dollars worth of radium. A half dozen hospitals in the United States now treat patients with X rays generated at a million volts.

Light is produced so abundantly by natural processes—illumination by the sun particularly—that one wonders next how X rays are produced. It is known that the gamma rays, which are the same as the very shortest X rays produced at the very highest voltages, come from spontaneously decomposing radioactive minerals on the earth. Unless X rays exist in the interior of the hot stars, as Jeans and Eddington maintain, nature cannot be depended upon to produce these valuable rays. Röntgen discovered X rays because he happened to be experimenting with a glass bulb. This bulb was nearly exhausted of air by suitable pumps, and 2 metal electrodes sealed into the bulb were connected with the terminals of an induction coil so that a high difference of potential existed between them.

Development of the X ray tube to the present highly efficient unit (which certainly can be improved still further) forms a most interesting story. With all the numerous modifications and designs for different purposes, all X ray tubes operate on the same principle. The essential parts of the X ray apparatus in the hospital are as follows: The tube in which X rays are produced, a high voltage transformer which supplies potentials of 100,000 volts or more from ordinary 110 or 220 volt a-c electric circuits, and a rectifier which changes alternating current to direct current so that one end of the X ray tube is always at positive potential and the other negative (although the X ray tube itself can rectify alternating current to direct current at potentials lower than 100,000 volts). In the X ray tube or bulb such as is illustrated in figure 1, which is exhausted of air to a very high vacuum, are 2 electrodes; one is a heavy piece of metal which looks like, and is, a target; the other consists of a fine spiral of tungsten wire which is heated to incandescence by a small independent electric current. Many years ago Edison, the great inventor, discovered that a hot wire emitted electrons, the tiny corpuscular negatively charged units of electricity. These electrons will pass at high speed across space to a positively charged electrode. In the X ray tube, therefore, a target (anode or anticathode) is bombarded by these minute electrical projectiles. The sudden stopping of these rapidly moving electrons results in X rays being generated at this target; a portion of the energy of motion is converted into radiation energy. The rays then pass out through the walls of the tube and through the body or other object. The higher the voltage, the faster will the electrons move and the "harder" or more penetrating or shorter in wave length will be the X rays.

All these phenomena, including the absorption of the rays in the human body, are governed by fundamental physical laws. The proper use of X rays for diagnosis and therapy involves absolute knowledge of the *quality* (or wave length distribution) of the rays and the *quantity* or dose. The proper voltage to apply to the X ray tube can be ascertained definitely for each medical application. Much "softer" rays (and lower voltages) will suffice for examination of a broken finger than for a complete chest radiograph. Skin diseases must be treated with soft X rays (voltages even as low as 8,000 volts for the so-called "grenz" rays) since only these will be absorbed—a process that necessarily must precede therapeutic effect. Rays with short wave lengths would pass through the skin layer with little

Fig. 2. Typical medical radiograph for location of foreign body (safety pin in throat of small baby)

or no effect. However, to reach a deep seated tumor the more penetrating rays must be used. If it were possible to generate X rays under given conditions with only a single wave length, the whole matter of medical X ray science would be greatly simplified; but, as a matter of fact, the beam generated in the X ray tube is quite heterogeneous and contains a wide range of wave lengths with widely varying absorbability and therapeutic effects. However, the whole heterogeneous beam will be found to have the same degree of absorption in a screen as some monochromatic ray (one with a single wave length). In other words, the complex beam has an "effective" wave length that is definite and that characterizes the beam always generated under the same conditions. The X ray technician may place a sheet of copper or aluminum in the beam to serve as a filter. These tend to make the X ray beam more nearly homogeneous by screening out the softer rays in the mixture, and thus control more perfectly the known characteristics of the beam.

Besides the quality, the quantity or dosage of X rays must be accurately controlled and measured, particularly in therapy if the best results are to be obtained, or indeed if deleterious effects of this powerful agent are to be avoided. In 1928 an international unit of dosage, the Röntgen unit or "*r*," based upon the ionizing power of the rays upon air, was adopted. Treatments for cancer, therefore, are designated in *r* units per minute.

Medical Diagnosis

Little need be said further concerning radiography or diagnosis by X rays, since this paper is not concerned with details of technic which must be gained by proper training and experience. Bones, teeth, foreign bodies (figure 2), and any dense parts are thrown immediately in shadow relief. A whole science has rapidly developed to the end of outlining some of the soft tissues and organs. Barium meal is fed to patients for the examination of the alimentary canal. Barium salts are heavily absorbing for X rays. The meal lines the canal without being absorbed by the body, and, therefore, outlines the tract. Injection of iodized oil and other chemical substances that are concentrated specifically in some organ also serve to assist in diagnosis of any normal and pathological condition. Thus gall bladder, kidneys, and other small soft organs can be distinguished clearly on films with proper technic. Diagnosis of conditions in pregnancy is being extended rapidly although greatest care is essential so that no injury occurs from radiation. In case of the possibility of twins, the X rays disclose such a contingency with certainty and thus make possible suitable preparation. X ray photographs of mummies, such as are on display at the Field Museum in Chicago, Ill., prove convincingly that these ancient people had the same kinds of ailments—rickets, tuberculosis, etc.—as afflict modern man. X ray equipment for diagnosis has been improved to such an extent that exposure of only $^1/_{100}$ second is required with tubes through which a current of 1,000 milliamperes may be passed.

Fig. 3. Radiograph of cast steel showing internal cracks

Fig. 4. Radiograph of imperfect weld

Industrial Radiography

Just as the inside of the opaque human body may be observed on the photographic film or fluorescent screen by virtue of the differential absorption of penetrating X rays, so also may any material object be radiographed without damage for the purpose of determining the gross structure and presence of inhomogeneity or defect. The immeasurable importance of this information is evident in terms of the satisfactory behavior or failure of metal or other objects of practical utility and of the safety of human life which so frequently is involved. The value of this method in promoting safety, in eliminating expensive machining operations on defective castings, for example, and in establishing proper technic to assure sound materials is so generally well known that comment scarcely is required.

Numerous industries have installed X ray plants as necessary equipment. A change in boiler code has made it practically essential that welded pressure vessels be examined radiographically in order to assure soundness. The technic of industrial radiography is practically the same as that employed in medical diagnosis. It has seemed to be entirely empirical in that suitable results were a matter of trial and failure. Just now, however, the technic is becoming so thoroughly scientifically based that radiography may be termed an exact science. Standardized data have been plotted in charts from which the exact time of exposure for a given thickness of iron may be ascertained. Such graphs, of course, apply only for a fixed set of conditions such as distance from specimen to photographic film,

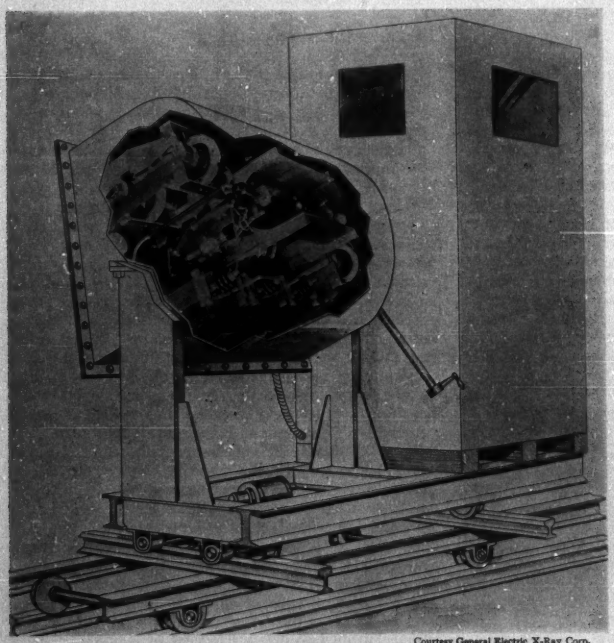
kind of film, use of intensifying screens, etc. Standard graphs have been published also for aluminum, copper, brass, and other materials. Next to quantitative aspects, the problem of greatest interest in radiography has been in the possibilities of examining still thicker sections by the use of special new X ray tubes operating at higher voltages than heretofore available. The practicable limit for iron or steel with commercial deep therapy tubes operating at voltages less than 300 kv has been about $4^1/_2$ inches. Recent experiments have been conducted with special new tubes operating at voltages up to 440 kv; however, increasing voltages give increasingly smaller increments in the limits of penetration, so that above 300 kv the increase in material thickness becomes almost inappreciable. Thus very short wave lengths, scattering, and recoil coefficients become very important in relation to the true absorption coefficient.

Practical Applications

Metal Castings. This is the most important application of X ray industrial diagnosis simply because of the wide use of castings and because of the uncertainty of gross structure with empirically developed foundry practice. Figure 3 shows a radiograph of a typically defective steel casting. Thus far the radiographic method of testing has been devoted largely to the development of technic. However, where expensive machining operations are involved, examination of every piece is fully justified. The great value of this application is so obvious that an extended list of the achievements is unnecessary. Standard X ray equipment is to be found on German railroads, by means of which fire boxes and boilers may be examined in position.

Welds. Since there is no positive assurance by the usual methods that a weld has been made perfectly, it is not surprising that an X ray examination for soundness has become practically a necessary operation. Gas inclusions and pipe cavities easily are detected (figure 4). The practical result has been a vast improvement in the technic of welding within the past few years. Practically all manufacturers of welded pressure vessels in the United States are equipped with X ray apparatus and every weld is carefully radiographed. A new X ray unit (figure 5) to operate at voltages up to 300 kv, mounted on a traveling crane, is used to examine every weld made at Boulder Dam now under construction.

Miscellaneous Applications of Metal Radiography. In addition to castings and welds, numerous other types of metal objects may be subjected to X ray tests. These include all automotive and aircraft parts, rolled and drawn metal for the discovery of slag inclusions or overdrawing by cold work that is too extreme, inspection of insulated wires and cables and coated metals for breaks, metal tubes and capillaries for clogging, intricate assembled objects for proper adjustment of parts, projectiles for proper location of caps and fuses and complete filling by explosives, gun barrels for rifling and defects, molten metals inside of furnaces for the determination of melting point and surface tension, ball bearings for soundness, electric insulators for the presence of metallic particles, metal radio transmitting tubes for proper position of grid and filament, all sorts of sheets suspected of corrosion, steel Dewar flasks used for liquid air or oxygen where corrosion may result in great decrease in wall thickness, and many others. Following a fatal accident, all fencing foils at the University of Illinois are subjected to radiographic examination in the writer's laboratory, and shockingly poor metal structure in the sense of inclusions, cracks, and holes are



Courtesy General Electric X-Ray Corp.

Fig. 5. X ray unit in use at Boulder Dam for radiography of welds

discovered in many of the foils.

Other Miscellaneous Applications. Besides the inspection of innumerable metal products many other practical applications of radiography can be enumerated. Some of these are as follows: examination of arc electrodes for soundness; coal for classification as to foreign mineral content (see figure 6) and for control of cleaning by flotation; rubber tires for imperfect bonding to cords; reclaimed rubber for foreign material; golf balls for centering of core; complicated glass, hard rubber, and bakelite pieces of various kinds with internal seals for improper fabrication; wood for cracks, wormholes, knots, and imbedded nails; railroad ties for compression or erosion under the plates; porcelain insulators; thermocouple tubes; spark plugs for internal cracks; location of pipes and wires in the walls of buildings; contraband goods in trunks with false bottoms; suspicious packages for bombs: and many others. One of the most fascinating of these applications is to be found in the field of art. A well established branch of radiography is now the examination of old paintings and objects of art for evidences of retouching or of original paintings covered over with others, and for distinguishing true masterpieces from copies. An X ray photograph made of Rembrandt's portrait of himself recently indicated that under the visible head of the master was a portrait of an elderly woman wearing a cap. It follows that excellent X ray laboratories are now a standard part of the equipment of great art galleries.

Radiography by the Use of Gamma Rays. Presentation of the subject of industrial radiography would be incomplete without mention of the remarkable results obtained with the gamma rays from radium emanation. By this method 11 or more inches of steel can be penetrated, but the times of exposure are, of course, very long—from 12 hours up. However, the extreme simplicity and economy of the method involving the use only of a tiny capillary tube of radium emanation gas and the possibility of examining all sorts of fabricated structures in position make this a great contribution to the science. A great many interesting achievements already have been recorded in the United States and in Germany. Among these has been the successful detection of defective stern posts in new U. S. Navy cruisers. Further progress and applications will be awaited with greatest interest.

Analysis of Fine Structure of Materials

The most thoroughly interesting and probably the greatest branch of industrial radiology is the determination of the ultimate fine structure of materials from the results of diffraction analysis. The great practical importance of scientific knowledge of the ultimate structure of solids that are more or less perfectly crystalline in the natural state is evident when consideration is given to the definition of desired physical and chemical properties. The strength of steel girders, the forming of an automobile body, the corrosion of aluminum alloys, the breakage of an airplane propeller, the performance of a watch spring, the plasticity of lime, dielectric capacitance of materials, lubricating properties of long chained paraffins or graphite, improvements in the tensile strength of rayon, stretching of rubber, the covering power of pigments, the mechanism of the stretching or contraction of muscles and tendons, molecular differentiation between normal and pathological tissues, and innumerable other practical phenomena of everyday life all depend upon ultimate crystalline structure.

Fig. 6. Radiograph of raw coal showing heavily absorbing mineral impurities

The first aim of X ray analysis of the fine structure of a solid material is to determine the arrangement of atoms and molecules in the crystalline units and to account for the properties of the material in terms of that arrangement. The interference of X rays in gases and liquids has made possible more recently fine structure determination even for these states.

Röntgen and his contemporaries early attempted to demonstrate diffraction of the new rays which seemed to have so many properties similar to those of visible light. Diffraction of the rays by optical gratings could not be demonstrated, as is known now, only because of faulty experimental technic. It was 17 years after the discovery of X rays before interference phenomena in the case of X rays were demonstrated by Laue, Friedrich, and Knipping. When a fine pencil of X rays was passed through a crystal of zinc blende a definite and symmetrical pattern of spots was registered upon the photographic plate placed at a fixed distance behind the crystal. This so-called Laue pattern proved that all crystalline substances were constructed in a highly organized fashion in which the ultimate atoms and molecules were arranged on equidistant parallel planes. These imaginary planes evidently were spaced at distances of the same order of magnitude as the wave lengths of X rays. Consequently, any crystal serves as a 3-dimensional diffraction grating. Depending upon the kinds and arrangements of atoms or molecules, a characteristic diffraction pattern will be obtained which can be interpreted in

terms of the characteristic building plan of the particular material. The fundamental relationship was discovered by the Braggs to be $n\lambda = 2d \sin \theta$. In this equation λ refers to the wave length of the X ray beam, d is the spacing of any particular set of planes in the crystal, and θ is the angle of incidence. In all diffraction methods and with all types of equipment the experimental measurement consists in the evaluation of the diffraction angle 2θ. Since all crystals are built on so regular a lattice structure, it follows that 3 pairs of planes will enclose a small unit cell which will be the fundamental unit with all the properties of a crystal. Diffraction information will lead directly to the estimation of the size and shape of this unit cell, and from a knowledge of the density the number of atoms or molecules within the unit cell is established.

Geometrical considerations indicate that there are 230 ways of arranging atoms or molecules in space. Another way of stating this is that if the 32 point groups or combinations of symmetry operations be placed at the points of 14 space lattices, 230 space groups are obtained. It is the aim of X ray crystal analysis to determine uniquely the space group characteristic of each crystalline substance. A careful analysis of intensities of the various interferences on a diffraction pattern is required before the final selection of one out of all the possible space groups can be made. Each one of these space groups has certain definite criteria which are sought and established in the experimental diffraction data. Intensity data are analyzed further by trial and failure methods, sometimes involving the application of advanced mathematics such as Fourier's series analysis in order to determine the exact parameters of atoms and the positions of atoms within molecules. By such methods, for example, it has been established definitely that in benzene, naphthalene, anthracene, and other aromatic derivatives the so-called benzene ring, long familiar to organic chemists, actually exists in the solid form as a hexagonal arrangement of 6 carbon atoms which all lie exactly in the same plane with carbon to carbon distances of 1.42 Ångström units.

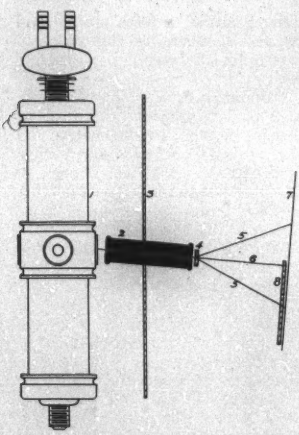


Fig. 7. Diagram showing arrangement for producing diffraction patterns

There are several experimental methods of diffraction analysis, but they all are directed to exactly the same end of measuring values of the angle 2θ. These various modifications are designed simply to utilize single crystals or finely powdered specimens. The most familiar of these methods are:

1. The Laue method in which a polychromatic X ray beam is passed through a stationary crystal mounted definitely with respect to the crystallographic axes.

2. The Bragg spectrometric method in which a monochromatic beam ordinarily is reflected from a single set of planes in a single crystal, as for example, from the cleavage face of a calcite crystal.

3. The powder or Hull-Debye-Scherrer method in which an essentially monochromatic beam is passed through or reflected from a specimen consisting of a fine powder or aggregate of very small grains (figure 7).

4. The rotation method in which the beam is passed through a single crystal rotated ordinarily completely around an important axis.

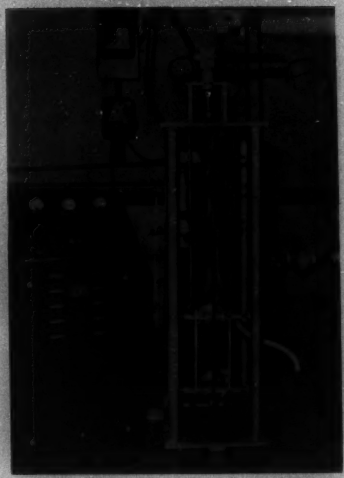
Excellent equipment is now available of universal and of multiple types by means of which interchangeable methods can be employed and several diffraction patterns photographed simultaneously from a single X ray tube. A photograph of such a modern diffraction apparatus is shown in figure 8. In practically all crystal analysis it was essential to have some information concerning the wave length λ of the X ray beam. Thus the predominating $K\alpha$ ray (really a close doublet) with a wave length characteristic of a particular target in the tube is utilized in all methods except the Laue method. The $K\alpha$ doublet is practically isolated by means of suitable filters. The target metals most frequently used are molybdenum with a predominating wave length of about 0.712 Ångström unit, which is suitable for studies of metals and inorganic compounds, and copper with a wave length of 1.54 Angström units, which is utilized for the study of organic materials. Voltages higher than 50 kv are not required or used. Consequently for purposes of attaining a very intense radiation which will cut down the necessary time for exposure to a minimum, diffraction tubes are designed especially to operate at high currents and also with minimum dimensions so that the specimen can be placed as close as possible to the focal spot. With some of the modern tubes, in which the beam passes through very thin windows, diffraction patterns may be photographed in a few seconds as compared with times of many hours or days required with the earlier types. Now when a diffraction pattern has been obtained for a given substance in solid state, whether in the form of a single crystal, powder, or any kind of aggregate of small crystals, grains, of sheet or wire, it may be measured and interpreted directly to the end of establishing the fundamental architectural plan, which then may be illustrated by large scale models.

It should be understood clearly that in this process accurate measurements actually are being made of distances of $^1/_{100,000,000}$ of a centimeter. The

Fig. 8. Apparatus for research on the structures of materials at the X ray research laboratory, chemistry department, University of Illinois

(Left) Multiple diffraction unit with X ray tube in upper small protecting cylinder and several pinholes

(Right) Complete unit for demountable X ray tube for producing beams of very great intensity

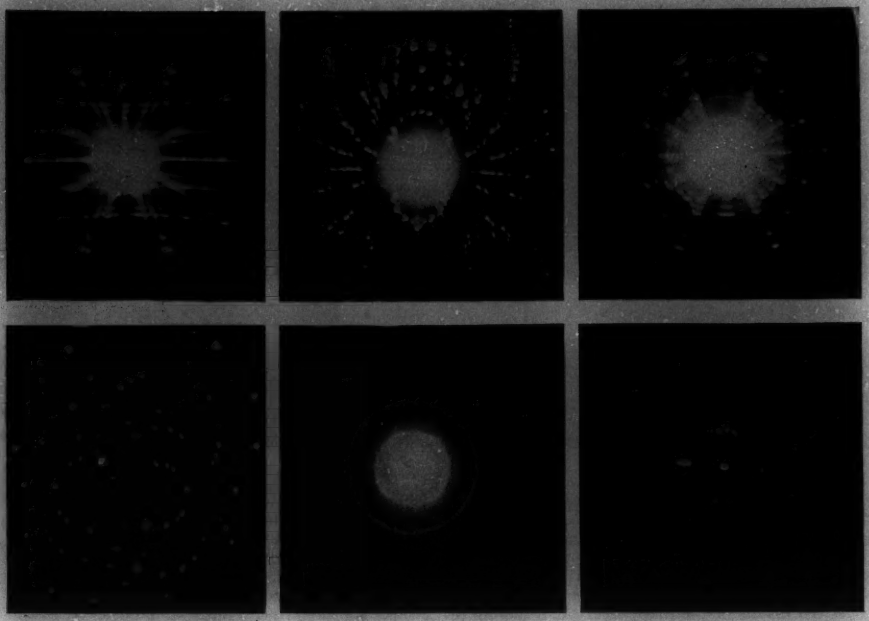


diffraction method then is, in a sense, an examination of ultimate fine structure with a supermicroscope. What appears to be homogeneous structure at the limit of resolution with the microscope, even with ultra-violet light, discloses a fine structure when subjected to the measuring rule of X rays.

As the results of the analysis of the structure of materials by means of X rays are surveyed, one is utterly amazed at the progress that has been made experimentally and at the great body of valuable facts concerning the building plan and behavior of materials heretofore unavailable. Some typical patterns are shown in figure 9. Nearly all of the chemical elements have been studied and their crystal forms classified, even some that are solid only at extremely low temperatures. It is perhaps fortunate that almost all of the familiar pure metals have very simple crystalline structures, either cubic or hexagonal. For example, some of the common metals like alpha iron, chromium, and tungsten are body-centered cubic, that is, the ultimate crystal cell unit is a tiny cube with an atom at each corner and one in the center. The ductile metals such as aluminum, silver, gold, copper, nickel, and lead are face-centered cubic, that is, the unit cell has an atom at each corner and one in the center of each face. Zinc, cadmium, magnesium, and other metals have a hexagonal close-packed structure. Some of the metals have more than one crystalline form, each being stable over a certain temperature range, as for example, iron, manganese, cobalt, and cerium. A few of the metals have very highly characteristic structure such as white tin, crystallized mercury, indium, and gallium. Besides the chemical elements, hundreds of inorganic compounds now have been analyzed. From these results it has been possible to ascertain something about the forces that hold atoms and molecules together, the shapes and sizes of different groups, and the explanation of every type of physical and chemical behavior. From a great mass of seemingly disconnected data has come a new science of crystal chemistry which has the greatest possible interest and significance. There is a perfectly sound reason why a given chemical compound should crystallize as it does. It would seem peculiar that there would be 16 ways in which inorganic compounds AB_2 should crystallize; but when the simplest geometrical conceptions of ratios of atomic radii are introduced to explain the packing of these minute units in space, a rational explanation immediately follows. In cases of exceptions there is good evidence in support of the fact that atoms may become deformed or are polarizable. The field of complex binary alloys may be taken as a very good example of modern trends.

Alloys, together with silicates, have been the bugbear of scientific exposition in terms of the usual chemical formulas, which might be expected. The formula for δ-bronze, for example, is $Cu_{31}Sn_8$. It is for such reasons that the alloy metallurgist has had to work empirically. Now with the results of X ray analysis, strictly scientific and rational classification is possible. The diffraction patterns for Cu_5Zn_8 (γ-brass), Fe_3Zn_{21}, $Cu_{31}Sn_8$, and others indicate the same type of structure—and they crystallize alike because the ratio of valence electrons to the number of atoms in the molecules is in every case 21/13 (Cu 1, Zn 2, Sn 4, Fe 0). Another whole series of intermetallic compounds crystallize alike because this ratio is 3/2 (β-alloys), and another with the ratio 7/4 (ϵ-alloys). The tremendous contribution of diffraction analysis to the field of alloys becomes apparent, since it leads to a knowledge of the whole constitutional diagrams, ranges of stability, discovery of new phases separating during aging or heating which are responsible for peculiar behavior,

Three varieties of the mineral asbestos



Single crystal of ammonium oxalate | Black diamond used in mining drills | Brass with poor structure cracked in auto radiator

Fig. 9. Typical X ray diffraction patterns of some common materials

and the prediction of properties in general. Similarly these rays have proved that in silicates with seemingly hopelessly complicated structures, oxygen atoms form the real network or backbone and all the other chemical elements appearing in the formulas are simply present in the holes of the oxygen network. Diopside is found to be built up of chains of silicon-oxygen tetrahedrons; asbestos is built from a doubled chain of the same kind, and mica in turn is the further sidewise coupling of chains into sheets—hence its characteristic cleavage.

In the field of carbon compounds besides the shape of the benzene ring already referred to, a great array of data is available with which the theories and models of organic compounds may be subjected to rigorous test. Of especial interest are the long-chain aliphatic compounds—hydrocarbons, fatty acids, alcohols, soaps, esters, greases, oils, and waxes. Diffraction patterns of thin films demonstrate a remarkable preferred orientation side by side of these long carbon chains, so that even the actual lengths of the molecules, as a function of the number of carbon atoms in the chain may be measured directly. Lubricating films in bearings then are characterized by oriented molecules which hold to the metal surface on one end, and slide over a layer of molecules similarly arranged on the other metal surface. Another practical application from the writer's laboratory is the study of the breakdown of high voltage cables. The whole process of molecular change, which consists in a polymerization or lengthening of the molecules of insulating oil originally present, is discovered and followed, where any other method would be futile.

Thus far consideration has been given only to the determination of crystalline architectural plan by means of X ray diffraction. An astonishingly long list of actual industrial achievements might be cited easily. Only a few of the materials and processes subjected to research and test are: lead oxides and storage batteries, minerals, clays and all ceramic materials, bone, gems, lime, cement, zeolites, electroplating, alloys of all types, petroleum products, drying oils, pigments, dyes, textiles (considered in a later paragraph), and rubber.

If the information obtainable from X ray diffraction results were limited purely to the question of crystalline structure, it is obvious that the method would fall short of greatest industrial usefulness. Many steel specimens under such circumstances would be expected to give identically the same lattice structure, but this would not be sufficient to demon-

strate why certain steel specimens perform satisfactorily and others are utterly unsatisfactory. It is one of the greatest achievements of X ray diffraction science that the exact condition of a given material also can be determined and the reason for a practical behavior demonstrated. In other words, the diffraction pattern gives convincing information concerning grain size, grain orientation, lattice distortion or strain, effects of mechanical work upon grain structure and orientation, and various other attributes of any given unit of a given material.

Information Concerning Grain Size. For a powder or random aggregate of and material in which the grain diameters are the order of 10^{-5} or $^1/_{1,000,000}$ of a centimeter, the diffraction pattern consists of a series of uniform continuous lines. If the grain size is larger than this these lines begin to appear spotted and these spots increase in size and become more random in distribution as the grains become larger. Careful research work in the writer's laboratory has demonstrated that the measured size of these diffraction spots is linearly related to the actual grain size. Consequently this range overlaps the microscopic range and the data obtained by the 2 instrumental procedures are fully consistent. There are many practical applications of this type of grain size measurement where the microscope cannot be used to advantage, especially inasmuch as specimens for the X ray study require no special polishing or preparation. If now the grain size becomes smaller than 10^{-5} centimeters, the colloidal range of particle sizes is involved. The diffraction lines become increasingly broader in proportion as the grain size decreases down nearly to the atomic dimensions of 10^{-8} centimeters. Consequently, a measurement of line breadth leads, by means of rigorous formulas which have been deduced to the evaluation of colloidal particle size, far more accurately than by any other method.

A further extension from the data properly interpreted is to the detection even of the shape of the colloidal particle. This is of greatest significance, of course, in the use of industrial materials such as carbon blacks in rubber compounding and in paint pigments. Colloidal graphite or carbon blacks may be prepared with particles of spherical or cubical shape or as thin flakes, or essentially a 2-dimensional particle, or as long tenuous almost unidimensional particles. These facts are differentiated clearly by these X ray measurements. Since most natural material such as proteins, cellulose, rubber, etc., are colloidal in nature, it follows that the estimation of colloidal particle size has been of great significance.

Grain Orientation. It is oftentimes advantageous to determine and to control the orientation of crystal grains in industrial materials with respect to some common direction, as for example, with respect to the surface of a sheet of silicon steel or the relationship of the crystallographic axis to the bearing surface in artificial sapphire pivots in watch movements. These orientations can be definitely distinguished and identified crystallographically by means of Laue diffraction patterns.

Effects of Mechanical Deformation. The diffraction patterns for metals and other materials that have been subjected to mechanical working such as drawing, rolling, torsion, stretching, or forging, are extremely interesting. Straightforward interpretation of such diffraction patterns proves that the mechanical forces have caused a realinement of small crystal grains originally at random into certain preferred directions. Thus in a cold drawn wire of aluminum the crystal grains all tend to turn with the body diagonals of the small unit cubes parallel to the axis of the wire or to the direction of drawing. Thus the pattern demonstrates not only qualitatively that a fiber structure exists, but a quantitative interpretation leads to the establishment of the exact mechanism and type of preferred orientation which usually is that which a crystal sets up in order to present maximum resistance to further deformation. Fiber patterns of fabricated materials of all kinds, therefore, have the greatest possible fundamental and practical significance, especially for metallurgical products. This includes also the possibility of preferred orientation of grains in electroplating where the final structure of the deposit as a function of the deposition variables can be ascertained accurately. In all rolled sheets, wires, bars, forgings, stampings, or in any material that has been stretched, bent, contracted, or deformed, we are just as directly concerned with a fiber structure as we are in a natural asbestos or cotton or wool fiber. X ray analysis of fiber structure is a whole science in itself.

Strain. One of the most important applications of diffraction analysis is in the detection of internal strain. Whenever crystal lattice planes become distorted or bent, the changed condition manifests itself in several different ways under the powerful scrutiny of X rays. The importance lies in the fact that there is no other satisfactory way of detecting a strained condition in the interior of opaque materials corresponding to the detection of strain in transparent materials by polarized light. Whenever a diffraction pattern is characterized by elongation of interference spots into radial streaks at random on the pattern, it is a clear indication of interior strain in the specimen. So many cases of failure in metallurgical and ceramic products especially can be accounted for easily since patterns of this kind can be obtained, whereas the microscope may disclose little or no indication of deficient ultimate structure. It follows at once, of course, that even greater practical utilization of diffraction information is to establish the absence of a distorted condition following proper heat treatment or revision of the processing in some detail.

Practical Metallurgical Results of Diffraction Analysis

Although X ray diffraction analysis is one of the newest sciences, a whole volume could be written already upon practical metallurgical applications. Of these the most important is probably the direct possibility of removing metallurgical heat treatment from the field of guesswork. It is the province of correct heat treatment of sheets of metal that are to be subjected to forming operations to remove com-

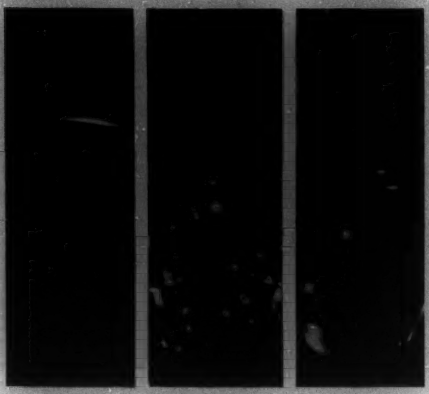


Fig. 10. Diffraction patterns showing changes in structure of aluminum alloy airplane propellers with use

(Left) Uniform metal in new propeller
(Center) Structure of same metal after 900 hours' flying showing marked grain growth
(Right) Development of strain after further use with danger of breakage and loss of life

pletely all traces of the original fibered structure introduced by rolling. Heating must eliminate also all evidences of strain such as are so common in castings. Hundreds of specimens have been submitted for examination in the writer's laboratory, of fabricated metals that have failed although apparently they had been treated in exactly the same way as products that have been satisfactory. Almost without exception the fault is to be found in faulty heat treatment. Case after case might be cited in which precisely the correct time and temperature of annealing has been established by simply following structure with X ray patterns. In watch springs, if the last trace of the rolled structure is not eliminated as detected by a single diffraction pattern, the spring is brittle and has what is technically known as fast motion. If the annealing treatment is taken just slightly too far and the recrystallized grains have grown slightly too large, the spring is soft and has a slow motion. The range between these, in which satisfactory springs are obtained, is exceedingly narrow, and the conditions must be controlled very exactly. It is not surprising that 50 per cent of all watch springs are unsatisfactory, although oftentimes this is not known until the spring has been incorporated into the watch movement.

Recently in the writer's laboratory a large number of new watch springs were examined with one diffraction pattern for each spring, and upon the basis of these patterns alone it was predicted how the spring would perform. These springs then were subjected to the usual manufacturer's tests and placed in watch movements. The predictions have been borne out to an astonishing degree. One common source of difficulty has been that the heat treatment may result in recrystallization; but instead of a random arrangement of the recrystallized grains, thus affording perfectly uniform properties for a sheet, the grains have taken up an entirely new preferred orientation, and consequently such a sheet will fail in forming operations.

Many interesting research results might be related for the study of gold alloy in fountain pen nibs, automobile steel, brass and copper sheets of all kinds, silicon steel for electrical purposes, defective structure in steel rails leading to transverse fissures, and amazing changes in structure with use and under the extreme conditions of fatigue of aluminum alloy airplane propellers. An extensive investigation now under way on the last named problem should go far toward preventing the loss of life that invariably accompanies the breakage of a propeller in the air. There is every indication at present that in those parts of the blades subjected to the greatest vibration and fatiguing forces occur the greatest structural changes (figure 10), including the deposition from solid solution of the intermetallic compound, $CuAl_2$.

These few examples must suffice to illustrate one of the most fertile fields for the application of research and testing by means of the X ray diffraction method.

Structure of Liquids and Amorphous Solids

The phenomenon of diffraction clearly depends upon some kind of regular arrangement of planes so as to constitute a grating. All crystals are built with such a plan. Many solid materials, long classified as amorphous because they appear so in the microscope, are genuinely crystalline in ultimate particles which X rays disclose. It hardly would be expected that liquids would produce any evidence whatever of ordered diffraction, but as a matter of fact they do. The patterns are characterized by only 1, 2, or 3 broad rings or halos, but these are evidence enough of some kind of transient but definite molecular arrangement. Stewart calls this cybotaxis. Extensive data are now available on the spacings in all kinds of liquids, which are a measure of molecular sizes and shapes, and thus permit the testing of theories of molecular structures. These molecular groupings which are "companies" in isotropic liquids are "regiments" in liquid crystals. In a true solution a single type of cybotactic group exists to which molecules of both solute and solvent contribute; for an emulsion such as phenol in water, diffraction halos appear for both constituents so that it is easily distinguished from a solution. An interesting extension has been the discovery of the orienting influences of electric and magnetic fields on liquids. Furthermore, the Harkins-Langmuir theories of definite molecular orientation at surfaces and interfaces of liquids are substantiated fully by diffraction studies. The newest triumph has been the explanation of the structure of a glass, an amorphous state of matter which produces only one or 2 diffuse diffraction halos. Around each silicon atom are definitely arranged *radially* other silicon

and oxygen atoms for a distance of 5.12 Ångström units, as in crystalline silica; but *around* these radii in azimuth there is statistically random arrangement.

Structure of Natural Polymerized Materials

In this class of materials are to be found all those of greatest biological interest as well as many of the most important industrial materials such as textile fibers. The X ray results indicate clearly, first, that these apparently noncrystalline materials are organized amazingly well or possess a crystalline constituent (figure 11), and that a common structural plan is utilized for such widely different substances as cellulose, proteins including silk fibroin, wool, hair, feathers, collagen, gelatine, nerve and muscle fibers, chitin from insect shells, rubber, gutta-percha, balata, and chicle. Briefly stated, this plan is as follows: Long primary valence chains or macromolecules are built up (or polymerized) from a relatively simple molecular group (or monomer), as for example dehydrated glucose residues $C_6H_{10}O_5$ in cellulose, isoprene C_5H_8 in rubber, and amino acid residues in peptide linkages in proteins. A bundle of these chains, which may be as long as 1.5 microns (molecular weight, one-half million), is held together by secondary forces to form the colloidal crystallite that recently has been isolated and identified for cellulose. The diffraction pattern of cellulose in wood, cotton, ramie, jute, hemp, sisal, flax, valonia, animal cellulose, etc., tells us that the unit monoclinic cell is 8.3 x 10.22 x 7.9 Ångström units and contains only 4 $C_6H_{10}O_5$ groups; that these groups are bound together in long chains by oxygen bridges; how long these chains are and how large the whole crystallite bundle is; and how these ellipsoidal particles are arranged in the fiber, whether in a random brush-heap fashion (as in cellophane) or in a nearly perfect alignment parallel with the fiber axis as in ramie (see figure 11).

In the writer's laboratory it has been possible to obtain direct measurements from interferences that appear when X rays of long wave length (magnesium $K\alpha$, 9.86 Ångström units) are utilized. It is by this technic that the first diffraction patterns from crystalline insulin were made possible. The unit cell dimensions from this familiar complex material are 80 x 100 x 130 Ångström units with 24 molecules having a molecular weight of 35,000 per unit cell.

Even the briefest account of achievements of scientific and practical significance in the study of these natural materials would run to a considerable length. It is safe to say that the improvements in the properties of commercial rayon noted in the past few years can be ascribed to X ray research.

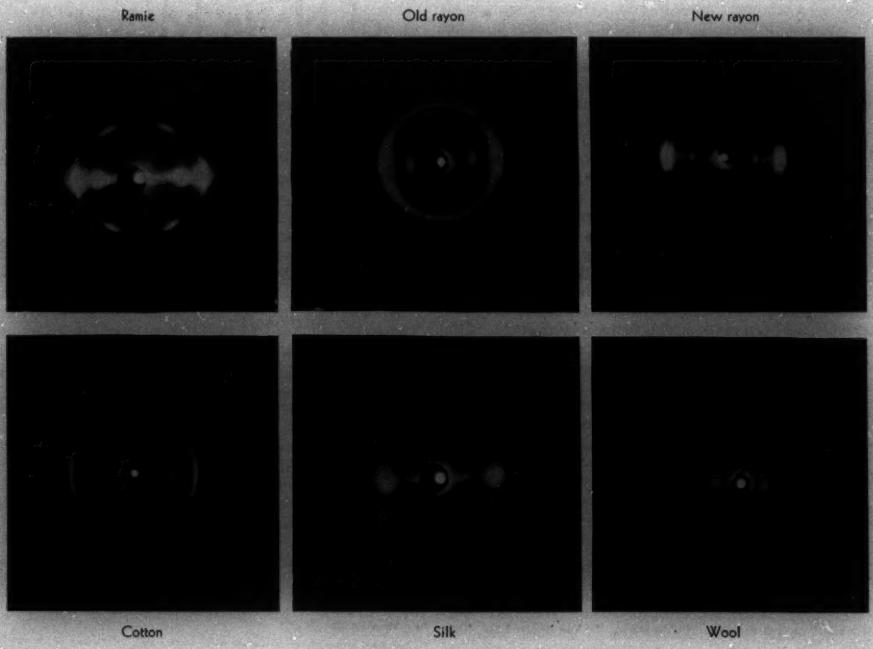


Fig. 11. X ray diffraction patterns of some typical textile fibers

The application of tension during coagulation of the regenerated cellulose alone led to greatly enhanced tensile strengths because the ellipsoidal particles were oriented in more perfect fashion. A highly oriented skin on a more random arrangement of particles on the interior is found. Stages of cotton growth and classification have been followed. Besides analysis of the crystalline structure of the remarkably beautiful and sharp patterns of natural silk, the highly oriented core and random skin are demonstrated. The faster the silkworm is forced to spin the fiber the more perfect is the preferred orientation. More has been learned about what rubber really is by analysis of the fiber pattern that appears when rubber is stretched than by decades of chemical research. This pattern is evidently the surest criterion of rubber molecular structure. A hundred synthetic rubbers have had a chemical composition identical with the natural product, but not one of these, until the discovery of duprene, gave a fiber diffraction pattern upon stretching—and the fundamental spacings in duprene are different. The identity of the hydrocarbon that exists in 2 polymorphic forms with a definite temperature of transition has been established in gutta-percha, balata, and chicle. The change in molecular form of protein chains in keratin fibers (hair, wool, quills, etc.) upon stretching has been shown strikingly from changes in the diffraction patterns. So Astbury has demonstrated a scientific procedure in permanent waving of hair; and in proofs of evolution theories in such facts as the structural similarities of feather keratin and turtle shells. X ray studies of catgut surgical sutures (collagen from sheep intestines) have led to greatly improved properties and uniformity.

Finally, we come to the structural studies of those materials of greatest medical interest, normal and pathological tissues. Fibrous collagen tendons, stretched gelatine, fabricated catgut sutures, and new work on living nerves are all analogous in showing a real though somewhat imperfect organization of complex protein molecules of great length. Muscle fibers, even studied in living frog legs excited to tetanus contraction, can be pulled into parallel diffracting alinement. An intensive study of fundamental molecular changes in normal and pathological tissues has been made in the writer's laboratory, with most promising results. Thus a great chemical and industrial science of X rays has brought back to medical science a third great use of the radiation that must be added to therapy and radiographic diagnosis, namely, the supermicroscopic vision of matter with its use in anatomy, pathology, and physiology, which the fundamental science of diffraction of radiation has afforded.

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Standardization of Noise Meters

A brief review of the present status of standardization of noise meters and measurements, and progress made to date by the technical committee on noise meters and noise levels of the American Standards Association.

By
R. G. McCURDY*
FELLOW A.I.E.E.

THE rapidly growing interest in noise reduction and the development work done by various industries to provide quieter apparatus to meet the public demand have created the necessity for consistent noise measurements. The standardization of methods of measurement and of units and scales for expressing the results are necessary first steps in arriving at standards for acceptable noise levels. These factors were important reasons that

A paper recommended for publication by the A.I.E.E. technical program committee, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 22–25, 1935. Manuscript submitted Nov. 2, 1934; released for publication Nov. 7, 1934.

* Chairman, technical committee on noise meters and noise levels of the sectional committee on acoustical measurements and terminology of the American Standards Association.

led to the organization of the sectional committee on acoustical measurements and terminology of the American Standards Association. As a result of the activities of its subcommittee on noise measurements, standards for noise measurement were adopted provisionally by the sectional committee. In these standards the loudness level of the sound is specified as a measure of noise. It is contemplated that the noise shall be measured by aural comparison of its loudness with that of a reference tone, and its loudness level expressed as the intensity level of the equally loud reference tone. The standards include the specification of the 1,000-cycle reference tone, the decibel scale, and reference levels for intensity and pressure and loudness level measurements. There was recommended also a group of curves termed loudness contours which indicate points of equal loudness of different single frequency tones together with a curve showing the relation between loudness and loudness level. These provisional standards were published in ELECTRICAL ENGINEERING for November 1933, pages 744–6.

Measurements by the ear-comparison method lead to many difficulties in experimental procedure. It is generally necessary to assemble a group of observers in order to obtain reasonably consistent results because of the large spread among the measurements made by individual observers. A reference tone must be provided and provision made for presenting this to the observers so that they may compare its level with the level of the noise being measured without having both sounds affect the ear at the same time. The comparison is particularly difficult to make where the noise is varying from moment to moment. When measuring in a complicated sound field where the noise may originate in several different points or be reflected from the boundaries of the room, measurements generally must be made at several points. By the ear-comparison method the procedure becomes cumbersome and much time may be consumed. Thus a need naturally has arisen for a meter that will eliminate as far as possible the "personal equation" and that can be moved readily from point to point so that the procedure for making noise measurements may be materially simplified and accelerated. Several of these meters have been made by different individuals and organizations and have been described in papers presented before the Institute.

There was a strong demand that efforts be made by the sectional committee to extend the standards to cover the use of noise meters. A technical committee on noise meters and noise levels, subordinate to the committee on noise measurements, was appointed to look into this matter and to recommend standards using as a basis the provisional standards already adopted by the sectional committee applying to the ear-comparison measurements. This committee was assigned the further duty of acting as an advisory group to the various industries in order to facilitate the coördination of activities leading to the setting of standard noise levels.

This technical committee has made substantial progress in agreeing on many of the characteristics of noise meters, such as the use of the decibel scale the zero of which corresponds to the loudness of a 1,000-cycle free wave having an intensity of 10^{-16} watts per square centimeter, the manner of combining the various single frequency components and complex noises in the indicating instrument, and the dynamic characteristics of the indicating instrument. The loudness level contours that should be adopted as a basis for the frequency weighting in the amplifier also have been selected.

The problems that have given the committee difficulty and upon which agreement has not yet been reached are concerned with the pick-up microphone. Measurements of noise usually are made in complicated sound fields in which the noise may originate at several points or in which reflections from the room, enclosures, or other objects cause the sounds to impinge upon the microphone from many directions. If the microphone response depends upon the angle of incidence of the sound wave and particularly if 2 meters are used having microphones with different directional characteristics, considerable divergence in the results may occur even though the meters are otherwise alike in their characteristics.

Appreciation of loudness is a complicated matter involving various physical and psychological reactions of human observers. These vary widely among different individuals, as is shown by the large spread among the measurements of a given noise made by ear by various observers. In constructing a noise meter it is necessary to make several approximations, endeavoring to approach as closely as practicable to the measurement of loudness level. Undoubtedly there is a field for measurements by the ear-comparison method where the noise is relatively steady and the necessity of assembling a group of observers in order to obtain consistent results is not an obstacle. It is recognized that comparison by ear is the fundamental standard; however, the advantages of the meter method give it a wide field of usefulness. Experience indicates that good correlation may be obtained between readings of meters and loudness comparisons made by a group of observers on many types of noise. The portability of the meters and the rapidity with which readings may be taken, including observations at several points in the room or other premises where the noise is of interest, are material advantages. They have been found very useful in isolating different types of noises, particularly those of short duration, when the noise in the room is composed of components from many different sources.

Demands made for standards for noise meters indicate that they may have a wide application in industry in determining whether machines and other manufactured apparatus meet specifications that may have been imposed as to their noise output. For this purpose the consistency of the meter method and its ability to distinguish with accuracy between different levels of noise of the same frequency composition are of great importance.

The committee is continuing its efforts to bring this work to completion and is hopeful of being able to make definite recommendations to the sectional committee on standards for noise meters in the near future.

Engineering in the Social Sciences

A successful manufacturing engineer looks at the social sciences. He points out that "all wealth is produced from land by the application of labor aided by capital." In order that every one might have an opportunity of securing his rightful share of land, a new system is proposed wherein every community would collect all community-created ground rent and all taxation on wealth would be abolished.

By
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Cleveland, Ohio

PERHAPS most engineers will agree that engineering education is the process of training the mind of the student so that he can apply the knowledge available at the time to the successful solution of problems arising in his profession.

All agree that John A. Roebling was a great engineer, because he applied the knowledge of bridge engineering available at the time. The Brooklyn bridge was built by solving the many problems presented by the construction of the first suspension bridge over the East river. All would regard Roebling as well educated in bridge engineering.

All agree that B. G. Lamme was a great engineer, when he successfully designed the electric generators that first were used at Niagara Falls in 1896. What made this design a great engineering achievement was the successful application of the principle of electromagnetic induction, the principle of the magnetic circuit as exemplified in the small dynamos of the day, to the vastly larger machines used at Niagara. Not only was an intimate knowledge of the principles governing the operation of electromagnetic machinery necessary, but also a correct appraisal of the many possible constructions. For instance, most of the material used for insulation at that time as well as at present was organic, such as cotton cloth, and not inorganic, such as asbestos or mica. For the insulation of the conductors in the armature of these large Niagara generators, Lamme used mica.

It has been shown since that this choice of insulation made possible the operation of these machines for many years, while if organic materials had been used the insulation would have burned out the first month, notwithstanding the fact that the calculated heat loss in these conductors would have permitted the use of cotton insulation. Experience in the operation of these generators showed that there was an unexpected, and, at the time of the design, an unknowable production of heat from eddy currents that amounted to several times the calculated heat loss.

Many years ago H. H. Dow, of Cleveland, Ohio, learned from his chemistry college work that free chlorine would break up bromine compounds, releasing bromine. This knowledge, plus the knowledge that in the brines from the salt deposits underlying parts of the lower peninsula of Michigan there was an unusually large amount of bromine, plus a lot of detail work in the commercial recovery of the bromine after it had been released in the free form, made possible the production of bromine at less cost than was previously possible. This was the beginning of what is now the Dow Chemical Company and the success of the company has resulted from the development of similar processes for several other materials.

Any teacher who helped to direct the development of Roebling and Lamme and Dow and the thousands of other engineers whose work has transformed the world in the last 50 years may look back on his work and have the supreme satisfaction of knowing that it was good.

When the engineering brains that have made possible the radio and the flying machine and the automobile are confronted by the problems in human relationships, what do they find? Some of the things they come upon are outlined briefly in the following paragraphs.

First, the science of human relationships is the most important of all. Many think that the great war came close to wiping out western civilization. It is certainly possible, that a future war may be the suicide of what is known as western civilization. Engineering developments in the science of killing people have progressed a great deal since 1918 and it may have reached the point where another war would result in killing enough people so that the western nations would sink into barbarism. This has happened before and may happen again. The civilization that existed in the valleys of the Tigris and Euphrates rivers was much superior to what exists there today. Most people would agree that the ancient Roman civilization was higher than that of the Goths and Vandals that succeeded it.

Second, in the science of human relationships, moral questions enter—questions of right and wrong that do not enter into the physical sciences. When the people who built one of the first bridges across the St. Lawrence River at Quebec made a mistake, the bridge fell into the river and only a few people were killed. When Philip II of Spain made the mistake of assuming that his brand of religion was the only right one, he was guilty of a great wrong when he and the ruling class tortured and burned thousands of people who would not agree with him. What happened to Spain as a result of this policy is a matter of history. Most people would admit that

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Philip and the ruling class of Spain made a bad mistake in human engineering. Many think also that it was grossly unfair and wrong to conclude the armistice with the Germans in 1918 on the basis of Wilson's fourteen points, and then, after Germany had been disarmed, to force on her the Treaty of Versailles. Many think that Hitler in Germany is making the same mistake in human engineering and is guilty of inflicting a great wrong on those people in Germany who he dislikes and who do not agree with him.

Third, when any change is proposed to improve human relationships, there is always a class that opposes the change for financial reasons. The real question at issue in the Civil War in the United States was the abolition of slavery. The ruling class in the South opposed abolition because they would be poorer without slaves than with them. It took the French revolution to make clear the fact that the ruling class in France did not have all the rights, that the common people of France, who had been practically serfs before the revolution, had some rights as well as the nobles.

What Is the Criterion of Good Human Engineering?

Most engineers could agree that good human engineering would require the construction of a system of human relationships in which every individual had equal rights and complete liberty limited only by the equal liberty of others. Theoretically, such a system exists now; but a fair examination of the facts will show that not all have the same rights and not all have complete liberty. In an examination of this sort, it is easy to see that the slave holders in the South were wrong in fighting for slavery in 1861 and that the Stewarts of England were wrong in fighting for the divine right of kings, for if good human engineering requires a system in which everyone has equal rights, there can be no privileges. It is not so easy to see what should be done to settle the questions of today. To suggest here: Shall tariff be raised or lowered or abolished? What is money? How much and what kind of money should be provided? What can be done to prevent unemployment and to make a system in which there is a just distribution of wealth? There is no excuse for an engineer to have the common attitude of mind expressed by the New England deacon, who said he was willing to be convinced, perfectly willing to be convinced, but that he would like to see the fellow who could do it. Would not good engineering insist on the right of a person to buy what he wanted, wherever he could get it, to the best advantage? When some coal mining companies insist that their miners buy all their supplies at the company store at 20 or 25 per cent more than the same thing can be bought from an ordinary store, the liberty of the miners most certainly is being interfered with. However, in buying a woolen suit made in England or sugar grown in Cuba, our tariff laws require that from 40 to 100 per cent more be paid for these things than the Englishman or Cuban would pay. Would not the good engineer recognize this as tyranny? And is tyranny any less tyranny because it is the tyranny of a majority and not the tyranny of a king or a small class?

All admit that exports are a good thing for business; but will not a good engineer see that if exports are to continue they must be paid for and that the only way exports can be paid for is by imports? When imports are limited by a high tariff wall or by quotas, exports are limited by the same amount. For 60 or 70 years some of the very large items in the exports from the United States were cotton from the South and wheat and meat from the West. When the latest addition to the tariff walls limited imports from abroad, will not the good engineer see that the cotton and wheat and meat exports correspondingly were reduced? This reduction in the demand for the products for the farms of America tends to decrease the prices the farmer can get. At the same time the high tariff wall makes the things the farmer has to buy more expensive than they otherwise would be.

A great deal is heard about what European countries owe to the United States, and in Congress is heard a good deal of abuse of these same countries because they will not pay these debts. This attitude is expressed in the question asked by the late President Coolidge: "They hired the money, didn't they?" Is it not the part of good engineering to recognize that these debts were created by the shipment of war materials at high prices and after the war by the shipment of goods to make up for the destruction caused by the war. No money was loaned. The debts were created by the shipment of goods. It should be apparent that the debt can be repaid only in the same way it was created and that there is no chance of being paid if the United States refuses to accept goods from abroad.

Will not the good engineer recognize that trade is what the name implies, that is, essentially barter? Money is a great invention that makes the process of barter much easier than it would be without money. However, the fact remains that when a farmer sells a bushel of wheat for, say, a dollar and uses the dollar to help pay for a suit of clothes, the essence of the transaction is the exchange of wheat for clothes. When the engineer takes his monthly salary and pays his rent, his grocery bill, and the payment on his automobile, the essence of the transaction is the exchange of services for the rent, the groceries, and the automobile. If it is clearly seen that trade is really an exchange of goods for goods and that money is merely a token used to make the exchange easier, it will be seen that the increase or decrease in the number of tokens is not controlling. Trade cannot be produced by increasing the number of tokens. In the long run, trade can be increased only by having more goods to trade. At the present time when the use of gold as money has been forbidden and all debts are paid by paper money or by checks, is it not clear that money is not wealth but is merely a token used to facilitate exchange?

The engineer should see, however, that if he is to set up a system in which all have equal rights, he will have to go deeper than the tariff question or the money question, important as these are. The

most fundamental right one has is the right to life; and if he has the right to life, he has the right to the means of making a living. According to legislators, and newspapers, and the American Federation of Labor, there are 2 factors in the production of wealth, labor and capital. The laborer is complaining because the capitalist is getting too much, and a good many capitalists have gone to the wall in the last 4 years blaming the unions and the communists for the trouble. When the engineer looks at the situation, he sees that the primary element in production is neither labor nor capital, but is natural opportunity. When one raises a bushel of wheat the labor used in plowing and harrowing the ground and in planting the seed is evident. The capital in the shape of seed, horses, and tools for preparing the soil and planting the seed also is evident; but the primary element in the production of the wheat is the land and sunshine and rain. All the capital and labor on earth could not raise any wheat without land. Take the production of a ton of coal: The labor in digging the coal is evident; the capital in the shape of hoisting machinery and tipples, etc., is evident; but is it not clear that the primary element in the production of coal is the land from which the coal comes? *All wealth is produced from land by the application of labor aided by capital.* That this statement is true of food and clothing and houses is evident from the mere statement. In the case of the automobile the number of steps between the land and the finished product is greater than in the case of food; but without the raw materials supplied by land, the automobile would be just as impossible as food without the land.

Now land is provided by the Creator for the use of His children and all have an equal right to it. This equal right is recognized by law in the ocean areas of the earth, but is denied in most of the land areas. No doubt everyone would admit that from a theoretical standpoint, everyone has an equal right to the earth from which his living must come; but experience has shown that if land is to be used properly, private, exclusive, and continuous *possession* of land is necessary. Since it is clearly impossible to divide the land upon the arrival of each new individual on earth, and since the present scheme of private ownership of land gives the private, exclusive and continuous possession of land so necessary for its proper use, the chance of securing to the new arrival on earth the use of his share of the earth looks rather slim. Is the solution of this problem impossible? What follows is an abstract of the solution given by one of the greatest thinkers of modern times.

A Proposed Solution

Every community, by its presence and activity, creates a fund which is the natural source from which its expenses should be drawn. This fund is ground rent. For instance, there is a little candy store on Euclid Avenue, in Cleveland, that is said to rent for $2,000 per year per foot. It is very clear that this $2,000 per year per foot is a community product which is appropriated by the owner of the fee to the property. It is further clear that this $2,000 per year per foot produced by the community, and appropriated by the fee owner, defrauds the community by just this amount. Present land laws make it legal for fee owners to defraud the community by appropriating the community created ground rent to the extent of 12 or 13 billion dollars per year in the United States. This fund is ample to take care of reasonable governmental expense.

A little thought will make it clear that the selling value of land is the ground rent, actual or expected, capitalized. The amount of this ground rent in such a city as New York is appreciated partially when it is realized that the privilege granted to the fee owner to appropriate the community created ground rent is, in places worth $400,000 per foot front. It is clear that the provisions of law that make it legal for fee owners to appropriate such enormous sums of money, which they do not earn, but which are created by the activities of the community, are unethical, unscientific, and should be changed. A hundred years ago it was legal to hold slaves, but most people are convinced that it was never right to hold slaves. Laws should be altered so as to make it impossible for individuals to appropriate the enormous amounts of community created ground rent, which it is now legal for them to do.

The Effect on Unemployment of Having the Community Collect Its Own Ground Rent

It might be well, at this point, to get clearly in mind that wealth producing employment is simply the application of labor to land or the products of land. It is very clear that employment in raising wheat, or cotton, or cattle, or dairy products, is the direct application of labor to land. Employment in manufacturing of automobiles, ginning of cotton, or milling of flour consists in modifying the products of land into more useful forms. Employment on the railroads and bus lines, and in express offices and post offices is increasing the value of the products of land by transporting them from one place to another.

Is it not clear that if all land were held out of use that all wealth producing employment would cease? If all land were held out of use, there would be no employment in raising food, or in mining coal, or in building and keeping up roads, or in building and keeping up houses. If all land were held out of use, life on this planet would cease!

It is clear then that if any land is held out of use employment is decreased to just that extent. Present land laws make it pay to buy land for speculative purposes and hold it out of use, or out of its best use, until it can be sold at a profit. During the summer, the writer lives in Aurora, a suburb of Cleveland, Ohio, and near his home are many thousands of acres that are held out of use in this way. In Arizona, where this paper was written, perhaps fully half of the land within 10 miles of Phoenix is held out of use until it can be sold.

Is it not clear that a large part of the load of bonds under which municipalities are staggering, are bonds

for paving, and sewers, and water lines in front of miles of vacant lots? These improvements were put in to help sell land. Had it not been for land speculation such of these improvements as were not needed would not have been made and millions of dollars worth of bonds issued for improvements the community did not need and which may be defaulted would not be a burden on the taxpayer today.

At the present time the actions of governing authorities in the United States are based upon the assumption that the use of capital makes employment, and consequently the Reconstruction Finance Corporation and other governmental agencies are making huge loans for the purpose of increasing employment. A moment's thought will make it apparent that land or its products are the only essentials to employment. The use of capital renders this employment more productive than it otherwise would be.

The pioneers who spread over the country from the Atlantic Coast to the Pacific during the century that ended about 1875 had no lack of employment, but they almost entirely did lack capital.

What would happen to land value if the community collected the ground rent created by its presence and activity? Since land values are simply ground rent capitalized, it is clear that if the community collected its ground rent, the selling value of land would become practically zero. If this occurred it would be unprofitable to hold land out of use. Consequently, it would be thrown on the market and be bought at an extremely low cost. Such a change as this would entirely prevent land speculation, but in no way interfere with the productive use of land. At the present time ground rent goes into the pocket of the individual. Under the proposed scheme the amount would be paid to the community in the shape of taxes. The use value of land would be the same in either event.

Community Has No Right to Take Individually Created Wealth

If the proposed scheme were adopted and the community took the ground rent created by its presence and activity for community expenses, it would not need to levy taxes on individually created wealth, as it does at present. This winter the writer is living in a house in the middle of an orange grove, in Phoenix, Arizona. All will agree that he has no right to take the fruit from this orange grove without paying the owner for it. The community, however, takes the position that it has a right to take a considerable part of the product of this grove in the shape of taxes every year. If there are 50,000 people in Phoenix, and the taxes on this orange grove equal the value of 50,000 oranges, it is equivalent to saying that each individual has a right to take one orange from this grove without paying for it. Most engineers are convinced that the government of Russia is doing an unjust thing in taking from the peasants of Russia such a large amount of the crops as it does; but is it not clear that the tax system of the United States does exactly the same thing, but possibly not to the same degree? To put it rather bluntly, our laws permit the fee holders to steal about 12 or 13 billion dollars per year of ground rent created by the presence and activity of the community. Then the community steals from individuals an almost equal amount to pay the expenses of federal, state, and local governments. Is it not clear that the United States does not suffer from lack of sufficient land to give everyone employment? What the people of this country do suffer from is the fact that this unused land is held at such a high price that the ordinary person is unable to obtain any of it to use.

It is not immediately apparent that the proposed scheme of collecting the ground rent produced by its presence and activity would raise the wages of the elevator operators, for example, in a city office building any more than it is apparent that the world is round; but if it be remembered that wealth producing employment is the use of land or its products and that this scheme would force vast areas of land into use that are now idle, and that increasing the use of land means increasing the number of jobs demanding workers, it becomes clear that the increased demand for workers would raise wages in general and, therefore, raise the wages of elevator operators.

The number of jobs that would be created if 25 per cent of the unused land in the United States were put to use would largely relieve the present unemployment situation. If all of it were put to use there would be more jobs than people to fill them and unemployment would be a thing of the past. Under a system in which there were more jobs than workers, wages would rise to a point where they practically equalled the value of the product, thereby obtaining a just distribution of wealth which must be obtained if civilization is to last. The foolishness of present taxation laws is apparent when it is realized that a man who builds a building, thereby furnishing employment for hundreds of people in its construction and for many people in its operation, is fined by the community in the shape of increased taxes. At the present time this tax item is great enough to decrease very considerably the number of buildings that otherwise would be erected. At the same time a person is allowed to hold title to iron ore lands, for instance, for 30 or 40 years until the owner can find somebody who will pay him his price for it, rather than levying taxes against this land so that it will have to be worked or sold to somebody who will work it. It is *land that is being worked* that makes employment, not land that is being held *unworked* until the owner can get the price that suits him.

At present, if a man starts a factory and gives employment to hundreds of people, he is fined in the shape of taxes on his building, taxes on his machinery, taxes on his inventory, and in some states taxes on his sales.

Present tax laws would make one think that it is a crime to add to the wealth of the community or to increase employment and that it is a praiseworthy thing to decrease employment by holding land out of use for speculative purposes.

It must be realized that land is provided by the Creator and that all His children have an equal right to a life use of an equal share. It must be realized that wealth is the product of an individual or of groups of individuals and that while the community does have the *power* to appropriate part of this wealth it has no *right* to do so.

It must be realized that society can be healthy only if it obeys the moral law, "thou shalt not steal," and that getting something for nothing is the essence of stealing. If society permits land values to rise by allowing fee owners to appropriate community created ground rent, it must pay the penalty in unemployment and low wages, caused by holding vast areas of land out of use or out of its best use. If society discourages thrift and individual initiative and business activity by appropriating part of the value created by the individual, in the shape of taxes on wealth, it must pay the penalty in the decreased employment and consequent lower wages resulting from lessened business activity. Until the people of the United States act on the very obvious truth that what the community produces should be collected by and for the community and not by and for fee owners, and also recognize that what the individual produces is his and the community has no right to it, they shall be plagued with unemployment and communism.

Very little change in the laws of this country would be required to obtain the results desired. Already part of the community created ground rent is being taken in the shape of taxes on land value; all that would be necessary would be to take the rest of the ground rent and abolish all taxation on wealth.

Quieting Substation Equipment

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With the aid of sound measurements made with an analyzing type of sound meter, it has been possible to ascertain the principal sources of noise in an electric power substation in a residential district and to reduce the noise to an unobjectionable level. The principal sources of noise were found to be an outdoor 6,000-kva transformer and the voltage regulators inside the station building; by replacing the noisy transformer with a quieter one and replacing the ventilating louvers in the regulator rooms with steel plates, the noise on neighboring properties was reduced to about 4 per cent of its original loudness.

IN DEALING with noise from substations in residential districts, The Detroit Edison Company encountered the familiar difficulty of trying to determine the effectiveness of any particular quieting move. Accordingly, it was decided to use sound measurements so that the relative value of various quieting experiments could be ascertained. The sound measurements were made by the author working in conjunction with engineers of the company, and the data obtained for one typical substation are presented and analyzed in this paper.

At first thought, the necessity of sound measurements on such work is not obvious. One naturally would assume that a given change would be of no practical importance unless the quieting were appreciable to the ear, and that the relative importance of various noise sources could be determined by shutting them down one at a time. The trouble with this plausible reasoning is that it does not work on actual problems. Before the work here described was started, one of the 2 transformers at this substation was replaced by one that was believed to be definitely quieter, but no appreciable reduction in the total noise of the station was apparent to the ear.

Shutting down the remaining original transformer gave a reduction that was readily apparent by ear, because it was by far the most prominent source, and, as will be shown presently, the loudness level was reduced nearly 30 decibels by its removal. It is rather unusual to encounter such a prominent source in measurement of machinery noise, perhaps because measurements are not needed to locate them. In most work several sources of about equal importance are found; consequently, the reduction obtained by removing any one of them is seldom more than a few decibels, and the ear cannot be sure of such changes. In fact, by listening, one often reaches the conclusion that *none* of the sources present are responsible for the noise because no practical reduction is obtained by removing any one of them.

The reason for this apparently anomalous result lies in the human sense of hearing and the physical

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Fig. 1. Substation on which the study was made

nature of most practical sounds. The range of sound energies to which the human ear will respond is so large that, on the average, a change of less than 25 per cent (1 decibel) cannot be perceived, and increases of 200 to 300 per cent (3.0 to 4.8 decibels) correspond to very moderate changes in loudness. Consequently, if in a practical example there are say, 3 sources of approximately equal importance, the complete removal of any one of them will reduce the energy by only 33 per cent (1.8 decibels) and the improvement is very slight indeed. The only effective procedure is, therefore, to determine the relative contributions from the various sources of sound and to devise reductions in *all* of the large contributors in order to bring about the required quieting. Reductions in the smaller components are obviously useless, so there is no point in working on them, nor in reducing any of the sources the noise from which is much below the general level. Sound measurements allow this to be done very effectively, and insure that important sources are not overlooked, nor effort wasted on unimportant ones. With data at hand on the results that can be obtained with various degrees of treatment of the individual pieces of equipment, one can compute with considerable certainty the results to be expected from any proposed change, and balance the comparative costs of obtaining various degrees of quietness, either at present or in the future.

This paper describes a series of experiments on the substation shown in figure 1 for the purpose of determining the noise levels existing in the neighborhood of the station and the reductions obtained by various quieting means. The sound sources in this case consisted of 9 200 kva and 1 120 kva self-cooled induction regulators in rooms inside the building and 2 6,000-kva 3-phase self-cooled transformers in the yard behind the building.

Experiments indicated that the noise, particularly that from the regulators, varied over a range of perhaps 5 decibels during the evening peak load, and, since time did not permit a study of all the variables of the problem, measurements were taken only between 10 a.m. and 4 p.m., except a few "shut-down" experiments which were made at about 2 a.m.

Preliminary tests indicated that so-called total-noise measurements, where all component frequencies of the sound are measured simultaneously, were not feasible for some of the measurements, particularly those some distance from the station, because of extraneous street noise. Although the analyzing ability of the human ear made the noise of the station distinctly audible in the presence of the street noise, even several hundred feet from the station, at these greater distances the latter often represented more energy and was, of course, very irregular so that it masked total-noise readings on the station. With the aid of an analyzing sound meter, the component frequencies of the station noise could be measured easily, and, accordingly, all measurements were made on these individual tones.

The quantity measured was the sound pressure; but since the ear is not equally sensitive to all frequencies, all the data of this paper have been translated to loudness level so that larger numbers represent louder sounds to the average ear. This was done by weighting the data according to the equal loudness curves of figure 2. If desired, the data can be changed back to physical units by the same curves. For example, a 100 cycle note of pressure 0.2 dyne per square centimeter (60 decibels above reference level of 0.0002 dyne per square centimeter) has a loudness level of 36 decibels, or a 200 cycle note of 40 decibels loudness level has a sound pressure of 0.045 dyne per square centimeter (53 decibels above 0.0002 dyne per square centimeter), etc.

Figure 2 is the same as figure 1 of "Proposed Standards for Noise Measurement" (ELECTRICAL ENGINEERING, November 1933, page 744) except that the ordinate is called "sound pressure level" instead of "intensity level." This procedure is consistent with the proposed standards because, except for minor differences due to temperature and barometric pressure, the 2 terms are identical for plane and spherical sound waves, the only ones to which the standards refer. No standards have been proposed for sounds with interfering waves, which include essentially all practical sounds, but the proposal includes a defini-

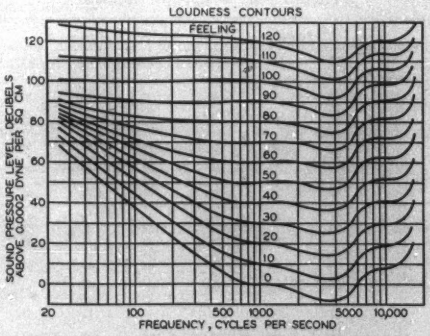

Fig. 2. Curves showing average characteristics of the human sense of hearing regarding relative loudness of tones of various frequencies and levels

These data were obtained at The Bell Telephone Laboratories and have been adopted as tentative standards by the American Standards Association (see Electrical Engineering, November 1933, page 744)

tion of intensity that makes it impossible to determine the intensity of a sound consisting of interfering waves by measurements with any meters known to the author. Since no provision has been made in the standards for expressing data taken with present-day meters in interference fields, this method, which is consistent with, but not authorized by, the proposed standards, has been used. (See "The Interpretation of Sound Measurements Used in Machinery Noise Reduction," E. J. Abbott, *Journal* of the Acoustical Society of America, January 1935.)

Table I—Loudness Levels of 120 Cycle Tone in Neighborhood of Substation, Decibels

Station	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6	Station	Line 3	Line 4	Line 5	Line 6
1	75	40	56	58	54	42	27	63	52	48	60
2	67	56	56	62	58	48	28	65	54	44	63
3	65	62	56	67	60	50	29	56	58	48	64
4	58	63	50	72	56	40	30	58	54	42	65
5	54	62	52	67	54	42	31	54	50	42	63
6	67	44	56	70	50	44	32	52	54	46	65
7	52	65	58	70	46	52	33	58	52	52	70
8	65	74	62	67	38	54	34	52	56	50	68
9	68	75	67	67	40	56	35	48	52	53	70
10		78	70	64	62	58	36	62	58	58	67
11		62	67	60	62	50	37	50	60	56	67
12		56	63	67	63	46	38	60	67	54	56
13		60	64	62	65	58	39	58	56	52	56
14		50	72	70	56	48	40	54	62	50	56
15		70	76	67	44	42	41	48	63	44	50
16		75	75	67	52	50	42	38	60	40	
17		73	72	67	48	50	43	36	65	38	
18		44	74	65	46	63	44	35	54	38	
19		70	78	65	48	68	45	33	60	42	
20		46	76	65	48	65	46		60		
21		67	75	58	50	63	47		46		
22		60	77	60	62	64	48		54		
23		54	72	60	60	67	49		60		
24		58	54	54	60	54	50		46		
25		38	67	54	56	65	51		58		
26			60	58	42	58	52		58		
							53		48		

Table II—Loudness Levels of 120 Cycle Tone at Different Heights Near Transformers, Decibels

Station	Transformer 1			Transformer 2		
	3 ft	6 ft	9 ft	3 ft	6 ft	9 ft
1	81	63	63	76	65	50
2	70			68		
3	68	80	60	73	70	35
4	75			75		
5	83	85	75	75	67	46
6	81			72		
7	77	80	60	67	62	58
8	67			70		
9	80	67	83	74	75	65
10	88			75		
11	92	85	81	76	78	67
12	93			72		
13	94	82	75	65	74	63
14	90			54		
15	89	76	68	52	65	64
16	88			65		
17	88	72	80	68	72	70
18	85			62		
19	83	80	73	54	72	63
20	75			67		
21	68	88	80	74	83	75
22	86			73		
23	86	88	82	68	80	67
24	78			52		
25	65	83	78	60	65	62
26	67			67		
27	77	63	67	70	72	72
28	80			67		
29	80	72	72	65	62	74
30	81			77		

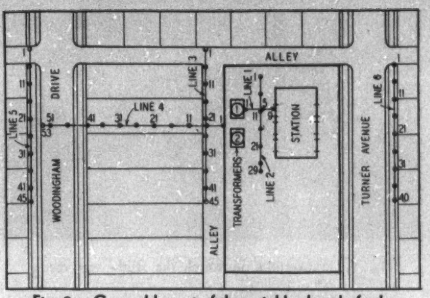

Fig. 3. General layout of the neighborhood of substation showing locations of lines of measurement stations. The stations were 3 feet apart, and the small circles indicate the location of every fifth station

Initial Survey of 120 Cycle Tone

Preliminary measurements both inside and outside the station showed that the noise consisted essentially of harmonics of 120 cycles per second, the odd multiples of 60 cycles being negligible. It was found also that in this particular case the 120 cycle tone was the loudest component. This is by no means a general conclusion for transformers and regulators; in fact, later measurements under other conditions showed that some of the higher harmonics were as important as the 120 cycle tone. Initially, however, the 120 cycle tone was predominant, and, accordingly, the first measurements were taken on it.

Six lines of measurement stations were laid out in the neighborhood of the station, as shown in figure 3. Readings of the level of the 120 cycle tone were taken at 3 foot intervals along these lines, with the microphone held 6 feet above the ground. The small numbers in the figure indicate the location of every fifth measurement station. The results of these measurements are shown in table I.

A second series of measurements was taken close to the transformers, which were about 10 feet in diameter and 12 feet high. Thirty equally spaced stations were laid out around the circumference of the transformers, and measurements taken at 3 different heights, 3, 6, and 9 feet. In all tests the microphone was held 8 inches from the transformer. These data are shown in table II.

Results of Initial Survey

The initial survey on the 120 cycle tone yielded 2 results: first, data on the distribution of the noise in the neighborhood of the station; and second, indication of the relative importance of various noise sources.

Distribution of 120 Cycle Noise. The outstanding feature of the measurements shown in tables I and II is the large and irregular variation in the loudness of the tone from point to point. Starting at any point in the neighborhood of the station and moving

Table III—Comparison of Averages of Measurements at Alternate Stations From Tables I and II

	Loudness Level of 120 Cycle Tone, Decibels	
	Odd	Even
Table I		
Line 1 (9 stations)	63	64
2 (25 stations)	61	59
3 (45 stations)	59	60
4 (53 stations)	59	60
5 (45 stations)	51	51
6 (41 stations)	57	56
Table II		
Transformer 1		
3 ft (30 stations)	81	80
6 ft (15 stations)	77	79
9 ft (15 stations)	76	70
	—	—
General Average	78	76
Transformer 2		
3 ft (30 stations)	67	67
9 ft (15 stations)	70	71
9 ft (15 stations)	63	61
	—	—
General Average	67	67

in any direction, the loudness did not remain essentially constant, or even increase or decrease regularly as the distance from the station was changed. Instead, in the matter of a dozen feet or so, the loudness ranged up and down by 20 decibels or more. These variations were not spaced uniformly, nor were the maximum or minimum values the same, although the reading at any single position was constant and ordinarily could be repeated within a decibel.

These point-to-point variations in loudness were clearly due to interference between the various direct and reflected waves of sound reaching the point of observation, and were particularly noticeable because of the long wave length (about 9 feet) and the constant frequency. Of course, they could be heard by ear as well as measured by meter. As shown in table II, these wave patterns existed right up to the surfaces of the transformers, the point-to-point variations on each transformer being approximately 30 decibels. This is attributed to the fact that the transformer shells do not pulsate as a unit, but instead the surface consists of many vibrating segments, each with its own phase and amplitude of motion.

As a result of these wave patterns, the data show some surprising facts. For example, transformer 1 is obviously much noisier than transformer 2; but at station 9, height 6 feet, transformer 1 measured 8 decibels less than the corresponding point on transformer 2. Also, the reading obtained at station 1 on line 4, about 10 feet from the transformers, was identical with that at station 52, on the far side of the adjacent street.

It would be an interesting, although somewhat laborious, task to plot these complex sound contours in 3 dimensions, but such data might be hard to interpret. While one might be interested in the location of the maximum values of loudness, particularly if one of them came at the head of his bed, it was thought that an average value of loudness for a given region would be of more value in this investigation. Accordingly, all conclusions were drawn from such averages. In the remainder of the paper, only these averages are tabulated, although the wave patterns were encountered in all measurements.

Accuracy of Averages. Obviously, when one attempts to average out variations of the order of 20 decibels or more, the accuracy of the results depends upon the number of values used, and the accuracy with which these values represent the range. One test of such averaging is to compare the averages of 2 halves of the data. Table III shows the results obtained by averaging the readings of alternate stations of tables I and II.

From the closeness of this check, it was decided that sufficiently accurate data could be obtained by taking measurements at every other station only, and this was done for the rest of the study. While these grand averages are probably correct within a decibel or 2, this accuracy does not apply to averages of smaller groups of measurements near transformers, etc. In such cases, it was suspected that the values might be altered by phase changes among the interfering waves due to shift of load, differences in reflections, or other causes. Accordingly, the tentative conclusions drawn from such figures usually were checked by subsequent measurements.

The average noise levels in the neighborhood of the station as determined from table I were as shown in table IV.

Relative Importance of Noise Sources. From this initial survey it was apparent that the noise levels on adjoining property on the back side of the station were determined by the transformers, not by the regulators. This is shown by table V, which gives averages of certain groups of readings in table I. The sound pressure was much greater in the alley than it was nearer the building, and also greater than it was at a corresponding position on the opposite side of the building, proving that it was due to the transformers.

The data also proved that the noise levels were determined by transformer 1, the noise from transformer 2 being negligible (see table VI). Transformer 1 was also louder on the side toward the alley than on the side toward the station.

Table IV—Average Noise Levels of 120 Cycle Tone in Neighborhood of Station

	Loudness Level, Decibels
In yard at rear, between station and transformers	60
In alley at rear of station	60
On sidewalk across street from front of station	57
On sidewalk on far side of street behind station	51

The range of values obtained in these various locations was approximately ±10 decibels above and below the average.

Table V—Averages of Readings Opposite Station Building

	Loudness Levels, Decibels
Line 2, in back yard between building and transformers (stations 5–24)	62
Line 3, in alley (stations 14–31)	68
Line 6, across street from front of building (stations 8–27)	57

These measurements furnished no information concerning the noise produced by transformer 2. While the measurements near it showed an average value of 67 decibels this is about the level of the remainder of the region resulting from noise from transformer 1 and the regulators. Hence, transformer 2 might be much quieter. It is hard to believe this when listening. When one placed his ear within a few inches of transformer 2, he seemed positive that the noise he heard came from it, but, as will be seen presently, such was not the case.

In making these comparisons of average levels, it should be kept in mind that if the pressure level of any component of a sound is 6 decibels or more below the level of the total sound, its complete removal will reduce the total by less than 1 decibel. If one component represents half the total sound, its removal reduces the pressure level by 3 decibels.

Experiments on Quieting Means

Shut-Down Test of Transformers. The initial measurements indicated that transformer 1 was the principal source of noise at the station; accordingly, arrangements were made to shut this unit down altogether for a short time and measure the resulting effect in order to obtain a more accurate measure of the relative importance of the other sources. This experiment was carried out at approximately 2 a.m., measurements being taken on line 5 on the opposite side of the adjacent street. Measurements were made under 3 conditions: both transformers on; transformer 1 shut down; and transformer 2 shut down. Averages of these measurements are tabulated in table VII.

A reduction of 29 decibels was obtained by shutting down transformer 1, proving beyond question that it was the principal source and that a large reduction would be obtained by replacing it with a transformer as quiet as transformer 2. To be consistent with this, the effect of transformer 2 on the total noise would have to be negligible; this was found to be true, the readings with and without it checking within the accuracy of measurement. This point having been proved, transformer 1 was replaced by a quieter one at this point in the investigation.

Experiments on Reducing Regulator Noise. Figure 4 shows the locations of the measurement stations

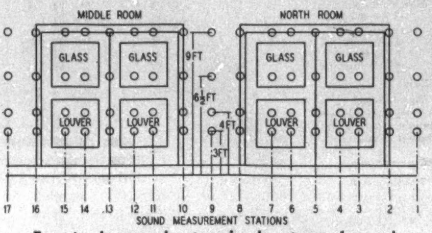

Fig. 4. Layout showing the locations of sound measurement stations near the doors of the regulator rooms on the front side of the station. The microphone was held 8 inches from the doors

used in testing the noise from the regulators on the front side of the building. The squares in the lower parts of the doors represent ventilating louvers, those in the upper parts, glass windows. Wave patterns probably were not averaged out as well in these studies as in the previous studies, particularly on the louvers, the dimensions of which were less than a half wave length; and it was suspected that changes in regulator settings might produce changes of pattern due to shifts in phase, or reflections that would affect readings considerably. For this reason, the readings probably are not as accurate as those previously described.

As shown in table VIII, it was obvious that most of the sound came from the louvers, as might be expected, the levels opposite these being even higher than near transformer 1. The obvious solution was to close these louvers and provide other ventilation for the regulators.

The company wished to test the effectiveness of several types of partitions in place of the outside doors of the regulator rooms. In order to do this it was essential that the noise level outside the doors would be determined by the noise coming through them rather than by noise coming from the other rooms, or by other paths. To test the extraneous levels, measurements were made with the regulators in the north room shut down. As shown in table VIII, this reduced the level at the louvers by about 30 decibels, but the level over the remainder of the door was reduced by only 13 decibels. With an uncertainty of measurement of 2 decibels or so, this precluded the possibility of testing partitions giving more than about 10 decibels reduction. As shown in figure 2, 10 decibels of loudness level corresponds to only about 5 decibels of sound pressure level at 120 cycles, which is a very small reduction factor for a partition. Hence it appeared useless to try to test partitions on one room, unless the other rooms were quieted also.

Table VI—Averages of Groups of Readings in Tables I and II Showing That Transformer 1 Was Principal Source of Noise

	Loudness Level, Decibels		
	Opp. Trans 1	Opp. Trans. 2	Opp. Bldg.
Line 2, in back yard	68	62	62
Line 3, in alley	75	61	68
	Sta. 10–19 Back Side	Sta. 26–30, 1–5 Front Side	Sta. 1–30
Transformer 1	81	72	77
Transformer 2	67	65	67

Table VII—Average Level of 120 Cycle Tone on Line 5

Condition	Average Loudness Level, Decibels
Both transformers on	54
Transformer 1 shut down	25
Transformer 2 shut down	53

Table VIII—Loudness Level of 120 Cycle Tone Near Regulator Doors on Front Side of Station

	Average Loudness Levels, Decibels		
	Louvers (8 Stations)	Remainder of Door (20 Stations)	Masonry Between Doors (4 Stations)
Middle room	83	68	65
North room	85	69	63
North room with regulators in north room shut down	55	56	

Table IX—Effect of Partition in Place of Outside Doors of Regulator Room on the Level of the 120 Cycle Tone Outside the Room

Louvers of other doors covered with steel plates. Readings represent averages of 20 stations inside and 24 stations outside. Wave pattern about ±10 decibels

	Average Loudness Level, Decibels	
Partition	Outside	Inside
Regular doors with louvers open: in front of louvers	83	
Regular doors with louvers open: remainder	64	85
Regular doors with louvers covered with 1/4-inch steel	54	87
Special partition *A*	54	88
Partition *A* plus regular doors with louvers covered with 1/4-inch steel	54	88
1/8-inch steel plate	48	85
1/8-inch "celotex"	60	85

Accordingly, the louvers on all the rooms on the north side of the station were covered by plates of 1/4 inch sheet steel, and measurements were made outside the station using the partitions listed in table IX. Measurements were made also at 20 stations inside the regulator room to check the effect of changes. The partition labeled *A* was made up as follows:

1/8-inch steel plate (inside)
1/4-inch air space
1/8-inch "celotex"
3/4-inch air space
1/8-inch "celotex"
1/4-inch air space
1/16-inch steel plate
1/4-inch air space
1/8-inch "celotex"

The air spaces were formed by wooden spacers at the edges, and the whole partition was bolted on the inside of the doorway with tight joints.

The measurements show that any one of the partitions, except the single layer of "celotex," was sufficient to reduce the noise to the point where the level outside the door was not determined by air sound passing through the partition. Apparently, the sound was due to vibration of the walls of the building, and in order to reduce this, vibration-reducing mountings for the regulators were indicated. Since it appeared that this expense would not be justified because of other noises, particularly that from the transformers, no tests were made of such mountings.

Another possibility of quieting is by installing sound absorbing material in the regulator rooms. While this did not appear promising, the large physical size of the source and wave length compared with the room dimensions indicated that computations based upon the ordinary reverberation formula were not justified; accordingly, to settle the question, the following test was made: Measurements were made of the noise level at 20 positions in one of the regulator rooms first in its usual condition, and then with 320 square feet of 1/2-inch "celotex" leaned against the walls. The 2 sets of readings agreed within a decibel; hence it was decided to spend no more time on this method, even though materials with larger absorption at this frequency might be obtained.

Measurements of Quieting Obtained by Transformer Replacement and Covering Louvers. Measurements were made on typical sections of the lines of measurement stations after transformer 1 had been replaced by transformer 1*A*, both with and without covering the louvers of the regulator rooms, to determine the reductions obtained and the relative importance of the sources under these conditions. The results are shown in table X.

These data indicate that replacing the noisier of the 2 transformers with a quieter one, and covering the louvers on the regulator rooms reduced average noise levels on neighboring property from 50 or 60 decibels to 20 or 25, which is a great reduction. According to data from the Bell Telephone Laboratories, this reduced the loudness (see figure 2 of "Proposed Standards for Noise Measurement," *loc. cit.*)

Table X—Data Showing Quieting Obtained by Replacing Transformer 1 and Covering Louvers

	Loudness Level of 120 Cycle Tone, Decibels		
	Transf. 1 and 2, Louvers Open	Transf. 1*A* and 2, Louvers Open	Transf. 1*A* and 2 Louvers Covered
Line 2, in back yard			
Sta. 5–23, opposite building	62	56	50
Sta. 7–13, opposite transf. 1 or 1*A*	68	54	48
Sta. 17–21, opposite transf. 2	62	60	52
Average of all readings in line 2	60	54	50
Line 3, in alley			
Sta. 15–31, opposite building	68	54	50
Sta. 17–21, opposite transf. 1 or 1*A*	75	56	50
Sta. 25–29, opposite transf. 2	61	52	50
Average of all readings in line 3	60	52	46
Line 5, on adjacent street	51	25	20
Line 6, across street from front of station	57	25	21

Table XI—Data on Relative Importance of Sources With Transformers 1A and 2, With Louvers to Regulator Rooms Covered

	Average Loudness Level of 120 Cycle Tone, Decibels			
Condition	Line 6, Adjacent Street Back of Station	Transf. 1*A**	Trans. 2*	Line 7, 8 In. From Covers on Louvers on Back of Building
Both transformers	20			
Transf. 1*A* shut down	19	46	62	
Transf. 2 shut down	17	52		54

* Measurements made at same positions as those in table II.

to about 4 per cent of its original value. When it is realized that street noise levels seldom fall below 35 decibels, even at night in residential districts (see "Results of Noise Surveys" by R. H. Gault, *Journal* of the Acoustical Society of America, July 1930, page 30) it is apparent that the 120 cycle tone usually will be completely masked and seldom, if ever, will be prominent.

Relative Prominence of Sources After Quieting. In order to determine the relative importance of sources after quieting, the experiments listed in table XI were made.

The data of tables X and XI show that, as far as the back side of the station is concerned, transformer 2 is the most prominent source of sound, and that the regulators with the louvers covered and transformer 1*A* are about equally important, the loudness level of the noise from each being several decibels below that of transformer 2. It should be noted also that the level near transformer 2 (see table II)was due to transformer 1 and not transformer 2. The actual level of transformer 2 was about 5 decibels less than the value given in table II.

Measurement of Other Component Frequencies

While the preliminary measurements indicated that the frequency of the predominant tone from transformer 1 was 120 cycles per second, the same might not be true after the changes mentioned in the preceding paragraph were made; accordingly, a few measurements were made of the other frequencies. For convenience, the transformer noise was analyzed at 10 stations near transformer 2, while the regulator noise was analyzed at 20 stations at a distance of 8 inches from each of 2 regulators selected by ear as being the noisiest and quietest in the station. The data are shown in table XII, the sound pressure measurements being converted to loudness levels by means of figure 2.

These frequency analyses show that, on the average, the loudest component in each is the 120 cycle tone, although because of wave patterns, it is likely that at some locations one of the higher harmonics is as loud. It is well known, as shown by figure 2, that at lower levels the ear is less sensitive to lower frequencies. Accordingly, at points some distance from the station, the higher frequency tones are relatively more important. The work of taking such measurements did not appear justified, because the practical problem already had been solved, but this effect can be estimated.

Assuming that all the tones are attenuated in the same ratio as the distance is increased, which seems quite reasonable, consider the region where the sound pressures are 0.1 as great as near the transformers (i. e., reduced 20 decibels). The corresponding loudness levels are shown in table XIII indicating that under these conditions, the 240, 600, and 720 cycle tones are louder than the 120 cycle tone. The conclusion to be drawn from these measurements is that it is not safe to assume which components of a sound are most important, but that actual measurements should be made.

Table XII—Frequency Analyses of Noise From Transformer and Regulators

Frequency, Cycles per Second	Average Loudness Level, Decibels		
	Transformer 2 (10 Sta.)	Regulator 4959669 (20 Sta.)	Regulator 5279613 (20 Sta.)
120	60	89	76
240	57	68	66
360	41	61	50
480	45	44	49
600	45	52	44
720	47	50	42
840	34	38	31
960	36	44	41

Table XIII—Frequency Analyses of Transformer and Regulator Noise Assuming All Sound Pressures 1/10 of Those in Table XII

Frequency, Cycles per Second	Average Loudness Level, Decibels		
	Transformer 2	Regulator 4959669	Regulator 5279613
120	22	60	40
240	28	44	38
360	16	36	25
480	22	21	26
600	23	30	22
720	25	28	20
840	12	17	10
960	16	24	20

Sound Measurements Give Definite Solutions

Conclusions reached from this series of measurements are obvious, in fact that is the principal advantage of sound measurements in industrial noise problems; arguments and matters of opinion are eliminated, the necessary lines of attack are indicated, and the results that can be obtained by various moves are determined. The second design of transformer was clearly much quieter than the first, and the fact that transformer 1*A* was noticeably quieter than transformer 2, even though they were supposed to be identical, was indication that more could be accomplished in this direction. Unless still quieter transformers could be obtained, or unless they could be enclosed, there was no point in quieting the remainder of the station more than covering the louvers of the regulator rooms. Better partitions than these obviously would be wasted expenditure.

The only question remaining was that concerning the most suitable means of providing ventilation for the regulators. A few experiments were made on baffles for the openings that would allow ventilation without allowing the sound to escape; but in the space available, it did not appear feasible to obtain the necessary muffling without too much reduction of ventilation. Accordingly, the louvers were replaced by steel plates, gratings were placed in the floor of each regulator room, and the air drawn in through the basement from an intake at the back of the station. This arrangement has been in use for nearly 3 years, and no complaints of noise from this station have been received during that period.

Wide Band Transmission Over Balanced Circuits

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Equipment for handling frequency band widths of the order of 1,000,000 cycles or more for telephone, telegraph, and television purposes was described in a recent Institute paper "Wide Band Transmission Over Coaxial Lines." This previous paper confines itself to the coaxial line structure, but points out that broad band transmission is also applicable to balanced conductor systems. The present paper discusses briefly some of the possibilities of the more familiar balanced circuits, circuits essentially as they now exist in the present plant being first considered, following which are considered circuits obtained by new construction. Wide band transmission over balanced circuits offers interesting possibilities both in the present plant and for new construction.

A HIGH degree of "electrical balance" has been for a long time a fundamental requirement of telephone transmission lines. This has been required not only to prevent interference entering into telephone circuits from other types of electrical circuits but also to prevent mutual interference between the closely adjacent telephone circuits on open wire lines or in cables.

As used here, the term "electrical balance" refers to the 2 sides of a telephone circuit. To secure such balance, the aim has been to construct the go and return conductors of each circuit of the same gauge and material and to locate them symmetrically with respect to earth and to surrounding conductors. The aim has also been to apply to each circuit terminal apparatus symmetrical with respect to its series impedances and shunt admittances to ground.

In the central offices, to be sure, unbalance in apparatus has been employed frequently for simplicity and convenience. In toll circuits, however, such office unbalance has been electrically separated from the outside plant by the use of repeating coils or otherwise. In local circuits the high standard of balance required for toll circuits has not generally been necessary since the exposures to interfering fields are less severe and the range of speech levels is much smaller. However, when local circuits are connected to toll circuits the unbalances are kept electrically separated from the toll circuits by the use of repeating coils. In recent years the tendency to the use of higher frequencies in communication circuits, the increase in the strength of interfering fields, and the development of highly efficient amplifiers has led to constantly more exacting requirements in electrical balance of telephone circuits.

The development of multichannel systems by carrier methods employing constantly increasing frequency ranges has placed particularly exacting requirements on such electrical balance. In a recent paper[1] on "Communication by Carrier in Cable" are described the balancing methods which have been developed to permit the use of an increased frequency range in such cables. The recently published paper[2] on "Wide Band Transmission Over Coaxial Lines" by L. Espenschied and M. E. Strieby points out the possibilities and possible requirements for very much wider frequency ranges. In that paper, coaxial lines are proposed which are particularly interesting in that they abandon electrical balance altogether and depend entirely on metallic shielding.

For such wide frequency range transmission, very interesting and important questions are raised, first as to the extent to which such wide bands can be placed on existing types of structure which are based on balance and, second, as to whether new construction designed particularly for such wide bands should depend on balance or shielding alone or a combination of the 2. It is the purpose of this present paper to discuss these questions.

As noted in the Espenschied-Strieby paper, the apparatus described for broad band transmission on concentric structures would also serve for other types of line structures. There would, of course, be problems in either balancing the apparatus or isolating its unbalances from the line structure. For the purposes of the present paper it is assumed that there will be no important reaction from the apparatus standpoint on this consideration of line balance and shielding.

Existing Cables

The attenuation of pairs in existing cables has a characteristic with respect to frequency generally similar to that of coaxial conductors but is, naturally, considerably higher because of the smaller physical dimensions and higher dielectric losses of the cable pair. For example, at 1,000,000 cycles an ordinary 19 gauge cable pair has an attenuation of about 18 decibels per mile, an ordinary 16 gauge pair about 14 decibels per mile, while a small sized coaxial structure

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1. For all numbered references see list at end of paper.

has an attenuation of about 6 decibels per mile. This means more repeaters for the cable pairs, 3 times as many for 19 gauge and a little more than twice as many for 16 gauge. Also, it means more difficulty in maintaining stability of transmission, including overcoming of the variations due to the effect of temperature changes.

Stable and highly linear repeater gain can be produced so readily nowadays, thanks to the negative feed-back amplifier invented by H. S. Black (see reference 3) that the idea of such high attenuations is no longer appalling even though on 16 gauge pairs it means repeaters spaced only about 4 miles apart. Overcoming the transmission variations due to temperature, with automatic regulators, introduces no fundamentally new problems, but, of course, the complexity and precision of regulation must be considerably higher due to the considerably larger variations.

Crosstalk, of course, must be given special consideration. First of all, it is necessary to restrict transmission of a given high frequency band to only one direction in a single cable; the other direction must be supplied by another cable[1] or other separate transmission medium.

Considering transmission in one direction only, if only one pair in a cable is set aside for high frequency transmission of, say, a million cycle band, most, but not all, of the crosstalk difficulty can be avoided. However, the fact must be reckoned with that if one pair in a cable is singled out and an amplifier is applied having 60 decibel or more gain at a point intermediate between voice-frequency repeater stations, the amplifier will have a strong tendency to sing due to crosstalk between the pairs connected to the input and output and the other pairs in the cable. If 2 cables are available, this difficulty can be avoided by jumping from one cable to another every time the high frequency amplification is introduced. If 2 cables are not available, overcoming the difficulty may call for the insertion of high-frequency choking devices in some or all of the low-frequency cable conductors at points where high frequency amplification is introduced.

Considering now crosstalk between 2 circuits in a cable transmitting in the same direction, assuming the amplifier difficulty to have been overcome, tests have been made on various cables in the field, from which these conclusions have been drawn. For telephone message purposes it is probably uneconomical to apply million cycle frequency ranges to more than a single pair in an existing cable. However, with television, the crosstalk requirements are much less exacting. This is because the range of intensities necessary for a good television image is much less than is needed to accommodate message telephone subscribers and, therefore, a considerably larger ratio of extraneous current to maximum signal current can be tolerated. Tests indicate that 2 or more television channels, each 1,000,000 cycles wide (possibly wider), can be transmitted over separate properly arranged pairs in the same direction in a single existing cable without serious disturbance due to crosstalk.

With respect to noise in existing cables, the matter of principal concern is noise produced in telephone offices by apparatus working on other circuits, since the natural shielding afforded by the cable sheath largely eliminates noise from outside sources. Two methods are available for control of the noise produced in telephone offices: (1) Introduction of high-frequency choking devices in all wires not assigned to carrier service at the points where the cables enter offices in which noise is produced; and (2) attack on noise at points where it is produced by introduction of spark-killers and individual high-frequency choking devices. The lenient noise-to-signal ratio requirement for television mentioned above makes high-frequency television application much easier than message telephone application.

While a million cycle frequency range over more than one pair in an existing cable seems unlikely for telephone message purposes, there are interesting possibilities in the use of lower maximum frequencies. For example, it seems likely that 12 same-directional telephone channels may be obtained from each one of a large fraction of the pairs in existing toll cables and that the crosstalk between the pairs may be kept within proper bounds by simple balancing methods previously described.[1]

Open Wire

With open wire, conditions are just about the reverse of those with cable. A mile of open wire has an attenuation of only about one decibel at a million cycles as compared to 6 decibels for the small sized coaxial conductor. However, overcoming crosstalk between different pairs of wires on a pole line presents very formidable problems, while avoiding interference from and to radio systems may be even more formidable.

The attenuation of open wire pairs has been checked up to several million cycles and it has been found that it behaves as expected. When there is little crosstalk from the high frequency band to other wires in the lead the attenuation-frequency characteristic is smooth; when there is severe crosstalk, the characteristic is bumpy. For a given length of circuit the attenuation is small compared with that of the small sized coaxial conductor and the variation due to changing weather conditions is also small—about $^1/_3$ that of the coaxial. It is interesting to note, however, that the percentage change in attenuation for the coaxial is less than half that for the open wire line. While it is, of course, evident that the open-wire transmission variations depend in part on changes in the series resistance of the wires due to changing temperature and in part to changes in leakage and capacitance due to varying weather conditions, automatic transmission regulating systems similar in general principles to those already developed for other purposes should be adequate to maintain the required stability.

Crosstalk between different circuits becomes so severe at high frequencies that special transposition treatment or respacing of the wires becomes necessary. Minimizing interference from and to radio systems calls for a high degree of balance which may or may not dictate changes in the wire configuration.

Here again it is necessary to distinguish between the requirements for television and for message telephone. Tests indicate that, in view of the more lenient television requirements, several million-cycle television channels can be transmitted over different pairs of a single open-wire line without serious disturbance and that to do this it will not be necessary to make radical changes in present wire configurations.

New Cables—Comparison of Different Types

For new construction, if television is not considered, effective carrier telephone systems may be set up by various methods. One might be a very broad band method, a good example of which is given in the Espenschied-Strieby paper. Another might be a much narrower band method using conductors similar to those in an ordinary cable. In the one case many telephone channels are obtained from a single pair by dividing up a frequency range, say 1,000,000 cycles wide, into somewhat more than 200 channels. In the other case only 20 odd channels are obtained per pair of wires and use is made of 10 pairs of wires to obtain the same total number. It is too early to say which of these plans might be best under various practical conditions.

To meet future television needs, it may be necessary to provide for transmission of continuous frequency bands 1,000,000 cycles in width or wider. It is interesting to compare the coaxial with balanced pairs surrounded by individual shields for such transmission.

For 6 decibel loss per mile at 1,000,000 cycles, it works out that a solid copper coaxial unit with the rubber disk insulation described in the Espenschied-Strieby paper has an internal diameter (inside of shield) of about 0.25 inch. For the same attenuation a pair of wires, each the same size as the central wire in the coaxial unit (70 mils diameter), insulated with rubber disks and with a copper shield, will have an inside diameter under the shield of about 0.4 inch. For outside conductors or shields made of lead the inside diameters become about 0.4 inch for the coaxial and 0.5 inch for the balanced pair. Therefore, if the thickness of the outer conductor is determined by mechanical considerations rather than outside interference, the coaxial is smaller and cheaper. As the frequency is made higher, the shielding from outside interference afforded by the surrounding cylinder increases, so that at very high frequencies mechanical considerations alone control and the coaxial is clearly cheaper than the balanced shielded pair.

In the frequency range up to about 1,000,000 cycles, however, interference from outside sources, including natural static and radio, must be considered in determining the thickness of the surrounding cylinder, and the cost comparison is not so clear. It will be evident that as regards shielding, the balanced pair is at a large advantage because the 2 sides of the circuit are designed to be electrically similar. By proper care in manufacture this balance readily can be made sufficient to insure adequate shielding with a surrounding lead tube of thickness determined solely by mechanical considerations.

With a coaxial structure, however, it appears likely that to keep interference within proper bounds, a simple lead tube must be made considerably thicker than required by mechanical considerations, so that such a structure would probably be more expensive than a lead shielded pair. However, by adding other materials an adequately shielded coaxial unit can be constructed which will have a considerably thinner outside wall.

For example, there is described in the Espenschied-Strieby paper a coaxial unit in which the inside diameter is minimized by first using copper tapes, the thickness of wall is minimized by adding thin iron tapes and the whole is made waterproof by a thin surrounding lead tube. This results in a unit of smaller inside and outside diameters than those of a lead tube surrounding a balanced pair of like attenuation. Since, however, the wall of the coaxial conductor is thicker and the structure more complicated, the costs of the 2 units are estimated to be not greatly different when they are designed for the frequency range up to 1,000,000 cycles. A minor advantage for the balanced pair remains, however, in that, whatever may be the top frequency, there is no limitation as to the lowest frequency permissible for interference reasons.

Other Considerations

In the above discussion of new cable construction the amplifiers and transmission regulators required have not been mentioned. If similar conducting and insulating materials are used, shielded balanced pairs and coaxials have similar transmission-frequency characteristics. The variations with temperature are also similar. The factors which limit the over-all amplifications are also the same. There is only one important point of difference between the amplifiers required for the 2 systems. This is the necessity for input and output transformers to be balanced to ground with the balanced pairs. The excellence of balance required, of course, depends upon the extent to which balance is relied on to reduce the required thickness of sheath. In view of the fact that very thin sheaths are impracticable for mechanical reasons it appears probable that only very modest requirements as to balance need be imposed on the design of these transformers.

To provide several circuits in new cables for meeting wide band television needs, another method may be considered, that is, to provide balanced pairs considerably larger in size than ordinary pairs and with the rubber disk form of construction, or other form giving low dielectric losses, but with no shields at all around the individual pairs. Shielding from outside disturbances would be provided adequately by the outside lead sheath of the cable. Crosstalk between different pairs would be the principal concern. If all of the high frequency pairs were to be used for television transmission, the crosstalk requirements, as already mentioned, would not be severe, so that by careful design the crosstalk could readily be kept within proper bounds—of course, restricting transmission of all wide frequency bands to a single direction within a single sheath. Such

high-frequency balanced pairs might prove suitable for telephone message circuits also. If not, the high frequency pairs would be restricted to television only, and other pairs, worked at lower frequencies, would be provided for telephone message service.

Summary

It appears feasible under certain conditions to transmit continuous frequency ranges of 1,000,000 cycles or more over conductors in the existing telephone plant. This may some day prove very important, particularly if the art of television develops to the point of calling for such wide frequency range circuits to carry television impulses around the country as sound programs are now carried.

For new construction, the balanced type of circuit, as well as the unbalanced coaxial circuit, offers many interesting possibilities.

References

1. Communication by Carrier in Cable, A. B. Clark and B. W. Kendall. Elec. Engg., v. 52, July 1933, p. 477–81.

2. Wide Band Transmission Over Coaxial Lines, L. Espenschied and M. E. Strieby. Elec. Engg., v. 53, October 1934, p. 1371–80.

3. Stabilized Feed-Back Amplifiers, H. S. Black. Elec. Engg., v. 53, January 1934, p. 114–20.

Cable System Neutral Grounding Impedance

Determination of the permissible neutral resistance or reactance for the grounding of cable systems for 3 phase power supply is considered in this paper. The theory of overvoltages which may arise as a result of intermittent arcs to ground through a cumulative action is discussed, and a description of the method for calculating these voltages is given. A simplified criterion for determining the value of neutral resistance or neutral reactance for limiting the overvoltages is proposed which permits the use of higher values than any preceding method.

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As power systems grow in generating equipment it becomes necessary to limit ground fault current to keep it within the rupturing capacities of circuit interrupting apparatus and to reduce the damage to operating equipment. Too much impedance in the neutral may permit the development of arcing ground conditions. This immediately raises the question as to what factors affect the choice of the value of impedance from this consideration and as to the maximum value of impedance that may be inserted in the neutral to limit the fault currents and still consider the system to be effectively grounded. It is the purpose of this paper to discuss this question and to offer for consideration:

a. A criterion upon which to base the choice of the neutral grounding impedance.

b. A method of calculating the limiting values.

Summary

It is proposed that the criterion for an effectively grounded system be based upon the requirement that calculated overvoltages from arcing grounds be kept down to harmless values. On this basis the following definition 15.10.153 has been proposed and is now being considered by the American Standards Association:

Effectively Grounded

Effectively grounded means grounded through a ground connection of sufficiently low impedance (inherent and/or intentionally added) that fault grounds which may occur cannot build up voltages dangerous to connected equipment.

This is a qualitative definition and permits those concerned with each class of apparatus to set their own quantitative limit which may be changed later if desirable. For cables, it has been tentatively suggested by the cable manufacturers and accepted by the operators that the calculated arcing ground voltages be limited to 3 times normal (crest to crest) line-to-neutral voltage. On this basis the following quantitative definition of an effectively grounded circuit can be set up:

Effectively Grounded Cable Circuit

A cable circuit may be considered to be grounded effectively if the maximum calculated arcing ground voltage under any operating condition does not exceed 3 times normal line-to-neutral voltage.

Resistance Grounded Cable Circuit

A cable circuit grounded through resistance will be effectively grounded in accordance with the foregoing criterion when the neutral

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grounding resistance is not greater than the value calculated by the following equation:

$R = 1.15\, X_s$

R = neutral grounding resistance

X_s = zero sequence capacitive reactance $= \dfrac{1}{\omega C_s}$

C_s = zero sequence capacitance
= $^1/_3$ capacitance of 3 conductors in parallel to ground

This expression may be written as follows in more familiar terms

$$R = 785 \frac{\log\left(1 + \frac{2T}{d}\right)}{P}$$

or

$$R = 342 \frac{G_1 S}{P}$$

The first expression applies to single conductors; type H cables; and single and 3 conductor, oil filled cables; the second expression applies to 3 conductor belted cables. In these expressions

T = thickness of insulation
d = conductor diameter
G_1 = geometric factor (Simmons)
S = sector correction factor
P = permittivity

Reactance Grounded Cable Circuit

A cable circuit grounded through reactance will be effectively grounded in accordance with the foregoing criterion when the neutral grounding reactance is not greater than the value calculated by the following equation:

$$X_n = X_1 \frac{2 + p}{6}$$

where

X_n = neutral grounding reactance
X_1 = positive sequence reactance of systems
p = ratio of zero sequence reactance of system (exclusive of X_n) to positive sequence reactance

The definition and the proposed limiting values of resistance and reactance are based upon arcing ground overvoltages because these are affected by system grounding conditions, while overvoltages due to lightning and switching surges are not.

In either case the insulation at the neutral of the transformers or generators should be based upon the neutral shift—practically 100 per cent if the maximum permissible resistance is used, and $^1/_3$ line-to-neutral if the maximum permissible reactance is used.

Determination of Maximum Neutral Grounding Resistance or Reactance

Resistance. To make an exact calculation it is necessary to determine the total zero sequence capacitance of the systems. This can be done by calculation or by measurements. The zero sequence capacitance is the capacitance of one conductor to ground when all 3 are considered to be in parallel. To calculate it there is required a knowledge of the conductor size and thickness of insulation for each section of cable. In general this would be tedious and a simple approximation is proposed.

The application of the foregoing formula is greatly simplified by the use of a tabulation giving the permissible neutral grounding resistance for various circuit conditions in regard to circuit voltage and size and type of cable. The use of this tabulation is based upon the fact that precise calculations usually are not necessary and in some cases may not be possible, and upon the reasonable assumption that the various cable sizes in a cable system may be grouped together in zones for the calculation, without serious error in the resultant calculated neutral grounding resistance. By proper grouping the use of the tabulation in this manner may be made to give results that will be slightly conservative, i. e., the calculated resistance will be lower than the limiting value which might be found from an extended calculation using the formula.

The tabulation is shown in table I. In the tabulation the maximum neutral grounding resistance is given for 4 representative conductor sizes and for the various types of cable over the voltage range. The use of this tabulation as indicated will give results sufficiently accurate for the large majority of cases and if more precise results are required a detailed calculation may be made by direct use of the formula. Table I is used as follows:

Table I—Resistance Grounding of Cable Systems

Circuit Voltage KV*	Type of Cable**	Neutral Grounding Resistance at 60 Cycles in Ohms for 4 Sizes of Conductors. 100 Miles of Circuit: 1/0	350,000 cir mils	750,000 cir mils	1,000,000 cir mils
4.1	A-B	37.6	22.4	16.7	10.6
	C	93.3	53.2	35.6	
6.9	A-B	47.1	28.9	20.6	13.8
	C	102.0	57.9	39.1	
13.8	A-B	64.1	40.3	29.3	20.0
	C	126.3	79.0	53.2	
23.0	A-B	81.6	53.0	39.3	27.2
	D	34.5	27.4	22.1	17.4
	E	56.9	35.5	25.4	
34.5	A-B	101.7	68.4	51.6	36.4
	D	43.1	34.6	28.0	22.1
	E	69.5	44.2	32.3	
46.0	A-B	115.5	79.7	61.0	43.6
	D	49.5	39.9	32.7	25.8
	E	78.4	50.5	37.4	
69.0	A-B	142.5	101.8	79.8	58.5
	D	63.7	53.0	43.1	34.4
	E	97.3	64.9	48.9	
138	D	94.1	78.8	66.6	54.5
	E	136.5	96.1	74.8	

* Insulation thicknesses according to 1934 standards of Association of Edison Illuminating Companies.

** A = single conductor cable; B = type H cable; C = 3 conductor belted cable; D = single-conductor oil-filled cable; E = 3 conductor oil filled cable.

The ohmic values in the tabulation represent the maximum permissible neutral grounding resistance for 100 miles of cable circuit for 4 sizes of conductors and various types of cable, and for permittivity factor $k = 3.7$.

The permissible ohms varies inversely as the length, so that values for other lengths may be obtained by multiplying the tabular value by $100/L$.

The permissible ohms varies inversely as the frequency, so that values for other frequencies may be obtained by multiplying the tabular value by $60/f$.

This tabulation may be used to estimate the maximum permissible neutral grounding resistance for any cable system based upon the estimated equivalent lengths of circuit in terms of the types and sizes of conductor listed in tabulation. For this purpose the cables approximately 1/0 in size and all smaller may be grouped as 1/0 conductor; the cables approximately 350,000 circular mils in size and

smaller, not included in the 1/0 group, may be grouped as 350,000 circular mils conductor; and similarly for the 2 larger sizes. The net effective value to be used is that obtained by considering the individual values all to be in parallel. For example, the neutral grounding resistance for an assumed 13,800 volt cable system is calculated in table II.

Arcing ground overvoltages are not the only factor to be considered by operating engineers in the selection of the value of resistance for grounding the neutral of a system. The final value to be used should be determined from consideration of a number of factors such as the rupturing capacities of circuit breakers, design of relay systems, and coordination with communicative circuits. After these factors have been considered and a desirable value of neutral grounding resistance selected a check should be made to see whether there is a chance that it is high enough to require the system to be classified as ungrounded. The tabulation offers a means of making this check rapidly and easily.

Reactance. To make an exact calculation it is necessary to determine the various system reactance values as for a short-circuit study. With these values in hand the determination of the limiting value of neutral grounding reactance for an effectively grounded system is a simple matter. For estimating purposes table III is given. This tabulation is used as follows:

The ohmic values in the tabulation represent the maximum permissible neutral grounding reactance for a 100,000 kva cable system based upon generator power supply $x = 0.15$ and transformer supply $x = 0.25$; the values are given for 2 values of system reactance. The permissible ohms varies inversely as the kilovolt-ampere capacity so that values for other kilovoltampere capacities may be obtained by multiplying the tabular value by (100,000 divided by the kilovoltampere capacity).

The maximum permissible neutral grounding reactance may be calculated directly from the following expressions:

$$x_n = \frac{2 + p}{.6}$$

$$p = x_0/x_1$$

It will always be found that when resistance is used for grounding a much higher ohmic value is permissible than when reactance is used.

Sources of Overvoltage in a System

There are 3 sources from which overvoltages in a system might occur: lightning, switching, and arcing grounds. Lightning overvoltages occur only on exposed circuits and are limited in magnitude only by the line insulation at the point where the stroke occurs. The circuit voltage itself has nothing to do with the magnitude of the lightning voltage, except indirectly through the different insulation levels used for different voltages. On the other hand, switching surges are a direct function of the rated circuit voltage. Surge voltage recorder records over a period of years indicate that less than 2 per cent exceed 4.5 times normal line-to-neutral voltage. There is also some definite evidence that switching surges of the higher magnitudes are sufficiently fast as to have some impulse ratio. A study of the surge voltage recorder records obtained during the lightning investigation over a period of several years confirms the fact that both lightning and switching overvoltages are independent of the system grounding conditions. Therefore, they need not be considered in selecting the impedance to be used for grounding.

Table II—Sample Calculation of Resistance for a 13,800 Volt Cable System

Size	Type	Length, Miles	Neutral Grounding Resistance
1/0	*A-B*	35	(100/35) × 64.1 = 286
1/0	*C*	87	(100/87) × 126.3 = 145
350,000	*A-B*	178	(100/178) × 40.3 = 23
350,000	*C*	41	(100/41) × 79.0 = 193
750,000	*D*	31	(100/31) × 29.3 = 85
1,500,000	*D*	8	(100/8) × 20.0 = 250

The net effective value to be used is the parallel value of the separate values, i. e., 13 ohms.

Arcing ground voltages are affected by system grounding conditions and consequently should be considered in selecting the type and value of the neutral grounding impedance until such time as experience proves otherwise. Arcing ground overvoltages are also directly proportional to the system voltage. On an isolated neutral system they are independent of the extent of the system.

There have already been published 2 general explanations of the mechanism of the building up of the overcharges due to arcing grounds. In the first, the arc is assumed to go out at the first zero of the oscillation, and in the second, the arc is assumed to go out at the first zero of the normal frequency current. The first theory was presented by Dr. Petersen,[1] and the second by Peters and Slepian,[2] while Clem[3] extended the first theory and applied it to grounded neutral circuits. In general the oscillatory arc extinction theory leads to higher arcing ground voltages than the other, the theoretical maxima being 7.5 times and 3.5 times the normal line-to-neutral voltage, respectively.

This overvoltage is built up through a step-by-step process[1,3] and finally reaches a maximum limiting value which may be maintained for some time. When the initial arc strikes, the faulty line goes to ground potential and the 2 sound lines go to an excess potential above ground. When the arc goes out there is a charge trapped on the sound lines which does not drain off completely before the arc strikes again. As a result the trapped or bound charge increases each time and the sound lines rise in steps to successively higher values until the limit is reached.

Connecting an impedance from the neutral to ground gives a path over which the bound charge may escape and therefore reduces the possible overvoltages. Resistance is more beneficial than reactance because of the damping it causes.

A certain amount of skepticism exists in regard to the existence of arcing ground overvoltages. This is not surprising since it is rather difficult to understand how the arc goes out at the first zero of the oscillation, and staged tests have been made which failed to result in arcing grounds.

If there were no arcing ground overvoltages there would be no need for differentiating between the insulation used on an ungrounded system and that

1. For all numbered references see list at end of paper.

Table III—Reactance Grounding of Cable Systems

Circuit Voltage in Kilovolts	Neutral Grounding Reactance in Ohms at 60 Cycles for 2 Values of Positive and Zero Sequence Reactance. 100,000 Kva Capacity			
	x_1 = 15 per cent, x_0 = 1.5 per cent		x_1 = 25 per cent, x_0 = 11.5 per cent	
	x_1	x_n	x_1	x_n
4.1	0.025	0.009	0.042	0.017
6.9	0.072	0.025	0.119	0.049
13.8	0.286	0.100	0.476	0.195
23.0	0.793	0.278	1.322	0.542
34.5	1.786	0.625	2.975	1.22
46.0	3.178	1.115	5.29	2.169
69.0	7.15	2.503	11.9	4.88
138	28.55	10.00	47.6	19.52

x_1 = positive sequence reactance
x_0 = zero sequence reactance, exclusive of x_n
x_n = neutral grounding reactance

used on a grounded system. The reluctance of operating engineers in this country to use cables with the so-called "grounded insulation" on an ungrounded system is very good proof of the fact that cable failures have resulted from arcing grounds. The extensive use of the Petersen coil in Europe is evidence that they recognize the existence of arcing ground overvoltages. Also, early experience in this country with ungrounded systems has proved that they do exist, and flashovers from time to time on partially grounded systems, explainable in no other way, indicate that the possibility of arcing ground overvoltages should not be disregarded.

Criterion of an Effectively Grounded System

It is customary to use insulation on a cable depending upon whether the system was grounded or ungrounded. In the past when there was any appreciable impedance inserted in the neutral the system was generally considered to be "ungrounded" and the heavier insulation was required. However, in recent years the attitude has progressively changed and it has been required that a moderate amount of impedance may be used and still consider the system to be effectively grounded, that is, grounded so that there is no appreciable chance of dangerous overvoltages resulting from arcing grounds. Systems may be grounded directly or through an impedance, which may be resistance or a reactance. The following definition has been proposed and is now being considered by the American Standards Association:

Effectively Grounded

Effectively grounded means grounded through a ground connection of sufficiently low impedance (inherent and/or intentionally added) that fault grounds which may occur cannot build up voltages dangerous to connected equipment.

Whether or not a voltage is to be considered as dangerous depends upon the overvoltage that may safely be allowed. The arcing ground voltages are generally of appreciable duration, and accordingly the Insulated Power Cable Engineers Association has at present proposed to limit the calculated value to 3 times normal, and this has been accepted by the operating engineers as a basis for consideration. This is in reality quite liberal as far as resistance is concerned since it will give a value sufficiently high to limit the fault current to moderate values, and will give higher values than previously obtained with any generally accepted formula.

Since arcing ground overvoltages are affected by the system grounding conditions, while the overvoltages due to lightning and switching surges are not, only the former need be considered in setting up a criterion for an effectively grounded system. If the idea of arcing ground overvoltages was discarded altogether then it would not make any difference what value of resistance was used and there would be no need for a rule. However, it is wise to be conservative and go slowly in the matter and base the criterion on the analysis which calculates the highest voltages until such time as experience indicates that higher values of resistance may be used. Accordingly, the analysis based upon oscillatory arc extinction will be used, it being recognized that experience may later indicate higher values.

Method of Calculation

In one of the papers previously mentioned[3] a method is given for calculating the overvoltages produced by arcing grounds, which may be adapted to the problem of determining the limiting value of the neutral grounding resistance or reactance in consideration of the permissible overvoltages. This formula is as follows:

$$V_1 = \frac{3}{2} E \frac{(2-d)(3-2b) - \left\{1 + 2\frac{c}{c_m}\right\}(1-d)}{3 - 2(1-a)(1-d)} \qquad (1)$$

in which

V_1 = maximum value of arcing ground voltage
E = system voltage line to neutral
$1 - a$ = reduction factor which takes into account the part of the bound charge that leaks off to ground over the neutral grounding impedance
$1 - b$ = reduction factor which takes into account the reduced neutral shift caused by the neutral grounding impedance
$1 - d$ = reduction factor which takes into account the damping of the oscillation
c = average capacitance to ground of the 3 conductors
c_m = average mutual capacitance between pairs of conductors

Equation 1 can be simplified through the following considerations. In a 3 phase circuit using shielded cables or single conductor lead sheathed cables, c_m becomes infinite so that $\left(1 + 2\frac{c}{c_m}\right)$ becomes 1. In the paper[3] referred to, the factor $(1-b)$ is shown to be equal to the neutral shift ratio e_n. Making these substitutions in equation 1 there results, with a slight change in notation:

$$e_a = \frac{0.5 + e_n(2-d)}{1 - \frac{2}{3}(1-a)(1-d)} \qquad (2)$$

in which the new terms are defined as follows:

e_a = ratio of arcing ground voltage to normal line-to-neutral voltage, i. e., V_1/E
e_n = ratio of neutral shift voltage to normal line-to-neutral voltage, i. e., E_n/E

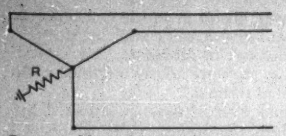

Fig. 1. Neutral grounding resistance, R

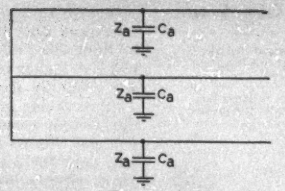

Fig. 2 (center). Zero sequence capacitive impedance Z_a and capacitance C_a

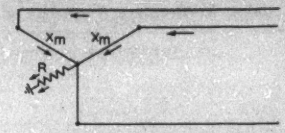

Fig. 3. Discharge path to earth of bound charge on the 2 sound lines, also discharge reactance, x_m

Dropping the factor c/c_m gives higher calculated voltages. Therefore, if equation 2 was used for 3 phase belted cables the calculated voltage e_a would come out higher than if equation 1 were used. Consequently limiting resistances for 3 phase belted cable determined on the basis of equation 2 will not be quite as high as might possibly be used. Since the resistances come out considerably higher than present practice, there seems to be no good reason for differentiating between the 2 types at the present time.

Evaluation of Reduction Factors

The reduction factors entering into this expression can be made to depend upon certain ratios, these are:

k = ratio of grounding resistance R used to the critical resistance r_n

$$R = kr_n \tag{3}$$

n = ratio of the zero sequence capacitive reactance x_a to the positive sequence reactance x_1

$$x_a = nx_1 \tag{4}$$

m = ratio of discharge reactance x_m to positive sequence reactance x_1

$$x_m = mx_1 \tag{5}$$

p = ratio of zero sequence reactance x_0 to positive sequence reactance x_1

$$x_0 = px_1 \tag{6}$$

The critical resistance r_n is that resistance in the neutral at which the discharge of the bound charge on the 2 sound phases to ground changes from oscillatory to nonoscillatory. It is defined by the expression

$$r_n = \sqrt{x_a x_m} \tag{7}$$

and x_m is defined by

$$x_m = \frac{2x_0 + x_1}{3} \tag{8}$$

For proof of equations 7 and 8 see development of equations 22 and 27.

The resistances and reactances mentioned in the previous paragraphs are defined as follows:

R = neutral grounding resistance. See figure 1
r_n = critical neutral grounding resistance
x_a = capacitive reactance of one phase when all 3 are in parallel with ground (sheath) return
= zero sequence capacitive reactance. See figure 2
x_1 = positive sequence reactance of system
x_m = discharge reactance. It is the reactance of one of 2 phases when the 2 are in parallel. See figure 3
x_0 = zero sequence reactance of systems

The positive and zero sequence reactances are the system reactances up to the point of fault which would be used in calculations to determine current for a ground fault. The zero sequence reactance of a cable is difficult of determination but fortunately it is usually a relatively small part of the total and therefore unimportant.

Usually the reactance x_1 and the charging current (corresponding to x_a) are expressed as percentages. If x is the per unit reactance and a the per unit zero sequence charging current,

$$x_1 = \frac{x\ \mathrm{kv}^2}{\mathrm{kva}}\ 100 \tag{9}$$

$$x_a = \frac{\mathrm{kv}^2}{a\ \mathrm{kva}}\ 1000 \tag{10}$$

And thus there follows

$$r_n = \frac{1000\ \mathrm{kv}^2}{\mathrm{kva}}\sqrt{\frac{x}{a}\ \frac{1+2p}{3}} \tag{11}$$

$$n = \frac{1}{ax} \tag{12}$$

$$m = \frac{1+2p}{3} \tag{13}$$

$(1-a)$ Discharge Leakage Factor

The reduction factor $(1-a)$ is the factor which takes into account the fact that part of the bound charge leaks off to ground from the 2 sound lines over the neutral grounding impedance. (See figure 3.) The discharge may be oscillatory or nonoscillatory, depending upon the circuit constants, but it is known in advance that for the resistance values which are of interest (the maximum limiting values) the discharge will be nonoscillatory. The general equation for the nonoscillatory discharge of a capacitor is:

$$(1-a) = \frac{e_t}{e} = \epsilon^{-\alpha t}\left(\cosh \beta t + \frac{r}{s}\sinh \beta t\right) \tag{14}$$

in which

e = initial voltage on capacitor
e_t = voltage at time t
α = damping factor

$$= \frac{r}{2L} \tag{15}$$

β = hyperbolic angular velocity

$$= \sqrt{\frac{r^2}{4L^2} - \frac{1}{LC}} \tag{16}$$

s = circuit impedance factor

$$= \sqrt{r^2 - 4\frac{L}{C}} \tag{17}$$

In this case the discharge is of 2 capacitors in

parallel (the 2 sound phases) and it will work out more conveniently if the constants for use in equation 14 are determined per phase.

r = resistance; it is twice the neutral grounding resistance plus the phase resistance. The equations will be simplified if the phase resistance is neglected, and if desired compensation may easily be made later on. Then

$$r = 2R \tag{18}$$

L = inductance; it is the inductance of one phase of the transformer or generator when current flows through two phases in parallel.

C = capacitance; it is the capacitance to ground and third conductor, when third conductor is assumed as grounded, of each of two conductors in multiple. For shielded cables it is the capacitance of the conductor to sheath, which is the same as the zero sequence capacitance. For belted cables this capacitance may be a little higher than the zero sequence capacitance. However, the zero sequence capacitance may be used since the omission of the factor $2\frac{c}{c_m}$ from equation (1) compensates for the difference.

Let

ω = normal system angular velocity

then

$$L = \frac{x_m}{\omega} \tag{19}$$

$$C = C_o = \frac{1}{\omega x_o} \tag{20}$$

When equations 18, 19, and 20 are inserted in 17 there results

$$S = \sqrt{4R^2 - 4x_m x_o} \tag{21}$$

When S becomes zero the discharge changes from nonoscillatory to oscillatory. The resistance which makes $S = 0$ is the critical resistance r_n so that

$$r_n = \sqrt{x_m x_o} \tag{22}$$

The reactance x_m is determined from the phase sequence theory as follows. (See figure 4—note that the subscripts used for equations 23 to 27, inclusive, are the conventional ones for phase sequence analysis and some may not agree with those used in the rest of the paper.)

$$I_a = i \qquad I_b = 0 \qquad I_c = i \tag{23}$$

$$I_{a0} = \frac{2}{3}i \qquad I_{a1} = -\frac{a}{3}i \qquad I_{a2} = -\frac{a^2}{3}i \tag{24}$$

$$e = \frac{2}{3}iZ_0 - \frac{1}{3}aiZ_1 - \frac{1}{3}a^2iZ_2 \tag{25}$$

$$\frac{e}{i} = \frac{1}{3}(2Z_0 - aZ_1 - a^2Z_2) \tag{26}$$

But Z_2 may be taken as equal to Z_1 without appreciable error and then

$$\frac{e}{i} = Z_m = \frac{2Z_0 + Z_1}{3} \tag{27}$$

The discharge period is assumed to last until the arc restrikes on the next maximum of the normal frequency, that is, during half of a normal frequency cycle. As an equation

$$t = \frac{1}{2f} = \frac{\pi}{\omega} \tag{28}$$

When the values of r, L, and C from equations 18, 19, and 20 are inserted in equations 15, 16, and 17 and these in turn with 28 inserted in 14 there results

$$(1-a) = e^{-\frac{R\pi}{x_m}}\left\{\cosh \pi\sqrt{\frac{R^2}{x_m^2} - \frac{x_o}{x_m}} + \frac{R}{x_m}\frac{1}{\sqrt{\frac{R^2}{x_m^2} - \frac{x_o}{x_m}}}\sinh \pi\sqrt{\frac{R^2}{x_m^2} - \frac{x_o}{x_m}}\right\} \tag{29}$$

which may be written in a briefer form

$$(1-a) = e^{-a\pi}\left\{\cosh \pi b + \frac{a}{b}\sinh \pi b\right\} \tag{30}$$

$$a = \frac{R}{x_m} \tag{31}$$

$$b = \sqrt{\frac{R^2}{x_m^2} - \frac{x_o}{x_m}} \tag{32}$$

If equation 30 is written in the exponential form it becomes

$$(1-a) = \frac{a+b}{2b}e^{-\pi(a-b)} - \frac{a-b}{2b}e^{-\pi(a+b)} \tag{33}$$

and the second part of the right hand term of equation 33 can be neglected without appreciable error, the error being such as to make the final result conservative. Then

$$(1-a) = \frac{a+b}{2b}e^{-\pi(a-b)} \tag{34}$$

The quantities a and b may now be expressed in terms of the quantities listed in equations 3 to 6 so that 33 becomes

$$(1-a) = \frac{k + \sqrt{k^2-1}}{2\sqrt{k^2-1}}e^{-\sqrt{\frac{n}{m}}(k-\sqrt{k^2-1})} \tag{35}$$

$(1-b)$ Neutral Shift Factor

The neutral shift when a fault occurs is the ratio of the voltage across the zero sequence impedance of the system to the normal line-to-neutral voltage. The voltage drop across the grounding resistance could be used but to be conservative the drop across the total zero sequence impedance will be used.

$$(1-b) = e_n = \frac{r_0 + jx_0}{r_0 + j(x_0 + x_1 + x_2)} \tag{36}$$

but

$$r_0 = 3R = 3kr_n = 3k\sqrt{x_o x_m} \tag{37}$$

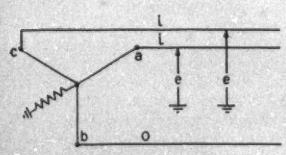

Fig. 4. Diagram for determination of x_m by sequence analysis

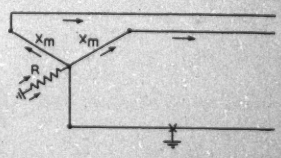

Fig. 5. Diagram for determination of neutral shift

so that using equations 36 and 3 to 6 there results

$$e_n = \sqrt{\frac{9nmk^2 + p^2}{9nmk^2 + (2 + p)^2}} \tag{38}$$

(1−d) Damping Factor

The reduction factor $(1-d)$ is the factor that takes into account the fact that the amplitude of the oscillation of the 2 sound lines when the arc restrikes is less than the applied voltage. The general equation for capacitor oscillatory charge is

$$\frac{e_2}{e} = 1 - \epsilon^{-\alpha t}\left(\cos \theta t + \frac{r}{q} \sin \theta t\right) \tag{39}$$

in which

θ = angular velocity factor

$$\theta = \sqrt{\frac{1}{LC} - \frac{r^2}{4L^2}} \tag{40}$$

q = impedance factor

$$q = \sqrt{4\frac{L}{C} - r^2} \tag{41}$$

and the other terms are the same as in the general equation for nonoscillatory capacitor discharge previously given.

The arc is assumed to go out at the first instant the oscillatory frequency current passes through zero and this corresponds to the instant of maximum voltage. At this instant cos θt is -1 so that

$$\frac{e_2}{e} = 1 + \epsilon^{-\alpha t} \tag{42}$$

from which it follows that

$$(1 - d) = \epsilon^{-\alpha t} \tag{43}$$

In this case the neutral grounding resistance and one phase are in parallel and are in series with the 2 sound phases which also are in parallel. The process of getting this reduction factor into the same terms as $(1-a)$ and e_n is as follows.

Referring to figure 5, the parallel impedance of the neutral grounding resistance R and one phase X_1 is

$$Z = \frac{RjX_1}{R + jX_1} \tag{44}$$

$$= \frac{R}{1 + (R/X_1)^2} + jX_1 \frac{(R/X_1)^2}{1 + (R/X_1)^2} \tag{45}$$

so that the values of r and L to be used in equations 39 and 43 are

$$r = 2\frac{R}{1 + (R/X_1)^2} = 2R_0 \tag{46}$$

$$2\pi L = 2X_1 \frac{(R/X_1)^2}{1 + (R/X_1)^2} + X_m \tag{47}$$

The figure "2" is put in to keep on a per phase basis. Equation 47 may be rewritten

$$L = \frac{X}{\omega} \tag{48}$$

$$X = 2X_1 \frac{(R/X_1)^2}{1 + (R/X_1)^2} + X_m \tag{49}$$

(This designation of X is only temporary for the section under the side heading $(1-d)$.) The capacitance is the capacitance of 1 phase of 2 in parallel to ground and the third phase when the third phase is at ground potential. This is the same as the zero sequence capacitance for shielded cables, and the zero sequence capacitance may be used without appreciable error for belted cables.

By proceeding as when developing the expression for $(1-a)$ it is found

$$a = \frac{R_0\omega}{X} \tag{50}$$

$$\theta = \omega\sqrt{\frac{X_a}{X} - \frac{R_0^2}{X^2}} \tag{51}$$

Since cos θt is -1 the time is determined on the basis that $\theta t = \pi$ so that

$$t = \frac{\pi}{\theta} = \frac{\pi}{\omega\sqrt{\frac{X_a}{X} - \frac{R_0^2}{X^2}}} \tag{52}$$

and then

$$\alpha t = \frac{\pi}{\sqrt{\frac{XX_a}{R_0^2} - 1}} \tag{53}$$

which gives for $(1-d)$

$$(1 - d) = \epsilon^{-\alpha t} = \epsilon^{-d} \tag{54}$$

$$d = \frac{\pi}{\sqrt{\frac{XX_a}{R_0^2} - 1}} \tag{55}$$

By using the relationships of equations 3 to 6 their results

$$R_0 = \frac{k\sqrt{nmX_1}}{1 + nmk^2} \tag{56}$$

$$X = mX_1 \frac{1 + (2 + m)nk^2}{1 + nmk^2} \tag{57}$$

and also there follows

$$d = \frac{\pi}{\sqrt{\frac{(1 + n(2 + m)k^2)(1 + nmk^2)}{k^2} - 1}} \tag{58}$$

and so $(1-d)$ is determined by equations 58 and 54.

Application

The grounding conditions are somewhat different when the ground is made through a transformer than it is when the ground is made through a generator because of the close coupling of the phases in a generator. In a transformer the zero and negative impedances are the same as the positive so that m and p are each unity. In a generator neither the zero nor the negative sequence impedance is equal to the positive sequence impedance. The negative is nearly equal to the positive and the zero may usually be taken as approximately 10 per cent of the positive.

In figures 6, 7, 8, 9 are shown curves giving the calculated arcing ground voltages for various values of neutral grounding resistance $R = kr_n$ and length of line $X_a = nX_1$. These curves can be used for estimating the maximum neutral grounding resistance for any given set of conditions as regards re-

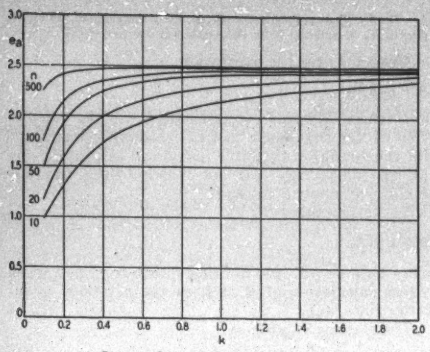

Fig. 6. Generator grounding; p = 0.1

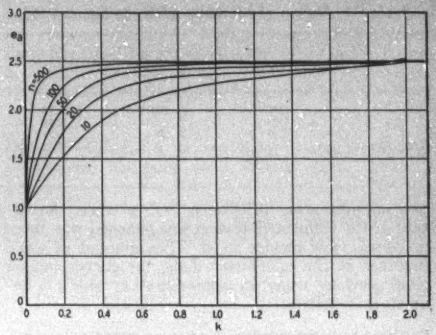

Fig. 8. Transformer grounding; p = 1

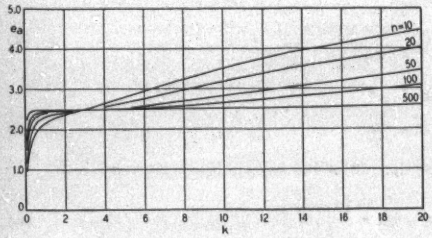

Fig. 7. Generator grounding; p = 0.1

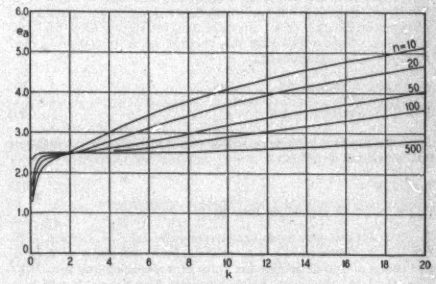

Fig. 9. Transformer grounding; p = 1

Figs. 6–9. Calculated values of the ratio e_a as a function of the ratio k for various values of the ratio n

E_a = ratio of arcing ground overvoltage to rated line-to-neutral voltage (crest to crest)
k = ratio of the neutral grounding resistance to the critical resistance
$n = \frac{X_0}{X_1}$ = ratio of the zero sequence capacitive reactance to the positive sequence system reactance

actances, permissible overvoltage, and length of of circuit. In making such calculations precision should not be expected.

For calculating these curves it was assumed that the total supply capacity (either generators or transformers) had grounded neutrals and that the point of fault was at the generator or transformer terminal. The zero sequence reactance of the generator was taken as 0.1 X_1.

The steps are as follows in using the curves:

1. Calculate X_1
2. Calculate X_0
3. Calculate p using equation 6
4. Calculate r_a using equation 7
5. Calculate n using equation 12
6. Determine k for $p = 0.1$ and $p = 1.0$ from the curves for allowable e_a and the given value of n
7. Interpolate between the values of k found to get the proper k for the given value of p and then multiply r_a by it to get R

The value of R thus found is the resistance which would be connected between the neutral and ground if all the neutrals were grounded at one point. If there are multiple grounding points then higher values may be used at each grounding point provided the multiple value does not exceed R and also providing that in case of separation no section is left with a resistance too high for its own conditions. To apportion the values for the different locations is largely a matter of judgment. The division might be made on the basis of generation, zero sequence reactance, total reactance; however, the best method is to apportion the grounding resistance in consideration of the possible capacitance combinations due to changes in length of connected circuit or disconnection of grounding points.

Development of Simplified Method

For an assumed system set-up, calculations made using the curves revealed that wide changes in generation had no effect on the limiting value of the

Table IV—Values of Multiplier of X_a in Equation 65

p	A_p	$\sqrt{\frac{1+2p}{3}}$	$A_p\sqrt{\frac{1+2p}{3}}$
0.1	1.85	0.632	1.17
1	1.15	1	1.15
2	0.95	1.29	1.23
Average			1.18

neutral grounding resistance. Only when the extent of the connected system was changed was there an appreciable change in R. The amount of work involved in the calculation using the curves can be eliminated by using an approximation which is developed as follows:

1. Points for k corresponding to an arcing ground voltage of 3 times normal for various values of n were read from figure 7 and figure 9 and plotted on log-log coördinate paper as a function of n. See figure 10, item 1. It was found that k could be represented as a square root function of n. As the curves are drawn they are conservative. This relationship was checked for $n = 500$ and found to hold. The equations are

$$k = 1.85\sqrt{n} \text{ for } p = 0.1 \tag{59}$$

$$k = 1.15\sqrt{n} \text{ for } p = 1.0 \tag{60}$$

Since the constant in these equations varies with p a general equation can be written as follows

$$k = A_p\sqrt{n} \tag{61}$$

(A_p = constant dependent upon p)

2. Calculations were made to determine the value of A_p for $p = 2$. For this the first step was to calculate e_a for $k = 6$ and $p = 2$, for a few values of n to determine the value of n corresponding to $e_a = 3$. The calculated values are plotted as item 2 on figure 10, and it is seen that when $e_a = 3$, $n = 40$. As a check the curves were drawn on semi-log and rectangular paper and values of $n = 40$ and $n = 38$, respectively, obtained. The next step consisted in calculating A_p for $n = 40$ and $k = 6$ from the square root law. From equation 61

$$A_p = \frac{k}{\sqrt{n}} \tag{62}$$

This gives $A_p = 0.95$ for $E_a = 3$ and $p = 2$.

3. The third step consisted of a simple mathematical transformation as follows. As previously stated

$$r_n = \frac{1{,}000\,\text{kv}^2}{\text{kva}}\sqrt{\frac{X}{a}\,\frac{1+2p}{3}} \tag{11}$$

from which

$$r_n = X_a\sqrt{ax\,\frac{1+2p}{3}} \tag{63}$$

also

$$k = A_p\sqrt{n} \tag{61}$$

from which by substituting equation 12

$$k = A_p\sqrt{\frac{1}{ax}} \tag{64}$$

As also stated,

$$R = kr_n \tag{3}$$

Now substituting equations 64 and 63 in this last expression for R, there results

$$R = X_aA_p\sqrt{\frac{1+2p}{3}} \tag{65}$$

4. The fourth step consisted in determining the value of the multiplier of X_a in equation 65 for the 3 values of p as in table IV.

Consequently the expression

$$R = 1.15\,X_a$$

is a reasonably close approximation for the calculation of the maximum neutral grounding resistance for the condition that this maximum calculated arcing ground voltage shall not exceed 3 times the normal line to neutral voltage.

The expression

$$R = 1.15\,X_a$$

can easily be put into another form which permits a direct calculation of R without the necessity of intermediate steps.

The standard equation

$$C = \frac{0.03882}{\log\frac{D}{d}} \text{ millifarad/mile} \tag{66}$$

when $2T + d = D$ is substituted becomes

$$C = \frac{0.03883}{\log\left(1 + 2\,\frac{T}{d}\right)} \tag{67}$$

But

$$X_a = \frac{1}{2\pi fc} \tag{68}$$

so that, R for 100 miles of line is given by

$$R = 785\,\frac{\log\left(1 + \frac{2T}{d}\right)}{k} \tag{69}$$

And also the standard equation

$$C = \frac{0.0169\,nk}{G} \text{ millifarad/1,000 feet} \tag{70}$$

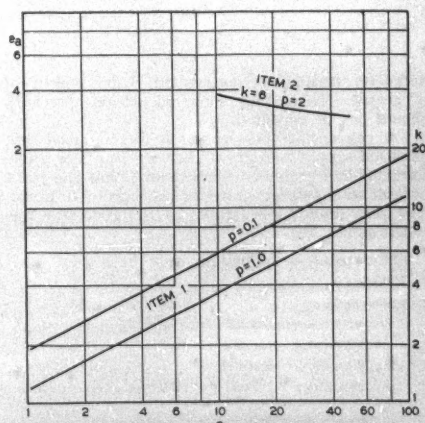

Fig. 10. Chart for the determination of the final expression, $R = 1.15X_a$

gives through the same process for 100 miles 3 phase belted cable

$$R = 342 \frac{G_1 S}{k} \tag{71}$$

the factor S is the sector correction factor. Since the capacitance per conductor is concerned the number of conductors n cancels out.

In this section, equations 66 to 71, the nomenclature, except R, is the same as in the "Underground System Reference Book" (published by the former National Electric Light Association) pages 297–9.

Comparison With Previous Methods

There have been other methods considered previously for determining the maximum permissible neutral grounding resistance. Lewis[4] suggested that the Petersen coil principle be applied, i. e., make the lagging component of the fault current with resistance grounding equal to the charging current in the fault. Later, Clem suggested that the critical resistance be the criterion for resistance grounding. In view of the widespread discussion and comparison of the Lewis method and the critical resistance method, a comparison of the 2 will be made.

When a ground occurs the current in the fault is

$$I_f = \frac{3E}{Z_0 + Z_1 + Z_2} \tag{72}$$

$$= \frac{3E}{\sqrt{r_0^2 + X_s^2}} \tag{73}$$

$$X_s = X_0 + X_1 + X_2 \tag{74}$$

and the lagging component is

$$I_s = \frac{3EX_s}{r_0^2 + X_s^2} \tag{75}$$

In one of the references[3] it is shown that the charging current in the fault is

$$I_c = \frac{3E}{X_c} \tag{76}$$

Now equate

$$r_0 = \sqrt{X_c X_s}\sqrt{1 - \frac{X_s^2}{X_c^2}} \tag{77}$$

and since $r_0 = 3R_m$

$$R_m = \frac{1}{3}\sqrt{X_c X_s}\sqrt{1 - \frac{X_s^2}{X_c^2}} \tag{78}$$

(R_m = maximum possible neutral grounding resistance on the basis that with a resistance grounded neutral the lagging component of the current in the fault be equal to the leading component)

By the critical resistance method the limiting resistance would be, from equation 7,

$$R_c = \sqrt{X_c X_m} \tag{79}$$

Divide equation 73 by equation 72

$$\frac{R_c}{R_m} = \frac{3}{\sqrt{1 - \frac{X_s^2}{X_c^2}}} \tag{80}$$

Thus, it is seen that the critical resistance method should always give the higher values, providing the calculations are consistently made.

In table V is given a comparison of the Lewis method, the critical resistance method, and the present proposed method. This tabulation is based on data furnished by D. W. Roper. Comparing items 2, 4, and 6, it is quite obvious that the method proposed in this paper permits the use of higher values of neutral grounding resistance than any preceding method. This is desirable in addition to the additional advantage of being much simpler in application.

Table V—Calculation of Maximum Permissible Neutral Grounding Resistance on a Chicago Cable System

Chicago System Studied	9 Kv	Crawford Station 12 Kv	66 Kv "Red"	66 Kv "Blue"	66 Kv Total
1. Using table of April 17, 1933					
a. Total LK (millifarads)	438	288	17	14	31
b. Total kva (in thousands)	209	424	1,000	1,000	1,000
c. Number of neutrals used	2	2	3	3	5*
2. Resistance calculated from Lewis' formula (ohms)		6	42	47	50
3. Resistance used in Chicago (ohms)	2.5	3	30	30	30
4. Resistance calculated from Clem's** formula (ohms)	6.95	10.6	179	218	110
5. Resistance calculated by critical resistance method (ohms)***		7.9-10.4	55-73	62-81	65-88

* If the 2 66 kv systems in Chicago, which are normally operated separately, were tied together, then the procedure would be to use only 5 of the 6 grounding resistances.

** Based upon LK values in tabulation.

*** Based upon proportionality to Item 2.

The data for Items 1, 2, and 3 were furnished by D. W. Roper.

Maximum Neutral Grounding Reactance

When reactance is used for grounding the neutral the determination of the maximum permissible value is much simpler. In this case the factors $(1-a)$ and $(1-d)$ are very nearly unity. If a value of 0.95 is assigned to them it can be shown that the permissible calculated arcing ground voltage of 3 times normal line-to-neutral voltage gives a limiting neutral shift of about 0.36 E. This limiting condition can be attained by setting a limit of the ratio of neutral grounding reactance to positive sequence reactance. The desired conditions will be obtained when the ratio of the neutral grounding reactance to the positive sequence reactance is calculated from the following expression:

$$\frac{X_n}{X_1} = \frac{2 + p}{6} \tag{81}$$

where

X_n = neutral grounding reactance
X_1 = positive sequence reactance of system
p = ratio of zero sequence reactance of system (exclusive of X_n) to the positive sequence reactance.

Insulation at the Neutral

There are cases where a saving may be made if the insulation at the neutral be reduced when the system is grounded. Whether or not any reduction might be made for an effectively grounded system depends

upon the method of grounding. If the system is grounded through resistance and the maximum permissible value used then practically full neutral shift occurs and full insulation will be required at the neutral. If the system is grounded through reactance the conditions are such that the neutral shift is limited to $^1/_3$ normal line-to-neutral voltage and it might be possible to use reduced neutral insulation.

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Industrial Electronic Control Applications

Electronic tubes are being applied in rapidly increasing numbers in the solution of industrial control problems. A review of several of the most frequently encountered types of problems to which these tubes are being applied is presented herewith. These include photo-electric control applications, electronic relays, electronic regulators, and a welding timer for seam welding.

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When the first electronic devices were brought on the market, it was often found that the applications were made indiscriminately, and electronic equipment was used on account of its novelty, in applications where mechanical or electromagnetic equipment previously had proved a success and was entirely adequate. At this stage of electronic development, most industrial engineers seemed very enthusiastic over the possibilities of electronic control, and the various electrical manufacturers received inquiries about electronic equipment for nearly every type of control operation. Gradually, however, it was more generally realized that electronic equipment was not destined to supplant the electromechanical and mechanical types of control apparatus entirely; and a sounder conception of the utility, scope of application, and importance of electronic equipment in the field of industrial control was attained.

The development of electronic equipment for industrial control has progressed so rapidly during the last few years that this type of equipment now, generally speaking, has passed the experimental stage and industrial application engineers are compelled, when planning new installations, to consider the advantages of electronic control as compared with electromechanical control equipment.

Considering the future of industrial control equipment, it should be realized that electromechanical control devices long have been manufactured more or less on a mass production basis, and the cost of manufacturing this type of equipment cannot be expected to be much reduced. In regard to electronic control equipment, however, it is not unreasonable to expect a reduction in manufacturing costs, as the general activity of electronic control equipment is increased. The cost of electronic tubes is at present a major item in the total cost of electronic equipment, and the cost of tube replacement in many cases prohibits the application of an electronic device, which, for purely engineering reasons might have been desirable. Reduced tube cost, brought about by quantity production of industrial electronic tubes, and possible increased tube life as a result of im-

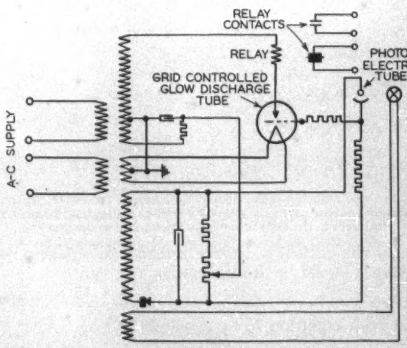

Fig. 1. Schematic diagram of photo-electric controller

Of the 2 relay contacts shown in the upper right-hand corner of this diagram, the upper one indicates a contact open when the relay is deenergized and the lower symbol indicates a contact which is closed when the relay is deenergized. These symbols are used throughout the diagrams of this paper

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provements in tube design, undoubtedly will change the picture of industrial applications and help to move the center of gravity over toward the electronic side.

I. Photo-Electric Control Applications

In many industrial control operations it may not be possible to use either mechanical or electromagnetic means to obtain the desired indication. This may be caused by the fact that the variations in the quantity to be controlled cannot easily be converted into mechanical or electrical forces, or, if this can be done, the energy available may be too low to operate any of the conventional mechanical or electromagnetic control devices. The photo-electric tube has proved a valuable tool in many of these industrial control applications.

The simplest type of photo-electric equipment, not considering the photo-voltaic cells, consists of a photo-electric tube connected to control a grid controlled glow discharge tube as shown in the schematic diagram in figure 1 and in figure 2. The grid controlled glow discharge tube amplifies the feeble current of the photo-electric tube to a value which will operate sturdy relays and contactors. The photo-electric controller may be connected so that the type *KU*-627 tube will break down and energize the relay if the illumination on the photo-electric tube is increasing or it may be connected to energize the relay if the illumination is decreased. A typical application of this photo-electric controller is the counting of moving objects when it is undesirable or inconvenient to use mechanically operated counters. Applications which have been made include counting automobiles at toll bridges, persons entering a movie theater, freshly painted objects moving on a conveyor, mail bags on conveyor systems, and hot steel ingots.

One of the first industrial photo-electric applications was the paper break indicator, and this application is representative of the type where methods requiring mechanical force would not be practical. During normal operation of a paper machine, the operators may all be working at one end of the machine, and some time may pass before a break is noticed. In the meantime paper will be piling up at the section where the break occurred, and production losses will result. Installation of a photo-electric controller as a paper break indicator will cut the outage time, and will in most mills prove a very advantageous investment. Light-sensitive devices have been employed to some extent in steel mills to initiate shearing operations or as a flag switch. Due to the pounding of the hot metal on the flag switch the maintenance of such a switch is often prohibitive. Furthermore a light-sensitive flag switch cannot cause cobbles such as are frequently started by the failure of the mechanical flag switch, or by the force exerted by the flag bending over the end of a steel sheet.

Fig. 2. Front view of photo-electric controller

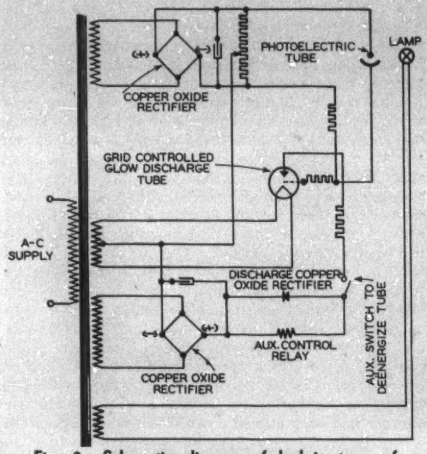


Fig. 3. Schematic diagram of lock-in type of photo-electric controller

Photo-Electric Inspection. Numerous applications of photo-electric equipment for inspection purposes have been made. In many applications the time available for inspection is so short that self-locking photo-electric equipment as shown in figure 3 and figure 4 must be used.

An interesting application of the equipment shown in figure 4 was made in connection with a labeling machine for nail polish bottles. The bottles were fed continually through the labeling machine at a rate of one per second. Each shade of nail polish used a different type label. The labels were supplied by the printer in stacks of one thousand, and although extreme care was exercised by the printer in

supplying the correct labels, there would occasionally be several unmatched labels in each stack. This condition was of course highly undesirable, and an investigation of the problem indicated that it would be less expensive to sort the labels at the labeling machine than to have the printer perform the sorting operation.

The labeling operation was performed by having the bottles travel intermittently on a conveyor past the stack of labels mounted in the label magazine, which would move horizontally forward toward the bottle when the bottle was stationary. The side of the bottle had previously been covered with glue, and a label would therefore stick to the bottle so that when the label magazine moved away from the bottle the label would be detached from the magazine, and would remain glued to the bottle. When the label magazine was moved away from the bottle, the magazine would remain stationary during 0.3 second and during this time the finished bottle would move away from the labeling position and a new bottle would move into position. During this 0.3 second the scanner shown in figure 5 was moved down in front of the label magazine in order to inspect the label which was next to be attached to a bottle. In order to be able to do this inspection, a black spot had been printed on the rear side of the labels. The position of this black spot was different for each of the 8 different labels, corresponding to the 8 different shades of nail polish. When the photo-electric scanner had been moved down to the correct position the beam of light would fall on the black spot on the label if the correct label was in the label magazine, and the photo-electric controller would not operate, because no light was reflected from the black spot to the photo-electric tube. If, however, the label should be upside down in the label magazine, or if an incorrect label was in the magazine, the light beam would scan the white rear side of the label, and part of the light would be reflected to the photo-electric tube which would cause the photo-electric controller to operate and give a signal so that the girl operating the machine could inspect the bottles and remove the bottle with the incorrect label.

Paper Cutter Control. In figure 6 is shown a special photo-electric controller which is designed to supply, normally, direct current to a solenoid or a relay, and to cause the current through this solenoid or relay to be interrupted during a definite time interval following a momentary decrease in the intensity of illumination on a photo-electric tube. This controller is particularly suited to intermittent type paper cutter machines, when it is desirable to use a spot printed on the paper as a means for deenergizing a clutch between the driving mechanism and the feed rolls, and thus stop the paper while the cutting operation is performed. The type *RJ*-550 tube

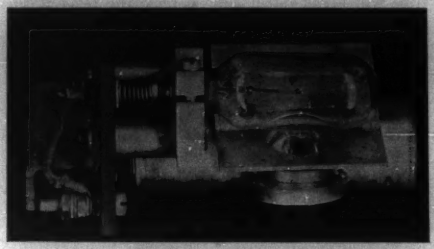


Fig. 5. Scanner for labeling machine

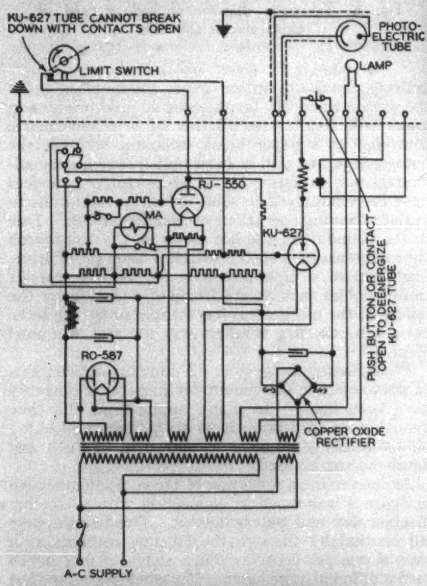


Fig. 4. Schematic diagram of lock-in type photo-electric controller with amplifier tube

anode circuit is connected to control the grid voltage of the type *KU*-627 tube so that the *KU*-627 tube will break down when the anode current of the type *RJ*-550 tube decreases. A potentiometer and a resistor are connected in series with the anode circuit of the type *KU*-627 tube, and the voltage drop is applied to the grid of the type *RJ*-563 tubes. Before breakdown of the *KU*-627 tube, the *RJ*-563 grid voltage is zero, and the current through the *RJ*-563 tubes, and consequently the solenoid current, is maximum. When the *KU*-627 tube does break down, the condenser in parallel with the tube discharges through the *KU*-627 tube until the voltage across the *KU*-627 tube is approximately 15 volts, which is equal to the arc drop across the tube. At this moment the discharge current is interrupted, and the condenser will start to charge up through the resistor. At the instant of breakdown of the type *KU*-627 tube, therefore, a high negative bias is applied on the grid of the type *RJ*-563 tubes, and the solenoid current becomes zero. As the condenser

becomes charged the negative voltage on the grid of the type *RJ*-563 tube decreases, and after a definite time interval, dependent upon the adjustment of the time delay potentiometer, the *RJ*-563 tube anode current, i. e., the solenoid current, will again reach its maximum value.

Elevator Control. Photo-electric equipment has been extensively used in elevator service to protect

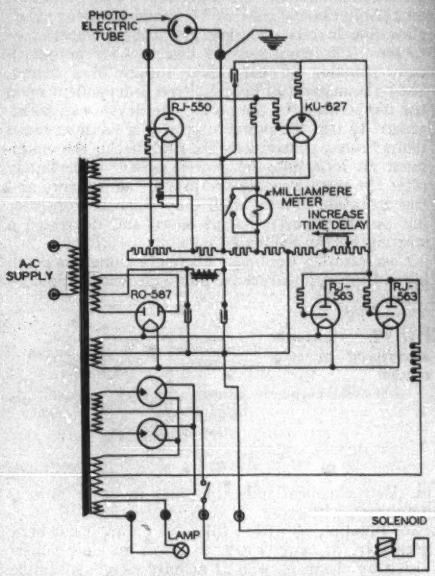


Fig. 6. Schematic diagram of lock-in type photo-electric controller with time delay

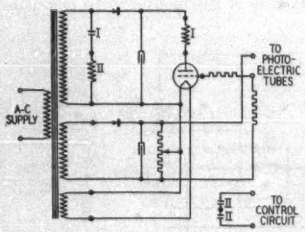


Fig. 7. Schematic diagram of protective door control device

passengers against closing doors, and for elevator leveling control. The protective door control device shown in figure 7 consists of 2 photo-electric tubes, amplifying equipment, and 2 light sources which project 2 beams of light across the door opening to the 2 photo-electric tubes. Obstructing either beam of light prevents the door from closing,

Fig. 8. Front view of device for turning lights on or off, depending on daylight intensity

or if they are already in motion, immediately causes them to reopen

Lighting Control. The photo-electric device as shown in figure 8, with diagram in figure 9, operates to turn electric lights on or off when daylight decreases or increases in intensity. The applications for this unit are many and they vary from eliminating twilight zone lighting, to lending a maximum of advertising value to illuminated signs and show-windows that no manual operation ever succeeded in reaching. Some of the places where this device is applied to turn artificial light on and off, without any supervision are as follows: Offices, industrial plants, show windows, schools, signs, floodlighting installations, street lighting, navigation lights, and airway and airport lighting.

The operation of this photo-electric light control device depends upon the variation in current through the photo-electric tube caused by variations in light intensity on the tube. This varying current is amplified in an amplifier tube and energizes a primary relay. The primary relay energizes the main contactor. Interposed between the relay and contactor is a time delay button functioning on both opening and closing to give several seconds time delay. The time delay avoids operation by walking in front of the unit or by lightning flashes at night.

If either the photo-electric tube or amplifier tube fails from a normal cause, the device will leave the light turned on, and in this way insure illumination

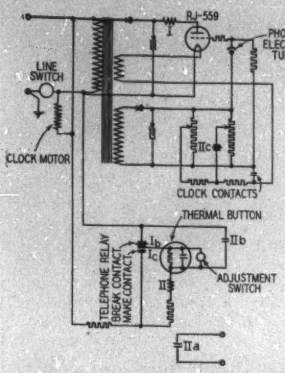


Fig. 9. Schematic diagram of device shown in figure 8

during periods of darkness and indicate failure in the daytime. Adjustment is provided by 2 convenient dials. One dial controls the light intensity at which the device turns on the light. The other dial controls the light intensity at which the device turns off the light.

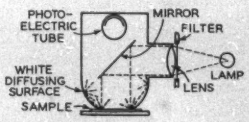
Color Matcher. The photo-electric color matcher is one of the new electronic tools which help to eliminate the error caused by human judgment in various industrial processes and operations. The color matcher contains a matching circuit consisting of a photo-electric tube, a low-grid-current amplifier tube, a coupling circuit, a sensitivity control, and 3 color screens. With the amplifier is a meter with a calibrated dial giving a quantitative indication of the amount of light the sample reflects. A rectifier tube and a filter provide anode and grid voltage for the matching circuit. A tungsten lamp furnishes the source of illumination. Other equipment includes a transformer and a voltage regulator. The latter is required to secure the close regulation on commercial circuits required because of the extreme sensitivity of the matcher. The color screens permit comparison to be made between a sample and a standard in each of 3 bands of the spectrum, blue, green, and red. The arrangement of the matcher is shown in figure 10. Light from a Mazda lamp passes through 1 of the 3 color filters, is concentrated into parallel rays by a lens system, and is reflected by a mirror onto the sample. This light reflected by the sample in turn reaches the photo-electric tube. The meter gives a quantitative indication of the amount of light of that particular color the sample reflects by reading the anode current in the amplifier tube.

Transparency Meter. A simple and accurate means of measuring the transparency of flat materials is obtained by the use of a photo-voltaic device in combination with a light source, a meter for indicating the transparency, and a potentiometer for sensitivity adjustment. The photo-voltaic device generates an amount of current proportional to the amount of light striking it, and therefore a meter reading can be obtained which can be expressed directly in percentage transparency, this term being used to designate the amount of light emerging from a material in comparison to the amount of impinging on it.

Temperature Control. Considerable work has been done during the last few years to adapt photo-electric equipment to pyrometric control of temperatures. In figure 11 is shown a diagram of equipment designed for heater control, which operates from the light emitted from a piece of hot metal which is being heated electrically. The light from the metal falls on a photo-electric tube which in turn actuates a grid-glow tube directly. The grid glow tube operates a contactor. The equipment is designed for automatically shutting off the power supply to a heater. Since the amount of light emitted is dependent upon the temperature of the metal, the device can be arranged to trip the power supply at a predetermined temperature. Provisions are included in the equipment to lock out the power circuit immediately after the metal reaches the proper temperature and the operation is reinitiated only when the operator has put in a new piece of metal and depressed a starting button manually.

Concentration Control. There are numerous possibilities for application of photo-electric equipment

Fig. 10. Schematic arrangement of color matcher



in electrochemical industries and in other process industries. In order to keep electrochemical processes functioning within tolerable limits, it has been necessary, in many cases, to resort to close supervision by chemists, who at definite intervals sample the liquids to determine their concentration. This procedure is expensive, and the accuracy of control obtained depends to a large extent upon the physical condition and fatigue of the analyst. To eliminate

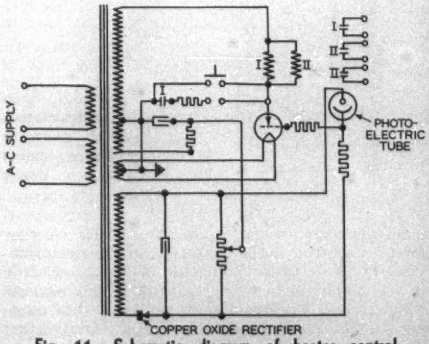


Fig. 11. Schematic diagram of heater control

the human element in various types of process control, a concentration indicator has been developed. This apparatus is at the present time available only as an indicator, but the design is arranged so that with minor modifications the equipment may be used also as a regulator.

The diagram of the concentration indicator is shown in figure 12, and the principle of operation is apparent from this diagram. A standard sample is placed on one side of a light chamber, while the material or liquid to be inspected is arranged to pass

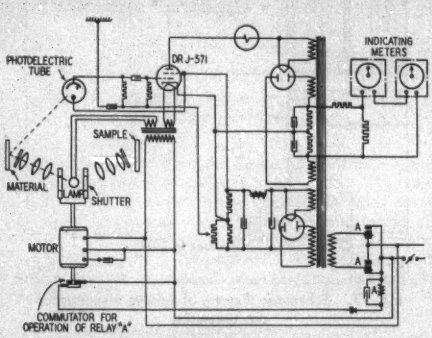


Fig. 12. Schematic diagram of concentration indicator

continuously by the other side of the light chamber. By means of a shutter operated by a synchronous motor, a beam of light is thrown alternately to the standard sample and to the material to be inspected, and is then reflected to the photo-electric tube. If the color of the sample matches with the color of the material, the photo-electric tube will obtain the same illumination during each half of the a-c voltage wave, and the output of the type *RJ*-571 screen grid amplifier tube will be such that the indicating meter will read zero. If the colors do not match, the photo-electric tube illumination will be greater during one half of the cycle than during the other, and the indicating meter will then deflect to one side or the other depending upon whether the color of the material is too dark to too light.

II. Electronic Relays

Comparatively little work has been done on the practical development of electronic relays for industrial and central station control applications. The characteristic of the various types of electronic tubes, and especially the characteristic of the grid controlled glow discharge tube is admirably suited to relay applications, and general adoption of electronic tubes in the relay art is bound to occur ultimately.

Synchronizing Relay. A few electronic relays are now commercially available and several installations of these relays have been made. A particularly interesting application is the electronic synchronizing relay which was developed and placed on the market in 1930. This relay is an example of an electronic device which due to superior operating characteristic has superseded the electromagnetic devices previously used in the same applications. The synchronizing relay shown in figure 13 was designed primarily as a low energy device to make synchronizing equipment available which could be operated from condenser bushing potential devices. The synchronizing relay which has a "proportional advance" characteristic will energize the circuit breaker closing relay a definite time ahead of the instant of phase coincidence, corresponding to the breaker closing time, so that, regardless of the frequency difference, the circuit breaker contacts will always close so as to give minimum equalizing current at the paralleling moment.

Time Delay Relays. Electronic time delay relays have been extensively used, both in circuit connections with other electronic equipment, and as separate electronic timers. The advantages of electronic time delay relays as compared with mechanical and

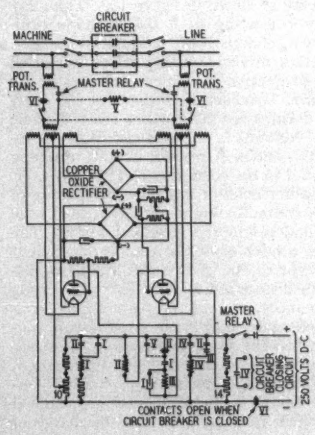


Fig. 13. Schematic diagram of synchronizing relay

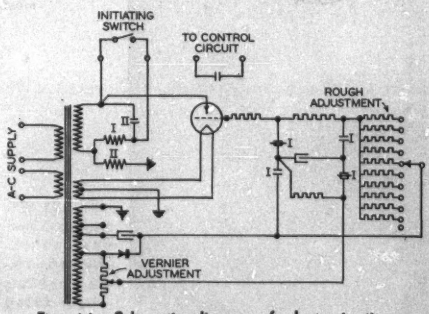


Fig. 14. Schematic diagram of electronic timer

electromagnetic relays, are the accuracy, the wide range and ease of time delay adjustment, and the low maintenance.

An electronic timer as shown in figure 14 was developed as an electronic spot welding control, but due to its reliability, simplicity, and ease of adjustment, the relay has found a wide field of application in industrial installations where definite time intervals are required. The equipment is arranged to stay closed a definite interval of time, which may be adjusted from 0.1 second to 40 seconds. The timing is practically independent of line voltage variations and is not affected by ambient temperature. The timer contains a relay II for external connections, and a relay I for changing internal connections. A grid controlled glow discharge tube in connection with a condenser discharge circuit is used for timing purposes. When both relays I and II are open, the tube does not pass current, but a condenser is being charged to a voltage determined by the position of one of the control potentiometers. When the external initiating switch is closed, relay I pulls in, reversing the condenser connections, and causing the tube to pass current to relay II. Relay II will

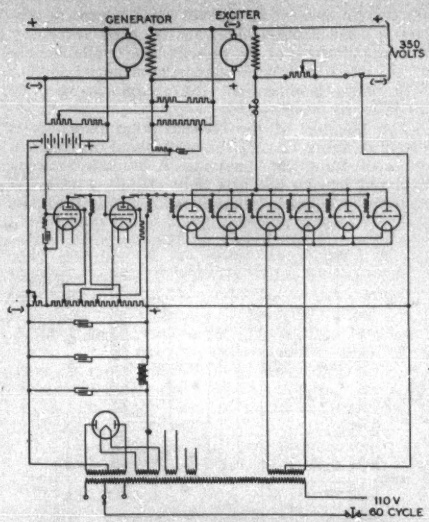


Fig. 17. Schematic diagram of voltage regulator for d-c generators

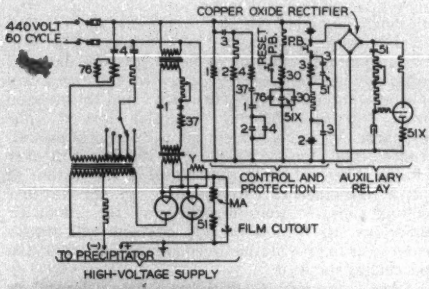


Fig. 15 (above). Schematic diagram of precipitation equipment

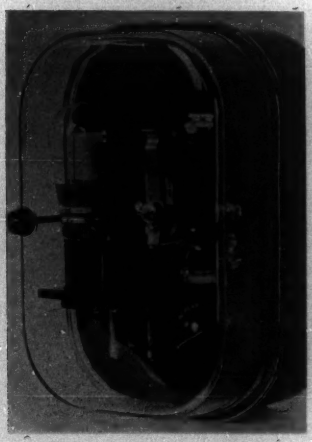


Fig. 16. Integrating time delay relay

therefore operate, and remain closed a definite time while the condenser is being discharged, until the condenser voltage has reached the value at which the tube stops passing current.

Precipitation Control. A special design of integrating time delay relay using a cold-cathode grid-controlled glow-discharge tube has been used in connection with precipitation equipment to protect the equipment against prolonged short-circuit conditions. The schematic diagram for precipitation equipment applying this relay is shown in figure 15. A photograph of the relay is shown in figure 16. The relay is an assembly consisting of a cold-cathode grid-controlled glow-discharge tube, a small condenser, associated resistors, and an auxiliary relay designated as 51*X*. This protective equipment operates in the following manner. One set of contacts of the overload relay 51 deënergizes the master relay 3 while the other set of contacts in the grid circuit of the relay energizes the condenser-resistor circuit, applying a certain potential to the condenser. This, however, is only a momentary contact, because the opening of the plate supply contactor 4 immediately removes the main current and resets the overload relay. The potential on the condenser at this time is insufficient to cause discharge of the grid controlled glow discharge tube, but it does not leak off for quite a long while. After a short interval the plate supply contactor is reclosed again, and if the short-circuit condition still remains, the same procedure is repeated, but this time the charge on the condenser is increased. The periodic opening and closing of the circuit continues until the charge on the condenser has reached the value at which the anode-cathode discharge of

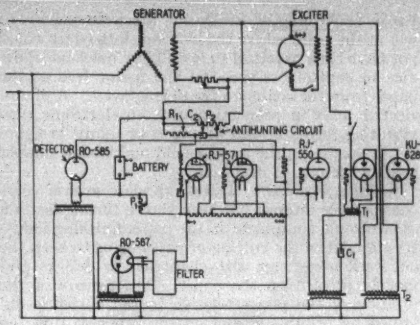


Fig. 18. Schematic diagram of voltage regulator for a-c generators

the grid controlled glow discharge tube will take place thus energizing the auxiliary relay 51*X*. The contacts of the auxiliary relay energize lockout relay 30, which in turn seals its own circuit, and by means of one of its contacts keeps the circuit of the plate-supply contactor 4 deënergized. The equipment is thus held out of service until relay 30 is reset by hand.

III. Electronic Regulators

During the last several years a number of applications have appeared in various industries, where the energy available to operate regulating equipment was of such low magnitude that application of the conventional type electromechanical regulators could not be considered. Most electromechanical regulators require approximately 100 voltamperes for operation, while electronic regulators can be designed to operate from considerably less than one microwatt. Due to this reduction in control energy requirements, brought about by the electronic tube, the entire art of automatic regulator design has been modified. While previously the only practical indicating element available to the regulator designer was the electromagnetic solenoid, a wide variety of indicating circuits varying from photo-electric to resistance or capacity controlled devices, are now at the disposal of the regulator engineer. In addition to this greater choice of indicating circuits, electronic tubes offer possibilities for design of regulators having extremely high sensitivity and a quick response characteristic. The quick response characteristic is obtained through the elimination of friction and inertia inherent with all electromechanical regulators, and through the development of special electronic antihunting circuits which permit powerful corrective regulator action, without any danger of overshooting or hunting.

D-C Voltage Regulator. An electronic voltage regulator for d-c generators as shown in figure 17 has been used in applications where high sensitivity and quick response action were of importance. In most industrial applications of d-c voltage regulators, a sensitivity of one per cent is entirely satisfactory and this sensitivity can be obtained with standard electromechanical voltage regulators. There are, however, applications where a sensitivity of 0.1 per cent is required, and for such applications the electronic type voltage regulator is particularly suited.

Speed Regulator. The d-c type voltage regulator has been used as a speed regulator for single motor paper machine drives. In applications of this type the problem of regulation becomes rather difficult if the equipment is designed to cover a wide speed range of, for example, 12 to 1. The reason for this is that the characteristic of the drive is different at one end of the speed range than at the other end. If a mechanical type of regulator is used, it is often found that if the equipment is adjusted for one speed, it may become unstable at the other end of the speed range. The inherent characteristic of the electronic regulator is such that sufficient antihunting action is always available, and it is therefore possible to stabilize the regulator at any point within the operating range of the equipment. In applying the electronic voltage regulator as a speed regulator, a pilot generator is coupled to the motor, and the voltage of this pilot generator is arranged to act on the regulator so that if the pilot generator voltage increases, the armature voltage of the generator which is supplying the power for the motor will be decreased, and thus the speed of the motor will be maintained at a constant value.

A-C Voltage Regulators. Various types of a-c electronic regulators have been available for a number of years, and the operating results obtained with these devices have been highly satisfactory. It may therefore be expected that in the future the electronic regulator for a-c generators will be generally accepted in the industrial and central station field. One of these a-c voltage regulators as shown in figure 18 was developed for lamp testing applications where an extremely high sensitivity was needed. Operation of this regulator during several months indicates that a sensitivity of 0.1 per cent was consistently obtained. For the average industrial applications such a high sensitivity is not needed and for such applications a simplified electronic regulator which uses no battery, and which employs only 1 control tube and 2 power tubes has been developed.

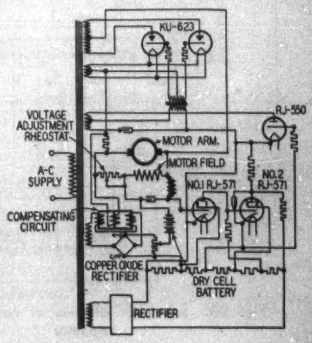


Fig. 19. Schematic diagram of voltage controlled rectifier for motor operation

Motor Control. Considerable interest has been shown in equipment for the control of d-c motors operated from an a-c source, and an electronic device has been developed which makes it possible to maintain a constant rectified d-c voltage supplied by grid controlled glow discharge tubes. This is accomplished by a voltage regulator which maintains the d-c voltage at a constant value regardless of variations in the a-c supply, as shown in figure 19. By means of a compensating circuit the regulated voltage may be given a compound characteristic so that the voltage will increase with increasing load.

Coating Machine Regulator. Various industrial regulators have been developed for special applications and a few of these applications will be referred to, to indicate the possibilities of, and the wide scope of industrial electronic regulators.

A regulator has been installed at a paper mill to control the speed of a motor feeding paper from a coating machine to a drying oven. The paper would form a loop between the coater and the dryer, and the regulating problem was to control the length of this loop so as to prevent the paper from tearing, or to prevent the loop from becoming so long that the paper would drag on the floor. Since the paper was wet at the point where the loop was formed, it would not have been practical to install any mechanical device to control the speed of the motor feeding the paper from the coater to the drying oven. A photoelectric relay in connection with an electronic type vibrating regulator was arranged as shown in figure 20, to operate in the mortor field and in this manner control the rate of paper feed.

Register Regulator. During the last several years considerable interest has been shown the application of electronic equipment in the paper finishing industry, to control the cutting of paper so as to keep the cut itself in register with characters or designs previously printed on the paper. The control of the position of the paper relative to the cutter is obtained by printing a spot on the paper so that the spot has a fixed location in relation to the design of the paper. By means of a beam of light reflected from this spot to a photo-electric tube, and by means of a selector switch geared to the cutter, an indication of the position of the paper relative to the cutter is given. Control relays as shown in figure 21 are arranged to correct the paper speed through a mechanical differential in order to maintain register between the cutter and the paper. Figure 22 shows the mechanical arrangement of a bag machine equipped for automatic register control. A unique feature of this register regulator is the compensated scanner. This scanner employs 2 photo-electric tubes. One is used as the pick-up tube, the other is used as a balancing tube. These photo-electric tubes are connected in a bridge circuit so that the equipment will remain in calibration if the a-c supply voltage should change, or if the color or finish of the paper should change.

Frequency Regulators. Since there is only a need for frequency regulators of the rheostatic type, there has been no particular incentive to develop an elec-

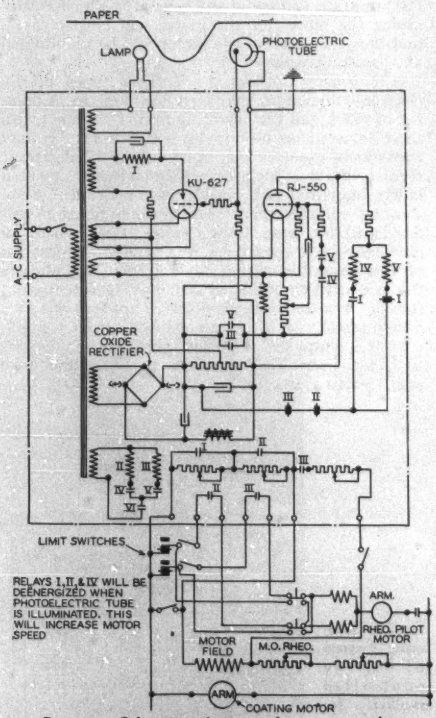


Fig. 20. Schematic diagram of coating machine regulator

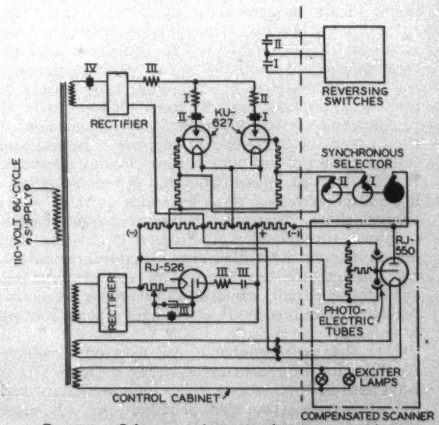


Fig. 21. Schematic diagram of register regulator with compensated scanner

Fig. 22. Schematic arrangement of bag machine control

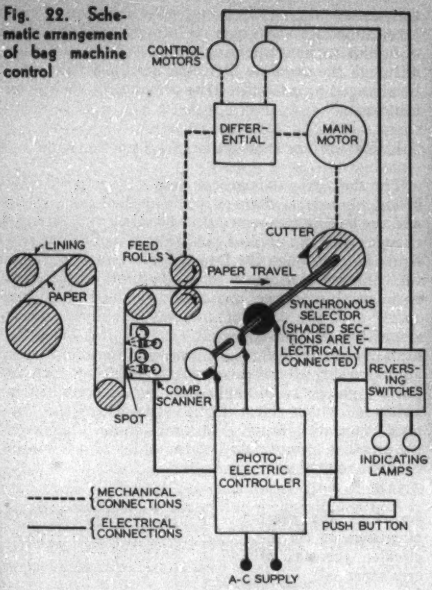


Fig. 23. Photo-electric frequency regulator

tronic frequency regulator. Experiments with electronic frequency regulators however have been made in various laboratories, and numerous patents have been issued covering electronic frequency control equipment. The majority of these experimental regulators employ tuned frequency circuits in various combinations with electronic tubes.

A photo-electric frequency regulator as shown in figure 23 has been used in a few installations. This device is not entirely electronic inasmuch as an electromagnetic indicating instrument is used in connection with photo-electric amplifying means. This regulator may be used for other purposes than frequency regulation and because the equipment embodies some novel regulator design features a description of the device may be of interest. A dynamometer type resonant circuit meter is used as the frequency indicating element. A small mirror is mounted on the shaft of the moving element of this meter and 2 light beams are projected to this mirror, and then reflected from the mirror to 2 photo-electric tubes. When the meter pointer is in the center position, both photo-electric tubes are dark, but for the slightest movement of the pointer, one of the photo-electric tubes will be illuminated, and the grid controlled glow discharge tube controlled by the photo-electric tube will break down and operate a relay, which picks up another relay controlling the speed changer motor. Antihunting is incorporated in this regulator by means of a rotating disc which intercepts the light beams. This disc which makes one revolution in 2 seconds permits a time of photo-electric tube illumination which is proportional to the deflection of the meter. The time of governor correction therefore will be approximately proportional to the error in regulated frequency.

IV. Welding Timer for Seam Welding

The process of seam welding consists of discharging an enormous current at low voltage through 2 or more pieces of metal to form a spot. The pieces of metal being joined together are passed between rollers of low resistance material which serves to conduct the high current into the metal being welded. The 2 pieces of metal being welded are forced together by mechanical pressure on the rollers so as to unite the 2 pieces after they have been heated to fusing temperature. This discharging of current lasts for only a few cycles and is then stopped until the material has moved along slightly, after which power is again applied to the welding machine. Seam welding is therefore merely a modification of the familiar spot welding so performed that the spots overlap each other and thus form a continuous seam which is liquid and gas tight.

A welding timer which depends for its operation principally upon electronic tubes, has been developed to meet the requirements of seam welding control where timing of the order of a few cycles on and a few cycles off is required. This welding timer has been described in detail in a paper "A New Timer for Precision Welding" by R. N. Stoddard, appearing in the October 1934 issue of Electrical Engineering, pages 1366–70. It permits very high welding speeds with highly accurate and consistent results. Typical applications include the welding of light gauge materials where ordinary methods fail to produce uniform results.

Dielectric Strength of Mineral Oils

The correlation of the pressure and temperature effects in determining the dielectric strength of mineral insulating oils is considered in this paper. The effect which gas dissolved in the oil has on the dielectric strength of the oil is shown by experimental results of tests on the effect of temperature and pressure. Based upon these results, simple formulas for expressing the dielectric strength of oil are obtained.

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It has been suggested[1,2] that for the proper understanding of those factors which determine the dielectric strength of liquid insulation under varying conditions of test, consideration must be given to the presence or absence of dissolved gases. The solubility of air and its constituent gases in mineral insulating oil has been described. The effects of such solubility have been traced by noting the dielectric response of the liquid under varying experimental conditions. Based upon such phenomena, an orderly arrangement of dielectric behavior for liquid insulation is easily obtained if the materials are classified into 2 main groups which have been designated as the "pure" and the "impure" classes of insulating liquids.

It is beyond the scope of the present paper to elaborate upon this classification. Reference should be made to the previous articles. The object of this paper is to demonstrate the application of the principles of the "impure" liquid classification. In the application of these principles, a correlation of the pressure and temperature effects in determining the dielectric strength of mineral insulating oils is obtained.

The "impure" liquid dielectric has been described as including all insulating liquids which contain dissolved gas. A de-gassed liquid, one free from all traces of dissolved air or other gases, is classified as a "pure" liquid dielectric. The presence of secondary impurities such as water and suspended particles, although important, is not necessarily involved in this classification. Such materials are referred to as "contaminants" and may be present in either class of liquids without affecting the general classification, although the absolute dielectric strength value may be changed as a result of the presence of such "contaminants."

The Effect of Pressure and Temperature

The dielectric strength of "impure" mineral insulating oils reflects changes in the applied gas pressure and the testing temperature. The dielectric strength changes with the applied gas pressure as illustrated in figure 1. Although the data of figure 1 are based upon the behavior of a transformer oil of low viscosity, experimental evidence has been obtained that irrespective of the type of mineral oil (and even irrespective of the chemical type of the "impure" liquid), the effect of gas pressure is of the same order, an increasing dielectric strength resulting with increased gas pressure applied above a certain critical value for which the dielectric strength of the "impure" insulating liquid is at a minimum. This critical pressure is invariably of the order of a few hundred microns of mercury.

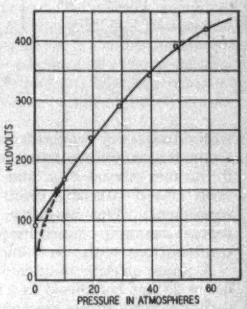

Fig. 1. The effect of pressure on the dielectric strength of transformer oil

Experimental data (circles) from Kock (reference 7)

With changing temperature of test an apparent contradiction in behavior is obtained. With light, low viscosity oils of the transformer type, the dielectric strength increases with increasing temperature from 25 degrees centigrade. With heavy, mineral, cylinder oils, the dielectric strength falls as the testing temperature is increased from 25 degrees centigrade, other conditions being unchanged. Figure 2 shows this relation.

The contrasting dielectric behavior of different oils with temperature change and the constant behavior of these oils under pressure change can be correlated with proper consideration of the "relative dissolved air density" existing in the oil under examination. For this interpretation, reference is first made to the recognized dielectric behavior of air.

The Characteristics of Gaseous Breakdown

The mechanism underlying the dielectric breakdown of gases is recognized as involving the phenom-

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1. For all numbered references see list at end of paper.

enon of cumulative ionization resulting from the collision of charged particles under the influence of the applied electric field.[3] As such, the dominating influence involves not only the strength of the field, but also the mean free path of the moving particles. Changes in the gas density, caused either by pressure or temperature variation, directly affect the mean free path with resulting change in the dielectric strength of the gas. The voltage at spark over under carefully controlled experimental conditions varies directly with changes in gas density, increasing with increasing pressure at constant temperature and decreasing with the increasing absolute temperature at constant pressure in accordance with the usual gas laws, the spark length remaining constant.[4,5] This linear relation (Paschen's law) holds true between widely varying limits.

The effect of changing density on the dielectric strength of air may be illustrated by reference to the change in dielectric strength with temperature. Accepting the relative air density as equal to unity at 25 degrees centigrade, 760 millimeters of mercury pressure, application of the gas laws shows the relative air density at 0 degree centigrade to be 1.091 and at 100 degrees centigrade to be 0.801. Applying Paschen's law without consideration of kinetic phenomena, the corresponding dielectric strength of air would be 32.5 kilovolts per centimeter and 23.8 kilovolts per centimeter, respectively, accepting the breakdown of air to be 29.8 kilovolts per centimeter at 25 degrees centigrade and 760 millimeters of mercury pressure. Over a temperature range from 0 degree to 100 degrees centigrade, the dielectric strength changes, therefore, 0.087 kilovolts per centimeter per degree centigrade. In terms of the breakdown of air (29.8 kilovolts per centimeter at 25 degrees centigrade, 760 millimeters of pressure)

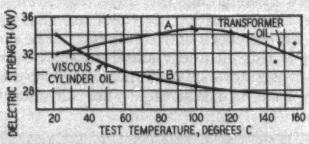


Fig. 2. The dielectric strength-temperature relation for mineral oils tested at atmospheric pressure

the change in dielectric strength is 0.27 per cent per degree centigrade, a value in agreement with the experimental results already reported by Ryan[6] and Whitehead.[8]

Relative Gas Density as Applied to "Impure" Insulating Liquids

Air solubility in mineral oil at 25 degrees centigrade, 760 millimeters of pressure depends upon the physical and chemical characteristics of the oil itself, being greatest with the low viscosity oils of the transformer type. The following tabulation serves to show the change in air solubility at 25 degrees centigrade in selected, refined fractions from the same parent crude oil stock of Texas origin. In this tabulation the volume of the gas is reduced to 25 degrees centigrade, 760 millimeters of pressure and is expressed in per cent of the total oil volume.

Low viscosity fraction (55 seconds at 37.8 degrees centigrade)—10 per cent

Medium viscosity fraction (100 seconds at 37.8 degrees centigrade)—8.3 per cent

High viscosity fraction (1,600 seconds at 37.8 degrees centigrade)—6.5 per cent

The dielectric strength at 25 degrees centigrade of these mineral oil fractions is independent of the stated variations in oil-dissolved air, all oil fractions having a dielectric strength ranging from 30 to 40 kilovolts when carefully tested between 1 inch diameter brass disk electrodes spaced 0.100 inch apart. The dielectric strength is affected, however, as the oil-dissolved gas content, characteristic of the oil under standard conditions (25 degrees centigrade, 760 millimeters) is varied. Stated in general terms, the absolute value of liquid-dissolved gas is not of major importance in determining the dielectric strength of the insulating liquid. It is the relative liquid-dissolved gas density which is the determining influence in affecting the electrical breakdown value. The effect is analogous to the effect of the relative air density in influencing the dielectric strength of air already referred to.

Definition of Relative Liquid-Dissolved Gas Density

The density of matter is usually expressed as the mass per unit volume, measured under accepted standard conditions. In discussing the amount of dissolved gas present in the "impure" liquid dielectric, expression has been made in terms of per cent gas per volume of liquid, the volume of the gas being reduced to 25 degrees centigrade and 760 millimeters of pressure, called standard or normal conditions. Since the gas volumes measured have all been reduced to a selected "standard" condition of temperature and pressure, defining as unity the liquid-dis-

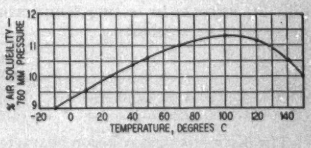


Fig. 3. The effect of temperature on the solubility of air in mineral transformer oil

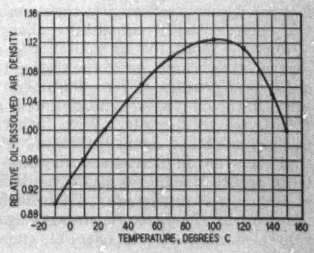
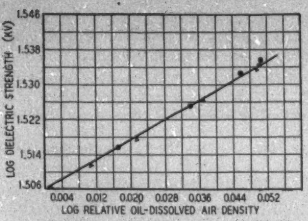


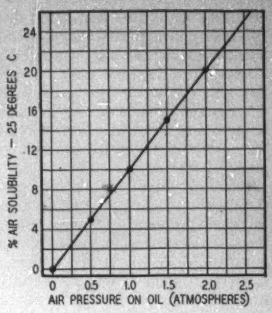
Fig. 4. The relative oil-dissolved air density in mineral transformer oil as a function of temperature



Dots represent values for tests from room temperature to maximum dielectric strength (approximately 100 degrees centigrade. Triangles represent values for tests from temperature of maximum dielectric strength to 150 degrees centigrade

Fig. 5. Showing the logarithmic relation between the relative oil - dissolved air density and the dielectric strength of mineral transformer oil

Fig. 6. The effect of air pressure on the solubility of air in mineral transformer oil, tested at 25 degrees centigrade



solved gas density under such conditions, the relative liquid-dissolved gas density may then be expressed as

$$D = \frac{V^1}{V} \qquad (1)$$

where

D = relative liquid-dissolved gas density

V = per cent gas solubility (by volume) in the liquid tested under standard conditions (25 degrees centigrade, 760 millimeters pressure)

V^1 = per cent gas solubility in the liquid (by volume) under the specially selected conditions, the volume of gas having been reduced to 25 degrees centigrade, 760 millimeters pressure

The application of this concept of relative liquid-dissolved gas density is used to correlate the often conflicting effects of temperature and pressure on the dielectric strength of insulating liquids.

The Temperature Effect

Under changing temperature at a constant gas pressure, the gas solubility in a liquid changes. The solubility of air in mineral insulating oil may increase or decrease depending upon the characteristic of the oil under examination. For low viscosity oils of the transformer type, the air solubility increases with increasing temperature. With heavy, viscous oils, an increase in testing temperature produces a decrease in air solubility.

	% Air Solubility at 25°C	% Air Solubility at 100°C
Oil *A*—a light oil of the transformer type	10%	11.3%
Oil *B*—a viscous cylinder oil	6.5%	4.8%

The distinctive gas solution characteristics of these 2 types of oils is reflected in their contrasting dielectric behavior with temperature change (figure 2).

Figure 3 shows the air solubility in mineral transformer oil as a function of the testing temperature at a constant pressure of 760 millimeters. The air solubility in the oil reaches a maximum at approximately 100 degrees centigrade. With higher temperatures the gas solubility again decreases. Figure 2 shows that the same oil increases in dielectric strength with temperature, reaching a maximum dielectric strength at 100 degrees centigrade. With further increase in temperature the dielectric strength again falls. The general similarity in the effect of temperature on the oil-dissolved gas content and on the dielectric strength of the oil is not accidental. The dissolved gas content of the oil plays an important rôle in determining its dielectric strength.

Figure 4 shows the relative oil-dissolved air density for mineral transformer oil, calculated from air solubility data which was experimentally determined. The dielectric strength of this same transformer oil is shown in figure 5 to be a logarithmic function of the relative oil-dissolved air density and is expressible as

$$K_v = AD^{0.55} \qquad (2)$$

where

K_v = breakdown value at a specially selected temperature, the oil being tested at 760 millimeters between 1 inch diameter disk electrodes spaced 0.100 inch apart

A = dielectric strength of the oil under standard conditions, 25 degrees centigrade, and 760 millimeters

D = relative oil dissolved air density as calculated from equation 1

The application of equation 2 to the problem of the heavy cylinder oil, the dielectric strength-temperature characteristics of which are illustrated in figure 2, allows check on its validity. The dielectric strength of this oil under standard conditions of 25 degrees centigrade, 760 millimeters pressure is given in figure 2 as 33.5 kilovolts. The air solubility in

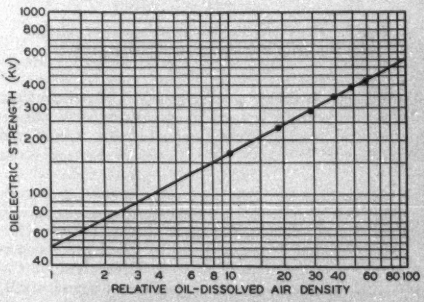


Fig. 7. Showing the logarithmic relation between the dielectric strength and the relative oil-dissolved air density for mineral transformer oil

Based upon figure 1

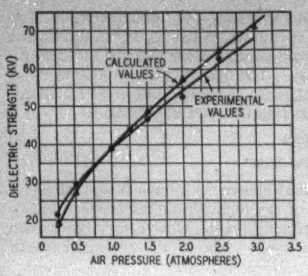


Fig. 8. Showing the relation between the dielectric strength and low values of applied air pressure for mineral transformer oil

this oil under the same conditions has already been stated to be 6.5 per cent. At 100 degrees centigrade, the air solubility is 4.8 per cent. The relative oil-dissolved gas density at 100 degrees centigrade thus becomes 0.73, calculated in accordance with equation 1. Substituting the approximate values in equation 2, it is therefore found that

K_v at 100 degrees centigrade = 28.2 kilovolts

a value in close agreement with the data of figure 2.

The successful application of the concept of relative oil-dissolved air density to the behavior of oils showing either a positive or a negative dielectric strength-temperature relation, or to an oil which first shows a positive and then a negative temperature-dielectric strength relation, clearly substantiates the importance of dissolved gas phenomena in determining the dielectric behavior of mineral insulating oils.

The Pressure Effect

The solubility of air in mineral oil obeys the usual gas solubility laws in that the solubility of the gas increases in a linear relation with the applied gas pressure. Figure 6 shows the relation over the pressure range from 0 to 2 atmospheres, transformer oil of Texas origin being used as the representative insulating liquid. It is possible that the air solubility may not continue to increase indefinitely with the pressure. Experimental confirmation in the extremely high gas pressure ranges is lacking.

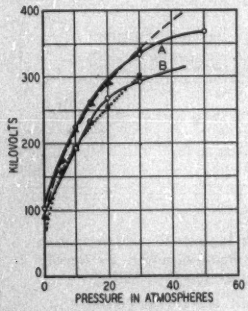


Fig. 9. Showing the relation between applied gas pressure and the dielectric strength of "petroleum" (for 2 different tests, A and B)

Solid lines—Experimental data from Kock (reference 7)
Dotted lines—Calculated data based upon logarithmic relation between the relative oil-dissolved air density and the dielectric strength

In the light of figure 6, figure 1 can now be redrawn showing the dielectric strength of the oil as a function of the relative oil dissolved air density, calculating this factor by the application of equation 1. Figure 7 shows such relationship to be logarithmic. The dielectric strength is expressed as

$$K_v = AD^{0.55} \qquad (3)$$

In figure 1 (based on Kock), it will be observed that the dielectric strength of the oil under zero gas pressure is given as 93 kilovolts. The breakdown for 1 atmosphere air pressure is not given. From the relation (equation 3) this value should be 50 kilovolts. In figure 1, the dotted line relation for the range of pressures from 0 to 10 atmospheres is based upon the application of equation 3.

The relation 3 applies in the range of gas pressures from 1 to 3 atmospheres as shown in figure 8, illustrating the changing dielectric strength of transformer oil, tested at 25 degrees centigrade. The experimental and calculated (equation 3) results are in close agreement.

The logarithmic relation established in equation 3 holds true only for pressures above the "critical gas pressure," below which value the dielectric strength of the oil again increases.

The Analogy Between the Gaseous and Liquid-Dissolved States

An "impure" dielectric liquid under the definition cited is a solution of a gas in a liquid, the usually occurring case being the solution of air in mineral oil. The great advance in physical chemistry of recent years has been in part traceable to the recognition of the far reaching analogy between the gaseous and the dissolved states of matter. The laws governing gaseous behavior are well known. Their application to solution phenomena has contributed valuable knowledge of the nature of solutions, ultimately culminating in the theory of electrolytic dissociation. This advance has been shared by numerous and prominent investigators. It was Newton who pointed out that the dissolved molecules in a solution tend to

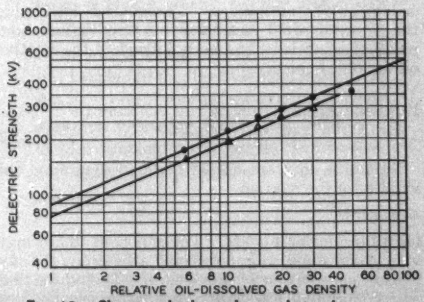


Fig. 10. Showing the logarithmic relation between the dielectric strength and the relative oil-dissolved air density for "petroleum"

Experimental data (Kock) from figure 9

get away from each other so that they finally become distributed uniformly in the solvent. There is, however, a difference between a gas and a dissolved substance, which has been expressed in the statement that the molecules in the gaseous state do not need a solvent to hold them in suspension in a certain volume; their mutual repulsion is enough for the purpose. On the other hand, when a solid, liquid, or gaseous substance is dissolved in a solvent, its molecules would not remain in the limited volume "if they were not united by their affinity to the molecules of the solvent."

It is the analogous behavior of the gaseous and the dissolved states of matter necessarily modified by the affinity of the molecules of the solute for the molecules of the solvent, which appears to determine the dielectric breakdown of "impure" liquid dielectrics.

Correlation of Pressure and Temperature Effects

In the preceding paragraphs, it has been shown that the temperature effect on the breakdown of "impure" liquid mineral oil dielectrics is a logarithmic function of the relative oil-dissolved gas density. In like manner it has been shown that the pressure effect on the dielectric strength is also a logarithmic function of the relative oil-dissolved gas density. The relationship has been expressed as

$$K_v = AD^n \text{ for temperature change} \quad (2)$$

$$K_v = AD^n \text{ for pressure change} \quad (3)$$

For mineral transformer oils, $n = 0.55$

The identity of these relations demonstrates the value of D in determining the dielectric strength of "impure" mineral insulating oils. Equation 2 has been shown to apply to oils showing either a rising or a falling dielectric strength with temperature. It has also been applied to an oil tested over a sufficiently broad temperature range such that the dielectric strength first rises and then falls as the testing temperature is increased. Formula 3 has been applied to transformer oil over an air pressure range as high as 60 atmospheres. The factor D correlating the behavior of oil under varying temperatures and pressure conditions, has been defined as the relative oil-dissolved gas density.

Further Application of the Concept of Relative Liquid-Dissolved Gas Density

Sufficient data are not at hand to determine the validity of the relation

$$K_v = AD^{0.55}$$

for all insulating liquids. The exponent (0.55) may vary from liquid to liquid, being affected by the molecular gas solution phenomena. It is obvious that where molecular association in solution occurs, such variation would be expected. Chemical reaction in solution would also involve deviations from the relation derived.

Figures 9 and 11 show the dielectric strength-pressure relation for benzol and "petroleum." Figures 10 and 12 demonstrate the logarithmic relation between the liquid-dissolved air density and the dielectric strength. The value of the exponent n varies somewhat from the value obtained for transformer oil. The relations are expressed as

$$K_v = AD^{0.95} \text{ for benzol} \quad (4)$$

$$K_v = AD^{0.41} \text{ for "petroleum"} \quad (5)$$

The dotted lines shown in figures 9 and 11 show the application of the logarithmic relations 4 and 5.

Further experimental work is necessary before the universality and exact value of the exponent n can be claimed.

The Mechanism of "Impure" Liquid Dielectric Breakdown

It has been suggested in a previous publication[1] that the dielectric breakdown of gas-containing dielectric liquids may involve the actual separation of the liquid-dissolved gas from the "impure" dielectric solvent, with resultant breakdown in a manner clearly distinguishing the "impure" from the "pure" insulating liquid. There is considerable reason to believe that such separation may occur. It is to be observed, however, that gas separation from solution is not necessarily involved. The close physical and electrical analogy between gaseous and dissolved states, modified as may be necessary by the forces of

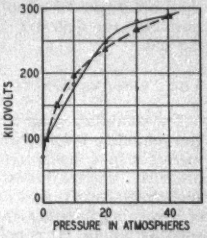


Fig. 11. The effect of air pressure on the dielectric strength of benzol

Solid line is based on the experimental data (circles) of Kock (reference 7)
Dotted line—calculated from the logarithmic relation of figure 12

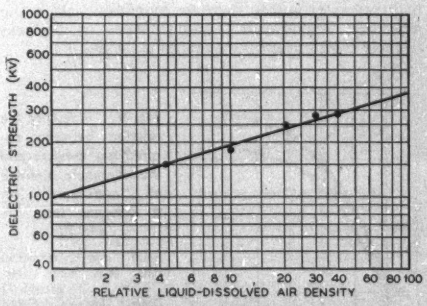


Fig. 12. Showing the logarithmic relation existing between the relative liquid-dissolved air density and the dielectric strength of benzol

Based upon experimental data of Kock (reference 7)

molecular solution, appears to indicate that liquid-dissolved gas may influence the breakdown of the "impure" liquid dielectric without actual gas separation. Further experimental investigation is in progress, the object of which is the solution of this problem.

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Noise Measurements for Engineering Purposes

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The 2 principles of noise measurement, namely, the subjective and objective principles, are discussed in this paper with special reference to electrical plant. Two forms of measurement embodying the subjective principle are considered: One is the proposed primary standard method, which is essentially a laboratory method; the other is the noise audiometer, which enables the subjective principle to be applied directly to the study of engineering noise problems. A form of audiometer and technique, together with their practical advantages, are described. The objective method of measurement is particularly needed for commercial acceptance tests. The evidence shows that the objective type of instrument now available evaluates the noise of many types of plant correctly, but that with noises predominantly harmonic in tone structure, the principle of the method is inapplicable. It is concluded that the audiometer provides the only practicable means at present available for measuring transformer noise and that no satisfactory solution for the commercial testing of such apparatus has yet been reached.

In industrial noise problems, particularly those arising in the electrical industry, a great variety of noises is met. For measuring such noises, the ideal instrument would be one that would indicate by means of a meter deflection the loudness of a noise of any type in terms of an accepted primary standard. The ideal instrument would have to simulate in a complete manner the response of the ear to noises of all types and complexities. A necessary preliminary to the production of such an instrument would be a complete understanding of the response of the ear to complex sounds, with means of predicting quantitatively their total loudness. At present much has yet to be learned about ear response, and so far no generally valid method of computing the loudness of complex sounds appears to have been advanced. Nevertheless, objective noise meters based upon simple assumptions have been developed empirically, as is well known, and these instruments go a long way toward meeting practical needs. However, in certain important noise problems in electrical engineering the basic principle of the objective instrument fails, and instruments of this type must be used with discrimination. The subjective or aural comparison method of measurement need involve no assumptions regarding ear response and, within certain limits, this method measures correctly any sustained noise. In its portable form and with the use of a suitable technique, it has been found technically satisfactory and convenient; however, it does not possess certain practical advantages of the objective method. The purpose of the present paper is to examine the suitability of each method of measurement for different problems that arise in engineering. In the author's opinion both subjective and objective methods should be used in the laboratory, factory, and field, and constantly compared, in order to insure that both aspects of

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noise are given adequate attention. In order to see the subject in proper perspective, it is advisable first to consider briefly the primary standard for sound measurement.

Primary Standard for Sound Measurement

The setting up and use of a primary standard for the calibration of noise measuring instruments is essentially a laboratory matter. It requires special facilities, and a rigorous experimental technique is necessary in order to remove all doubt as to the validity of the measurement. The standard that almost certainly will be agreed upon for international use is a plane or spherical sound wave having only a single frequency of 1,000 cycles per second, or, in other words, a 1,000 cycle pure tone in free space. The loudness of the sound to be measured, which may be called X, can be compared with that of the standard only by the ultimate criterion of relative loudness, namely, the introspective judgment of a representative group of observers. A consideration of this matter[1] shows that for the highest precision it is desirable that observers do nothing but judge which of 2 sounds presented is the louder. Judgments of equality are not used. Observers are not allowed to make adjustments or to know the results of their own or other observers' judgments. The test tones are controlled by independent operators who adjust them to intensities unknown to the observers. Careful precautions are taken against fatigue. Several observers, *e. g.*, 9, are employed and the standard tone and X are heard alternately with both ears, the observer facing the source. The judgments then are treated statistically and the intensity of the standard that is judged to be as loud as X is deduced.

In this way any type of sustained noise may be measured in terms of the primary standard. If observations of X are made also with a portable noise meter, the calibration of the meter for that type of noise can be deduced.

With this rigorous technique, which for brevity can be called the statistical technique, individual judgments show considerable dispersion. In the paper referred to, a spread of about 13 decibels is shown, apart from one isolated case of 24 decibels. Geiger and Abbott[2] report that the spread of their observations, taking all observers into account, varied from 13 to 31 decibels (their technique was not precisely the same as that just described). Hence in order that sufficient precision may be obtained in the final result, the statistical technique, which is entirely necessary and appropriate for fundamental measurements, requires a considerable number of subjects. Also considerable time is required to obtain a measurement.

The Subjective Method for General Noise Measurements

It would appear that the cumbersome nature of the statistical technique and the uncertainty in individual observations has led to the impression that subjective methods of measurement are, in general, unsuitable for engineering purposes. However, experience shows that this is not necessarily true, provided that suitable apparatus and technique are employed.

In view of the fundamental nature of the aural comparison method, the author and his colleagues have thought it essential to make the method conveniently available for everyday measurements in the laboratory, factory, or field. The liberal use of the aural balance method in a suitable form seems a necessary step in the evolution of a satisfactory basis for commercial noise measurements, whatever principle of measurement or form of instrument eventually may be adopted.

Portable aural comparison instruments are not new, and several forms and measuring techniques have been devised. The author and his colleagues have studied the factors entering into aural comparison measurements and have evolved a form of instrument and a technique which have been described elsewhere.[3] There is no need to give in detail here the steps that led to the instrument and technique adopted; these mav be found in the original paper.

A Noise Audiometer for Industrial Measurements

General Principle. A pure rather than a complex reference tone is employed, as it is capable of simple and precise definition and reproduction. For reasons that will be apparent later, there are special objections to reference tones with harmonic components. The apparatus must be easily portable and capable of use in a wide variety of surroundings. Hence a free space reference tone set up by a loudspeaker is impracticable. As the range of industrial measurements normally extends up to 110 decibels above 0.0002 dyne per square centimeter, the production of a pure reference tone up to that intensity is a further reason for using telephone receivers.

The presenting of the reference and unknown sounds to the observer simultaneously rather than alternately is clearly a practical necessity as, in general, the unknown sound cannot be interrupted suddenly. Means must also be provided for adjusting and observing the intensity of the reference tone in relation to that of the unknown sound. The reference tone frequency should be in the middle region, say, between 700 and 1,000 cycles per second. The standard frequency of 1,000 cycles may be used, but a somewhat lower frequency, *e. g.*, 800 cycles, has the advantage of being nearer the average frequency of the noise emitted by machinery in general and is therefore slightly easier to match with machinery noise. Also an 800 cycle tone may be compared directly with the standard 1,000 cycle tone without difficulty. The reference tone is applied to one of the observer's ears by means of a close fitting cap on the receiver, the other ear being turned toward the unknown noise. The spaced-telephone technique is not used on account of the baffling of the ear to the unknown sound by the receiver, which produces a frequency-discriminating effect. There are

1. For all numbered references see list at end of paper.

also other objections to the spaced-telephone technique.[3] Furthermore, an excessive receiver input would be required to produce an intensity of 110 decibels with a spaced receiver.

Apparatus. The reference tone is generated by a battery-operated valve oscillator giving a pure wave form. The voltage is applied to 2 attenuators, the output current of which is applied to the telephone receiver. The voltage applied to the first attenuator is observed by means of a miniature voltmeter and is adjustable over a small range by means of a rheostat controlling the valve filament current. Adjustment in larger steps is provided on the high voltage battery. The main attenuator is adjustable from 0 to 100 decibels in 5 decibel steps. The auxiliary attenuator is continuously adjustable from from +6 to −5 decibels. By temporarily doubling the normal working voltage, intensities up to 112 decibels can be obtained if required. The selection of the telephone receiver is an important matter. The form used is tuned mechanically to 800 cycles per second, which not only decreases the oscillator output required for a given intensity, but also further purifies the tone produced. The tuning is adjusted under the acoustical conditions obtaining when the receiver is worn on an observer's head. The receiver is provided with a close-fitting soft-rubber cap. This cap effectively seals the ear to which the reference tone is applied against the entrance of other sound; it also minimizes the possibility of direct conduction of sound from the body of the receiver to the head. The receiver used has a linear characteristic up to 112 decibels as shown by acoustical pressure measurements. The whole apparatus is contained in one box $7^3/_4 \times 14 \times 6^3/_4$ inches, the total weight being $16^1/_2$ pounds. A carrying strap is provided, which can be extended to pass over the shoulder of the observer so that measurements can be made while carrying the instrument.

Method of Using Noise Audiometer. Bearing in mind the statistical laboratory technique, the following technique is used: A single observer making equal loudness judgments is employed. The oscillator is switched on and the output voltage adjusted to the standard value. The telephone is adjusted on one ear, the other being turned toward the source of sound to be measured. It is found that the sideways position facilitates concentration of attention on the sound under observation. When extraneous noise is present, or when because of surrounding conditions the sound field unavoidably is distorted, it gives a bias in favor of the sound under observation. The facing position can be used if desired, but in general the calibration will be altered slightly. The attenuator with the coarse setting is adjusted until the reference tone is appreciably louder than sound X and the setting mentally noted. The reference tone then is made appreciably softer than X and the setting noted. By successive trials the observer narrows down the interval between the 2 settings to within 5 decibels. Leaving the attenuator with the coarse adjustment set at the nearest stud, he completes the aural balance as nearly as he can by the attenuator with the fine adjustment. Thus by a series of converging adjustments a final setting is reached at which the observer is equally aware of the standard and sound X. The process is repeated with the reference tone applied to the other ear and the mean of the 2 final settings taken as the considered judgment of that observer. The justification for this technique will be discussed after instrumental errors have been considered; but for the present it may be noted that in measuring the complex sounds ordinarily met in engineering problems, the spread of the mean final settings of the observers normally does not exceed ±2 decibels at 100 decibels level, ±4 decibels at 80 decibels, and ±6 decibels at 50 decibels. With pure tones the spread is larger, as will be seen later.

Sources of Error. Before the free-space primary standard had been formulated, the calibration of the noise audiometer was carried out on the following lines: The reference pressure for the 800 cycle reference tone was taken as 0.000215 dyne per square centimeter for an observer facing the source. This is the mode threshold value given in table I of reference 3. In order to relate this free-space pressure with that set up in the ear canal of an observer, a series of measurements was made on 10 subjects by means of a microphone fitted with a fine nonresonant probe tube. The combination of probe tube and microphone was calibrated by placing the end of the tube in a known sound field, i. e., at the front of another microphone the field calibration of which was known accurately. It was demonstrated that the presence of the probe tube did not appreciably alter the field. In the observations on the 10 subjects it was found that the pressure at the entrance to the ear canal was higher than the field pressure, the excess varying from 2 to 4 decibels with an average of 3 decibels. The canal pressure corresponding to 0.000215 dyne per square centimeter therefore was taken as 0.00030. (It should be noted that the difference between canal and field pressures at 800 cycles shown by figure 10 of Sivian & White's recent paper[4] is about 6 decibels, but as this difference is measured only indirectly the figure of 3 decibels has been adhered to.)

The next step is to find the setting of the audiometer voltmeter that corresponds to the required canal pressure. For this purpose a probe tube connected to a microphone was fitted into a soft rubber cap of the type used on the receivers. The probe tube is calibrated for canal pressure measurements by fitting the cap to a receiver and forming a sealed cavity by placing against it the working face of a calibrated microphone. A known pressure thus is obtained in the cavity and the indications of the microphone fitted to the probe tube are noted. To calibrate the audiometer, the receiver with the cap fitted with the probe tube is placed on the ear of a representative person and the audiometer attenuator set at 70 decibels. The oscillator voltage then is adjusted until a canal pressure of 0.947 dyne per square centimeter is recorded by the probe tube microphone and the voltmeter reading noted. It was found that the variations in pressure set up for a given receiver input attributable to differences in the acoustical impedance of the ears of different persons did not exceed 0.5 decibel. The reproducibility of the

generated pressure with a given person showed variations not exceeding 0.1 decibel without any particular care in the adjustment of the receiver on the head.

Tests were made on the efficacy of the sealing by the rubber cap, in order to ascertain whether sound other than that of the reference tone could be heard by that ear. Pure tones of various frequencies in free space were set up and the thresholds of a subject noted. Standard receivers then were placed on both ears and the threshold again determined. The mean threshold shifts of 4 subjects are given in table I from which it may be seen that the sealing is very effective.

Tests also were made to ascertain whether appreciable sound transmission other than by the air pressure pulsations took place. The hole in the front of a receiver was sealed and it was found that the input had to be increased by 60 decibels above threshold before the reference tone was audible. Direct transmission to the head is therefore negligible. It is known that the attenuation through the head is of the order of 50 decibels. Since under conditions of aural balance the equivalent intensities are equal, the 2 ears may be regarded as independently receiving the reference tone and noise under observation, respectively.

Table I—Effectiveness of Sealing Provided by Rubber Caps

Frequency, Cycles per Second	Threshold Shift, Decibels
100	11
200	10
400	11
800	22
1,600	15
3,200	37
6,400	29

All receivers are checked for linearity of characteristic up to 112 decibels for effects of temperature changes when worn on an observer's head and for secular change before being passed for use. The latter variations do not exceed 1 decibel.

Calibration in Terms of Primary Standard. Since the formulation of the primary standard, the opportunity has been taken to calibrate the noise audiometer in terms of it. The standard specifies listening with both ears to a tone in free space, the observer facing the source. Comparison of this tone with another sound also in free space, involves the statistical technique with alternate listening. Therefore complex sounds of various types might be set up and evaluated both with the primary standard and with the audiometer. This, with the difference that equality of loudness judgments and an 800 cycle standard tone were used, already has been done for motor and transformer noise, the results being given in table 8 of reference 3. Motor noises of 81 and 58 decibels above threshold and transformer noises of eighty-six and 45 decibels were examined. Four practiced observers were employed and the mean of their observations did not show any serious divergence between the noise evaluated in terms of the 800-cycle free-space tone and the audiometer, the largest difference being 6 decibels. The spread of the loudness equality judgments by simultaneous listening did not exceed 4 decibels (45 decibels transformer noise) whereas with alternate listening the spread reached 11 decibels with an 86 decibel motor noise. West[3] has pointed out that the simultaneous listening values yield on the whole results 1 or 2 decibles higher than for alternate listening, and has obtained differences of 2 to 3 decibles.

In calibrating a noise audiometer directly in terms of different types of noise it is difficult to insure that all important types have been covered. It seemed probable that any variation in the audiometer calibration, in terms of the primary standard, as between one type of noise and another would be dependent mainly on the frequencies of the important components of the noise. With the audiometer, the reference tone is presented to the auditory mechanism solely by the pressure pulsations set up in the ear canal. However, the complex sound under observation not only sets up pressure pulsations in the ear to which it is presented but the surface of the head also acts as a collector of sound. As the head is turned sideways to the sound, the surface presented is considerable, and the collecting power certainly will be dependent in some degree on the frequency of the incident sound. In the first place the audiometer therefore was calibrated directly in terms of pure tones of selected frequencies.

The measurements were made in a lined test room[5] 24x24x13 feet, inside dimensions. An electrodynamic loud-speaker mounted in a large baffle was set up in one corner of the room so that sound was radiated toward the center. Irregularities from wall, floor, and ceiling reflection were shown by

Table II—Calibration of Audiometer for 80 Decibel Level in Terms of 1,000 Cycle Tone

Frequency of audiometer reference tone, 800 cycles per second. Number of observers, 10. Reference pressure, 0.0002 dyne per square centimeter

1 Test Tone Intensity Level in Terms of 1,000 Cycles, Db	2 Test Tone Frequency, Cycles per Second	3 Test Tone Intensity Level, Db	4 Mean Corrected Audiometer Reading, Db	5 Difference Col. 4—Col. 1	6 Deviations, Db Max. +	Max. −	Mean	7 Intensity Level of Largest Harmonic, Db
80	103	82	79	−1	7	9	3	37
80	219	80.5	81.5	+1.5	7	21	8.1	34
80	370	80	82	+2	7	11.5	5.0	34
80	1,000	80	83	+3	7	9.5	3.4	42
80	3,000	74	81	+1	5	3	1.8	20
80	6,000	84.5	82	+2	8	7.5	4.4	>30

microphone measurements to be negligible because of the large amount of absorption present, the entire room being lined with a 6-inch thickness of cotton waste spaced 6 inches from the walls. The double brick wall construction and the location of the building gave entire freedom from extraneous noise. The acoustical pressure measurements rest on the following basis: The type of condenser microphone employed is $2^1/_2$ inches in diameter and has a flush face, so that cavity resonance effects are absent. Pressure calibration is carried out in terms of the Rayleigh disk in a resonant tube.[6] The field calibration is derived from this by means of probe tube measurements, using a substitution method, and is checked by Rayleigh disk measurements in a lined testing cabinet.

The audiometer to be calibrated was placed on a stand together with an attenuator controlling the test tone, so that either could be manipulated by an observer whose head was somewhat farther than 1 meter from the source. The test tone attenuator was calibrated for intensity at a given frequency by swinging a microphone into the position of the observer's ear that was presented to the test tone, and measuring the absolute pressure. The microphone, in conjunction with a sound analyzer, also was used to explore the purity of the test tone.

It is clear that the conclusions reached in regard to the calibration of an audiometer at different frequencies depend upon the equal-loudness relations with respect to frequency that are assumed. The equal-loudness relations hitherto used by the author and his colleagues consist substantially of Kingsbury's data modified by some experiments of their own, and are given in reference 3. Another set of relations is provided by the proposed U.S. standards.[7] These have been determined by a more rigorous method than has hitherto been employed. However, certain unexplained irregularities and disagreement in certain respects with other data do not allow it to be supposed that finality in this matter has been reached. Nevertheless, they are probably more generally valid than any previously put forward and are used for comparison in the present paper.

Calibrations were carried out principally with test tones adjusted to give an audiometer reading of approximately 80 decibels. The test tone of selected frequency was adjusted to a suitable value and the audiometer set at zero. The observers then were asked to "measure the test tone" by means of the audiometer, or, in other words, to obtain an aural balance with the test tone using the normal audiometer technique including the taking of readings with first one ear and then the other presented to the test tone. No observer had any information as to the nature of the tone he was asked to measure nor was he aware of results obtained by other observers. Ten observers were employed. Observations also were made by setting the audiometer tone and varying the test tone, but no significant difference was obtained. The results are given in table II. For convenience in comparison, the results have been corrected to the 80-decibel equal-loudness contour. They are corrected also for the difference in the observer's sensitivity when facing the source and when turned sideways to it, respectively. Column 7 gives the intensity level, in terms of 1,000 cycles, of the largest harmonic present in the test tone, so that a comparison with column 1 indicates the purity of the test tone. Column 5 gives the divergencies between the audiometer indications and the equivalent 1,000 cycle intensity of the test tone, which are seen to be small. If the 80 decibel contour be assumed to be correct, it is seen that the audiometer reads about 2 decibels high, except at the lowest frequency.

Table III—Comparison of Values of Harmonic Noise* as Determined by Several Different Methods

	Decibels		
	Test A	Test B	Test C
Primary standard, Mean	61	72.5	..
Deviations { Max. +	4	4.5	..
Deviations { Max. −	4	3.5	..
Audiometer, Mean	64	74	81.5
Deviations { Max. +	3	4	2.5
Deviations { Max. −	4	5	4
Number of observers (4 practiced, others unpracticed)	8	10	10
Objective meter (weighting 40 db U.S. contour)	40	46	56.5
From analysis and energy summation (U.S. contours)	36	41.5	..
Mean audiometer − mean primary standard	+ 3	+ 1.5	..
Audiometer, Max. error of any observer	+ 6	+ 5.5	..
Objective meter − mean primary standard	−21	−26	−25

* Core of 4 per cent silicon steel magnetized at 50 cycles per second.

A set of observations at 60 decibels level also was carried out with similar results, the audiometer readings being found to deviate from the 60-decibel equal-loudness contour by +4 decibels on an average. It was intended to carry out observations at 100 decibels level, but the difficulty of producing sufficiently pure tones of that intensity precluded this. Taking this and the previously quoted evidence into consideration, it has been decided for the present to apply an empirical correction of −4 decibels at 60 decibels and −2 decibels at 80 decibels to audiometer readings. Finally experiments were carried out on a harmonic noise, which was measured both in terms of the primary standard using the statistical technique and by the audiometer. An objective meter also was set up and used to measure the noise. A complete analysis also was taken, from which the summed equivalent energy could be computed. The results are given in table III. At 61 decibels level, the mean of the audiometer observations gives the absolute value to 3 decibels, and at 72 decibels level to 1.5 decibels. The spread of the primary standard observations is satisfactorily small and no difficulty was encountered in using the specified technique. It is seen that any audiometer reading gives the mean audiometer reading to 4 decibels at 61 decibels level, 5 decibels at 72 decibels, and 4 decibels at 81.5 decibel (audiometer) level. Also any audiometer reading gives the absolute value to 6 decibels at 61 decibel level, and 5.5 decibels at 72 decibels. The absolute accuracy at higher levels is probably greater, but could not be checked because a standard tone of the required intensity and purity was not available. It should be noted that these results are not confined to skilled observers.

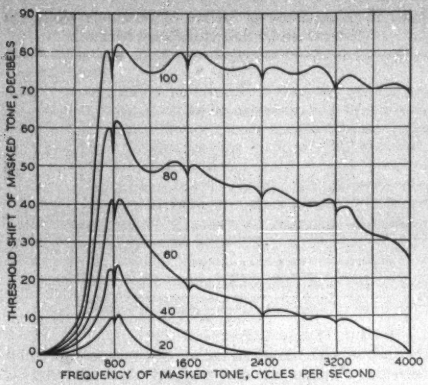

Fig. 1. Masking of one tone by another

Numerical designations on curves indicate intensity level of masking tone in decibels above threshold value (Wegel and Lane)

The question of the consistency of audiometer readings, about which so much doubt has been expressed, is illustrated further by table 10 of reference 3 which gives some figures obtained by beginners. These figures and those given in this paper bear out the order of consistency mentioned in a previous section of this paper, *viz.*, ±6 decibels at 50 decibels, ±4 decibels at 80 decibels, and ±2 decibels at 100 decibels. This experience by no means is confined to the author and his associates. Where the type of audiometer described has been used by others, inquiries have been made as to the agreement between observers in normal engineering measurements and it has been found that their own experience is confirmed. Two factors appear to contribute to this result. The necessity of memory retention with alternate listening tends to increase the spread compared with simultaneous listening. The large spreads that frequently appear when pure tones are measured seem to be attributable to local irregularities in the equal-loudness contours of individuals, as individual observations are reproducible. The much smaller spreads obtained when measuring complex noises appear to be attributable to a modification in the subjective contribution of one component not greatly affecting the total result.

The Objective Method of Noise Measurement

General Principle. As is well known, the objective instruments at present in use operate on the following general principle: A microphone is placed in the sound field under observation and the electrical output of the microphone amplified. The amplified current then is passed through a weighting network and then through an indicating meter which will be assumed to operate on an effective or root-mean-square basis. The weighting network is so adjusted that the over-all response of the instrument is greatest at those frequencies at which the ear is most sensitive. The adjustment is based upon accepted equal-loudness relations. The adjustment is made with respect to 1,000 cycles and a reference pressure approximating the threshold of persons of normal hearing. Hence if pure tones of different frequencies be presented to the instrument, it will indicate the equivalent 1,000 cycle values if the weighting is carried out correctly. The instrument generally is calibrated to indicate directly equivalent 1,000 cycle intensities in decibels above the reference intensity. The required weighting depends to some degree upon the intensity of the tone presented as well as on its frequency, and adjustment in a few steps is provided to allow for this. The instrument is made in various forms and sometimes is combined with a sound analyzer, which is particularly convenient for the study of engineering noise problems. However, it is more with the underlying principle than with particular forms of this instrument that this paper is concerned.

The use of this type of instrument to measure complex sounds implies the following assumptions: (1) that a pure tone that alone appears as loud as another pure tone still appears so when tones of other frequencies, harmonically or otherwise related, are present; (2) that the loudness of a complex sound is equal to that of a series of pure tones of a common frequency and severally equal in loudness to the components of the complex sound; and (3) that the law of summation of such a collection of pure tones is known.

With a meter indicating effective values, the operation of the instrument amounts to taking the sum of the energies of the equivalent tones of common frequency and expressing it as a pure tone of that frequency. It seems probable that the first assumption holds for the important components of a noise, but it is not true for the small ones because of selective masking. The second assumption is certainly often untrue as it neglects the subjective sum and difference tones that are formed by each component with every other component present. The third assumption introduces the question of the relative phasing of the pure tone equivalents. The difficulty does not arise if the ear is responsive to the total energy of these equivalents.

The interest and importance of the objective method lies in the fact that in spite of the incompleteness with which it simulates the response of the ear, it often does give approximate agreement with more fundamental methods. Because of the commercial advantage of a method of measurement independent of personal judgment, it is important to examine how far the objective method can be used in industrial noise measurements, especially those arising with electrical plant.

Applicability to Different Types of Noise. This subject is discussed in a recent paper[3] by the author and 2 of his colleagues. The main conclusions reached will be given briefly here, together with some additional evidence since obtained. Allusion already has been made to sum and difference tones, which are the inevitable result of the nonlinearity of

the ear. In certain classes of electrical plant they assume great importance. The principle of operation of the present objective noise meters makes no provision for the effects to which such tones give rise.

In 1924 Wegel and Lane[8] carried out experiments on the masking of one tone by another. Imagine a pure tone at an intensity just sufficient for audibility in a quiet room. If a second or masking tone of considerable intensity be sounded, the first tone becomes inaudible and its intensity level must be raised by a certain amount before it can be heard again. Figure 1 shows the results of Wegel and Lane's experiments. In the experiment illustrated by the bottom curve the masking tone of 800 cycles was kept at an intensity level of 20 decibels above threshold. As the frequency of the masked tone is increased, the degree of masking, as indicated by the threshold shift of the masked tone, increases to a maximum and then abruptly decreases to a lower value, increasing again and finally decreasing to zero. When the intensity of the masking tone is raised to higher levels, it may be seen that new kinks appear in the curves at certain frequencies. The kinks occur when the masked tone is equal in frequency to the masking tone or when it is a harmonic of the masking tone. When exact harmonic frequency relation is obtained, the masking is somewhat smaller than for a frequency relation slightly removed from exact harmonic relation. These effects result from the correspondence in frequency between the subjectively formed overtones of the masking tone and the masked tone. Hence it is to be expected that when 2 tones of given intensities are sounded simultaneously, the total loudness will be greater when their frequencies are in exact harmonic relation than when they are slightly removed from this relation. When a complex sound consists of several harmonically related tones, there will be many opportunities for the reënforcement of the physically present components by those formed subjectively, and a considerably enhanced total loudness is to be expected.

Attention was called to the importance of this phenomenon in relation to transformer noise by a letter to *Nature*, September 1933 (volume 132, page 350). In the subsequent paper[9] comparisons are given for different types of electrical apparatus of aural balance measurements made by the method described in a previous section of the present paper and the sum of the energies of the equivalent 800 cycle tones, i. e., the value that an objective meter yields. The frequencies and intensities of the components of the various noises were obtained by means of a sound analyzer accurately calibrated for free space measurements. They then were converted into equivalent 800 cycle decibels above threshold by the equal loudness relations given in the paper. The general conclusions reached may be summarized as follows: For noises not predominantly harmonic in character, *e. g.*, turbine-generator sets, induction motors, motor driven fan, the subjective values are from 1 to 10 decibels higher than the objective values; or, if the empirical correction of −2 decibels is applied to the subjective values, the discrepancies vary from −1 to +8 decibels. For harmonic noises, *e. g.*, the noise from transformers, the objective values were of the order of 30 decibels lower than the subjective values. Full particulars are given in table III of that paper. In order to confirm that the large discrepancies met in transformers resulted from the harmonic character of the sound, tests were carried out on synthetic sounds produced with a loud speaker in the laboratory. Table V in the paper referred to gives the results of these experiments in detail. With nonharmonic tone combinations, discrepancies between subjective and objective values from −4 to +6 decibels were obtained. For harmonic combinations of 2 tones, the subjective values were 2 to 5 decibels higher than the objective values, but with large numbers of components discrepancies up to 38 decibels were obtained.

It was shown that the enhancement of loudness with purely harmonic sounds was greater at low physical intensities than at high. For instance, in reference 3, table V, examples appear as follows: A harmonic sound of 12 components and a fundamental frequency of 500 cycles per second had a summed equivalent energy of 83 decibels above threshold in terms of 800 cycles. Its subjective value was 96 decibels giving a discrepancy between subjective and objective values of 13 decibels. On reducing the objective value to 48 decibels, the

Table IV—Comparison of Subjective and Objective Methods of Measurement; Nonharmonic Noise From Experimental 2,000 Horse Power Turbine Driving Brake Through Gearing

Test A			Test B		
Frequencies of Components, Cycles per Sec	*Db Above Threshold		Frequencies of Components, Cycles per Sec	*Db Above Threshold	
	M	N		M	N
53	78	88	64	90	92
155	77	83	150	85	76
385	85	85	260	81	78
400	78	79	295	76	78
760	86	86	400	89	72
860	75	75	780	75	75
930	74	74	890	67	67
1,160	72	72	2,350	99	94
1,300	77	77	3,100	101	93
1,540	78	78	3,700	105	96
1,950	86	85	5,000 }	96	90
2,370	95	91	8,000 }		
2,500	99	94			
3,100	99	91			
3,700	96	87			
4,750	87	78			
6,200	99	88			
9,900	83	70			
Equivalent energy summation (Objective values)	105.2	99.2		107.6	100.5
Largest components	99	94		105	96
Audiometer values (subjective values):					
Observer 1	100			105	
Observer 2	101			105	
Mean	100.5			104.5	
Mean audiometer value minus calculated value:					
M	−4.5			−3	
N	+1.5			+4	

* Intensities of components given as decibels above threshold of equally loud 800 cycle tone. *M* denotes values calculated on basis of equal-loudness relations of reference 7 (U. S. proposals); *n* on basis of reference 3.

physical structure of the tone being unchanged, the subjective value fell only to 86 decibels giving a discrepancy of 38 decibels.

In another case it was shown that with a harmonic sound having a large fundamental of 108 cycles per second, the energy contribution of the harmonics was negligible. However, by removing the harmonics, which left the objective value unchanged, the subjective value of 100 decibels was reduced by 12 decibels.

Apart from equivalent energy summation from analysis, an objective noise meter adjusted in accordance with the equal loudness relations used gave general confirmation of these results. These experiments were regarded as confirming the anticipation that because of its principle of operation the objective or weighted network noise meter would give indications of the wrong order of magnitude for predominantly harmonic sounds, such as those emitted by transformers. However, in view of the importance of the objective method for commercial measurements, some further consideration of the matter seemed advisable. It is evident that the indications of objective meters or the computation of the summed equivalent energy of complex sound are entirely dependent on the basis on which the weighting with respect to frequency is carried out. As previously mentioned, the equal loudness relations hitherto used by the author and his colleagues consist of Kingsbury's data modified by some experiments of their own, and are given in reference 3.

The equal loudness contours of the proposed U.S. standards[7] are now also available. To show that the conclusions in regard to the use of the objective method in measuring harmonic noises are not materially affected by the equal loudness data used, results computed from both will be given in a few cases.

Table IV shows the results of subjective measurements and noise analysis of a nonharmonic noise typical of those met in engineering problems. A 2,000 horse power turbine loaded by means of a brake through gearing consisting of several stages was set up in a works testing department. Tests *A* and *B* correspond to different conditions of operation, which need not be discussed here. The noise emitted by the set-up in test *A* may be considered substantially nonharmonic because while 2 series of harmonics are obviously present (i. e., 760, 1,540, 3,100, 6,200 and 2,370, 4,750 cycles per second), the presence of so many other large and nonharmonic components is sufficient to diminish greatly the harmonic effect. In test *B* the harmonic series (150, 295 and 400, 780 cycles per second) are small in intensity and have no appreciable effect. In order that the normal consistency of audiometer measurement of complex sounds may be illustrated, the readings of individual observers are given. Practiced observers were employed. In tests *A* and *B* it may be seen that at the order of intensity involved,

Table V—Comparison of Subjective and Objective Methods of Measurement, Harmonic Noise From Ring Cores of 4 Per Cent Silicon Steel Magnetized at 50 Cycles per Second

Frequency of Components, Cycles per Sec	*Intensities in Decibels Above Threshold of Equally Loud 800 Cycle Tone							
	Test 1		Test 2		Test 3		Test 4	
	M	N	M	N	M	N	M	N
100		12.5		10		6		0.5
200	7	19	5	17	13	27.5		6
300	47	55.5	22	32	20	30	26	38.5
400	42	47.5	40	45	30	35.5	23	28
500	42	45.5	35	38.5	57.5	61	22	26.5
600	43	44	38	40	36	37	13	14.5
700	35	35.5	29	29.5	39	39	19	19.5
800	36	36	31	31	34	34	18.5	18.5
900	30	30	29.5	29.5	27	27	16.5	16.5
1,000	28	28	31	31	30.5	30.5	13	13
1,100	25.5	25.5	31	31	32	32		
1,200	33	33	35	35	23.5	23.5	18	18
1,300	29	29	27	27	27.5	27.5		
1,400	28	28	31	31	25	25		
1,500	31	31	27	26	20.5	20.5		
1,600	32	31	31	30.5	27	27		
1,700			42	42				
1,800	46	47			34	35		
2,000					29	27		
2,200					30.5	28		
2,400					32	30		
2,800	34	30						
3,000	37	32.5	40	37				
4,800			31	22				
5,000					26	24.5		
Equivalent energy summation (objective values)	52.2	57.3	47.7	49	57.7	61	30.2	37.7
Largest components	47	55.5	42	45	57.5	61	26	38
Audiometer values (subjective values):								
Observer 1	85		85		87		67	
Observer 2	84		83		86		63	
Mean	84.5		84		86.5		65	
Mean audiometer value minus calculated value:								
M	32		36		29		35	
N	27		35		25		27	

*M denotes values calculated on basis of equal-loudness relations of reference 7 (U. S. proposals); N on basis of reference 3.

i. e., 100 decibels, agreement to 1 decibel between observers is obtained, which is not unusual. From test *A* the difference between subjective and objective values is −4.5 decibels on the basis of the proposed U.S. standards (*M*) and +1.5 decibels for the equal loudness relations used by the writer (*N*). For test *B* the differences are −3 and +4 decibels, respectively. Hence these are cases in which approximate agreement between subjective and objective measurements is obtained.

Table V gives some results of laboratory experiments on the noise emitted by ring cores of transformer steel, magnetized by conductors passing through the core, but spaced well away from it so as not to interfere with the sound radiated by the core. As may be seen, the noises are purely harmonic. The tone structures in the different tests were obtained by altering the mode of clamping of the core. The flux density was adjusted in tests 1, 2, and 3 to give subjective values of about 85 decibels. It may be seen that in the audiometer measurements the disagreement between the 2 observers employed does not exceed 2 decibels, which is not unusual with complex sounds of about 80 decibels. The disagreement is greater in test 4, but not serious. In all cases the objective value is much lower than the subjective, whether the former be computed on the *M* or the *N* basis. Test 3 is one in which the value of the summed equivalent energy is decided by the largest component, the 500 cycle component in this case. The equivalent energy contributions of all the other components are negligible, that is, the indications of an objective meter would not be affected by them, and yet they can cause the subjective value to be higher than the objective value by about 25 decibels. Comparing tests 2 and 3, the 2 noises are equally loud to within the equivalent of 2.5 decibels and yet their objective values differ by approximately 11 decibels. Neither the objective values N nor the magnitudes of the largest components are any guide to the subjective effects of harmonic noises. Further evidence on the inapplicability of the objective meter to harmonic noise is afforded by table III.

Data on Objective Method From Other Sources. Geiger and Abbott[2] give the results of observations on several different types of noises in terms of a 1,000-cycle free-space tone judged to be equally loud and by a Western Electric objective noise meter. The statistical technique was not used. Instead, the observer adjusted the 1,000 tone to loudness equality with the noise, the 2 sounds being heard alternately. Groups of 10 to 20 observers were used. Taking all observers into account, the spread of their observations varied from 13 to 31 decibels at a level of about 70 decibels. The weighting of the objective meter was in accordance with Kingsbury's 60-decibel equal-loudness contour. The readings of the objective meter compared with the subjective data varied from +0.2 decibels to −4.4 decibels over the whole range of noises examined. That the objective meter should read not more than a few decibels low for sounds not predominantly harmonic in character is in accordance with the author's experience. Geiger and Abbott do not give the compositions of the noises they examined, but several of them (*e. g.*, the "raytheon" noise) one would expect to be harmonic and therefore to show greater discrepancies than 4.4 decibels.

Table VI—Data on Harmonic Sounds Having Components of Equal Intensities in Terms of 1,000 Cycles

Number of Components	Fundamental Frequency, Cycles per Sec	Db of Each Component	Summed Equivalent Energy, Db	Subjective Value, Db	Difference, Col. 5 — Col. 4
2	1,000	20	23	24	1
		40	43	47	4
		60	63	68	5
		80	83	88	5
10	1,000	20	30	41	11
		40	50	63	13
		60	70	78	8
		80	90	94	4
10	50	20	30	36	6
		40	50	53	3
		60	70	73	3
		80	90	93	3
10	100	20	30	42	12
		40	50	60	10
		60	70	78	8
		80	90	93	3
10	530	20	30	45	15
		40	50	70	20
		60	70	89	19
		80	90	103	13

In their paper on the calculation of loudness,[1] Fletcher and Munson give some interesting data on harmonic sounds of a particular kind, *viz.*, those having components of equal intensities in terms of 1,000 cycles. In such cases the summed equivalent energies in decibels may be readily estimated. Table VI summarizes some of these results. As might be expected, the difference between subjective and objective values increases with the number of components. Also the difference is larger for low intensities than for high. The effect appears to be larger for medium and high fundamental frequencies (*e. g.*, 530 or 1,000 cycles per second) than for low frequencies (*e. g.*, 50 and 100 cycles). Also it may be seen that differences up to 20 decibels are shown for a fundamental frequency of 530 cycles and 12 decibels for 100 cycles. The general tendency of these results. is in accord with those obtained by the author except that occasionally he has obtained differences of more than 30 decibels with a fundamental frequency of 100 cycles (see table V). There are probably 2 reasons for this. The examples of table V have many more than 10 components, which spread into the middle and high frequency range where the effect appears to be largest. Also the components are by no means equal in equivalent 1,000 cycle intensity. The summed equivalent energy usually is only a few decibels more than the energy of the largest component, and it has been shown previously how harmonic components may have a considerable subjective effect without contributing appreciably to the total equivalent energy of the sound. Hence for sounds having a given number of components and a given subjective value, it is to be expected that the objective value will be lower when the components are of unequal equivalent intensity than when they are equal. These factors would lead to the larger differences that have been observed in transformer noise.

In a recent paper[9] Fletcher has discussed the special properties of harmonic tone combinations or musical tones, using the theory of Fletcher and Munson[1] to derive examples.

Conclusions Regarding Accuracy of Objective Method. The evidence from the various sources considered indicates that the objective type of instrument measures ordinary noises that are not predominantly harmonic in character to within approximately 8 decibels, the error often being considerably less than this. The meter tends to read low in the majority of measurements.

With harmonic noises, the energy summation principle upon which the instrument is based fails and errors of 30 decibels or more are possible, the meter reading low in all cases. Thus the meter can indicate 50 decibels when the correct value is 80 decibels. In terms of loudness (see appendix) the discrepancy is enormous, being the difference between 3.0 and 32. Thus with harmonic noises the objective meter can lead to results of the wrong order of magnitude.

Summary and Conclusions

Primary Standards.[7] The use of a 1,000 cycle pure tone in free space, the listener facing the source and listening with both ears, and the statistical technique for comparing the unknown with the standard tone has strong arguments in its favor. From the author's experience, it seems an entirely adequate final court of appeal.

The proposed equal loudness contours appear to require reconsideration, and it is to be hoped that this will be undertaken in the near future.

With regard to the suggested decibel-loudness relation, it is noted that this is referred to as an "additional" loudness scale for the purpose of estimating percentage reductions in loudness; that is, it is viewed as something extraneous to the accepted decibel-loudness scale and as provided to meet the needs of particular interests. In the author's view, the only scale that can properly be called a loudness scale is one based upon subjective data, and which yields numerical values proportional to the loudness sensation. In other words, a scale of the kind that has been called an "additional" loudness scale would be a real loudness scale. The decibel loudness scale unquestionably gives a measure of a purely physical quantity, the intensity above reference intensity of the equally loud reference tone. In the author's opinion it gives nothing more. It can be called a loudness scale only by the adoption of a very strained line of argument. With regard to the particular decibel-loudness relation suggested, the author doubts whether this is representative of the evidence available and considers that it contains elements that are not fundamental. The whole question is discussed in another paper[10]; see also the appendix of the present paper.

Audiometer Methods. Since aural comparison is the fundamental principle of loudness measurement, it is important, on quite general grounds, that the principle be employed directly in the study of engineering noise problems where possible. Rapid progress in the theory and technique of noise measurement has been made in the past few years. While perfection is still far off, it is reasonable to suppose that progress will continue. If during this evolutionary period the principle is not kept continually active and used, there is danger that much of importance may be missed. A case in point is that of the properties of harmonic tones.

Again, it has been suggested that tones, besides possessing the attributes of pitch and loudness, possess also "volume" and "density."[11] Then there is the question of the "disagreeableness," "annoyance" or "nuisance"[2] attributable to a sound. If an observer can discriminate between these different additional attributes, he presumably can make aural comparison observations in respect of each of them. He cannot obtain information on them from objective measurements.

If everyday noise measurements were conventionalized into the indications of the objective meters at present available, there would be a risk that the whole subject would be seen in wrong perspective.

The aural comparison method embodied in the primary standard is only appropriate to the calibration of instruments for everyday use and for research into the fundamental problems of noise measurement. It is essentially a laboratory method. In the present paper, it has been shown that the audiometer form of the aural balance method can be used for engineering measurements provided a suitable instrument and technique are employed. It yields results in terms of the primary standard. For ordinary purposes, within the limits of ± 4 decibels at 80 decibel level, one observer may be relied upon for the sustained noises met in engineering problems. If necessary, the accuracy can be improved by employing 3 observers and by using practiced observers. A beginner, after a few attempts, usually obtains values agreeing with those of a practiced observer. The method is convenient and quick. Apart from being technically generally applicable, the instrument described has the practical advantages of being unaffected by ordinary electrical or magnetic interference from electrical plant, entirely self-contained, easily portable, of small dimensions, light in weight, and of moderate cost. While the choice of 1,000 cycles per second for the primary standard reference tone frequency is acceptable, there is no need to tie audiometer reference tone frequencies to that value. Many workers have thought that for engineering purposes a somewhat lower frequency is desirable and a frequency of 800 cycles per second gives several small advantages which need not be discussed here. The indications of 800 and 1,000 cycle audiometers are, of course, directly comparable.

Where it is more important to obtain facts than to avoid argument, the aural comparison principle is required. Thus in the author's opinion, for ordinary research or engineering measurements, whether carried out in the factory or the field, a suitable audiometer should be used. If an objective meter is used alongside the audiometer, additional and useful information will be obtained; but only in so far as the objective meter readings are in accord with aural

comparison measurements can the former be accepted.

Objective Methods. The importance of the objective method lies in its elimination of the personal element and the possibility of obtaining a measure of fluctuating noises. It is essential, however, to bear in mind that there is nothing inherently valid about the basic principle of the objective meters now made, *viz.*, the equivalent energy summation. If this simple principle sufficed, there would be no reason for the existence of the elaborate theories of the loudness of complex sounds propounded by Steinberg, Fletcher, and Munson, and by Steudel. Nevertheless, it has been demonstrated that the objective meter yields approximately correct indications for noises not strongly harmonic. From an engineering point of view, this covers turbine-generator sets, generators, motors, fans, and general machinery and such miscellaneous sounds as factory, power station, or street noises. The errors arising with partially harmonic sounds, such as the noise of induction motors, probably can be reduced by calibrating the noise meter for the particular type of noise under observation. This could be done for the factory testing of large numbers of similar machines by semiskilled workers. For commercial acceptance tests, the definition of the type of noise might present some difficulty, but the experience of other workers may throw light on this point.

With strongly harmonic noises, such as those emitted by transformers, reactors, and a-c contactors, the energy summation principle fails and large errors appear. The objective meter reading is no certain guide to the loudness of a harmonic sound and, as has been shown, may not give even correct relative values.

The practicability of eliminating the error by applying a correction to objective meter readings does not seem very great. In many practical cases the correction would have to be large, *e. g.*, 30 decibels in 80 decibels, and it depends on several factors. Acoustically it would depend upon the tone structure, which in turn depends, for transformers, on the flux density, voltage wave form, mechanical construction, and other factors. It may be possible to show from exhaustive tests on transformers of different types that for particular types some rough correspondence exists between subjective and objective values, but it is doubtful whether large corrections applied on such a basis would be generally acceptable. To the author it seems far simpler to make direct audiometer observations of transformer noise, which for purely technical purposes presents no difficulty.

Commercial acceptance tests, which are likely to be contentious, present a real difficulty with transformers and no satisfactory solution is at present available. Where the parties involved are prepared to coöperate unreservedly (such situations are within the author's experience), audiometer measurements can be made by a small group of observers provided and approved by both parties, and, if the spread of the observations is normal and shows no obvious bias, the mean taken as defining the noise of the transformer under agreed test conditions. The employment of observers independent of either party is possible but inconvenient. Beyond doubt objective measurements are desirable for all commercial acceptance tests, but so far as the author is aware no universally applicable objective meter has yet been produced. It is highly important that efforts be directed toward the difficult problem of developing such an instrument so that audiometer measurements, where they are unsuitable, may be eliminated.

No attempt has been made here to discuss the practical conditions of engineering noise tests, as to deal adequately with the subject another paper would be needed.

Appendix—Relation Between Decibels and Loudness

It now is recognized that the decibel scale, used as a loudness scale, does not yield numerical values proportionate to the loudness sensation experienced by a person of normal hearing. Both practical experience and recent published experimental evidence show that loudness increases much more rapidly than the first power of the number of decibels above threshold. Experimental evidence tends to show that the nerve-impulse theory of audition provides an explanation for the well authenticated faculty of making intuitive estimates of relative loudness, which is possessed of most persons. The theory also explains the effects observed when a given stimulus is applied alternatively to one ear and to both ears. Further, relations between decibels above threshold and loudness sensation deduced from the loudness estimates and from monaural-binaural listening experiments are in substantial quantitative agreement.

The final conclusion is as follows: If the number 100 be assigned to the loudness sensation experienced when a 1,000 cycle pure tone stimulus of 100 decibels above threshold (0.00020 dyne per square centimeter) is applied, the loudness L for any other level between 30 and 115 decibels is given with sufficient accuracy for practical noise measurements by the following expression:

$$L = d^3 \times 10^{-3}$$

where d is the number of decibels above threshold. Thus when the decibel observations of practical noise measurements refer to the 1,000 cycle pure tone that evokes the same loudness sensation as the noise under observation, they may be converted immediately to loudness values. Where loudness values are given in this paper, they have been calculated on the foregoing basis.

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Expulsion Protective Gaps on 132 Kv Lines

During the last few years, the expulsion protective gap, consisting of an arrangement of spark gaps inside of fiber tubes and in series with an external gap, has been applied to a few medium voltage transmission lines for protection against outage due to lightning. The first extensive application of such gaps on 2 typical 132 kv lines during the past 2 lightning seasons are presented herewith. These expulsion protective gaps are shown to be an effective device for preventing lightning flashovers of a line and reducing line outage.

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THE problem of lightning protection on high voltage transmission lines can be solved, in theory at any rate, by 3 different methods of approach. These are:

1. Keep the lightning off the transmission line by cloud dispersion or by diverting wires.

2. Over-insulate the line and at the same time reduce the magnitude of lightning voltage to be contended with. This reduction of lightning voltage can be accomplished by properly arranged ground wires in combination with low tower footing resistances and counterpoises.

3. Discharge the lightning current at or near the point of origin. This can be accomplished by letting the lightning current discharge normally, accompanied by the usual dynamic follow-up, but in turn followed by very quick interruption of this dynamic current so that the net effect from a load standpoint is equivalent to no interruption to service. This latter can be done in 2 ways: First, by tripping the affected line and reclosing with high speed oil circuit breakers; and second, by the use of the expulsion protective gap, previously described,[1] which interrupts the fault current in the order of 0.5 cycle, without interrupting the normal flow of power.

This paper deals with the last of these methods, namely, the expulsion protective gap, and more particularly with the application, engineering details, and operating experience obtained on 2 132 kv lines of the Appalachian Electric Power Company, namely, the Glenlyn-Roanoke line 65 miles long and the Roanoke-Danville line 68 miles long. The expulsion protective gaps have been in service on 1 circuit of the first line for nearly 2 lightning seasons and on the second line for 1 lightning season.

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1. For all numbered references see list at end of paper.

Fundamental Requirements for Use on 132 Kv Lines

In applying this particular device to a group of 132 kv steel tower transmission lines, the fact was confronted that the final device had to meet the following specifications:

a. First and fundamentally it had to prevent line (insulator) flashover, and this meant it had to have a lower impulse breakdown than the line insulation.

b. The gap had to interrupt successfully any power current that the particular system could impose on it.

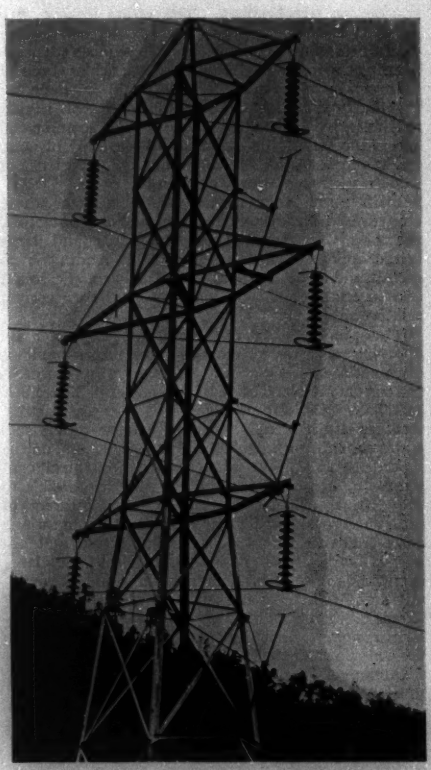

Fig. 1. 30 degree mounting. 132 kv expulsion protective gaps mounted on a suspension tower of the Glenlyn-Roanoke Line

Tube located below the insulators shown on the right, and at approximately 30 degrees to the vertical

c. It was desired that the device stand up well under weather and, if possible, give a life equal to the rest of the transmission line equipment.

d. If the line was to give lightning-proof performance, it appeared essential, that tubes be installed at each tower location. This in turn meant that if the tubes were to be justified from an economic standpoint, that not only did the first cost have to be held down, but that the design would have to be such that the maintenance would be very nominal.

e. It was desired that the appearance of the tower and of the completed line in general, with the tubes installed, be not adversely affected. In other words, what was very definitely not wanted was a "Christmas tree" effect on the line.

f. It was essential that tower clearances, from a climbing and flashover standpoint, be not reduced any appreciable amount in order not adversely to affect in any manner, ease of regular line maintenance.

g. The tube installation itself, it was felt, in view of the newness of the device, would have to be not only accessible, but easily removable to take care of such maintenance as could not be eliminated except after years of experimental work and further development of the device.

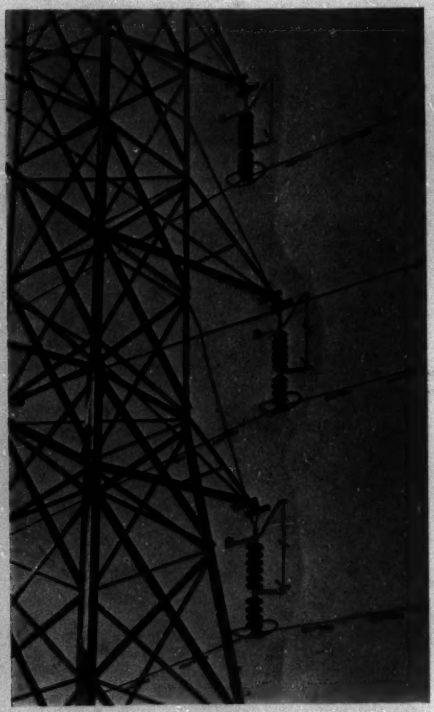

Fig. 2. Glenlyn-Roanoke tower showing all 3 phases of one 132 kv circuit equipped with expulsion protective gaps

Note the neat appearance and lack of tower cluttering shown in figure 1

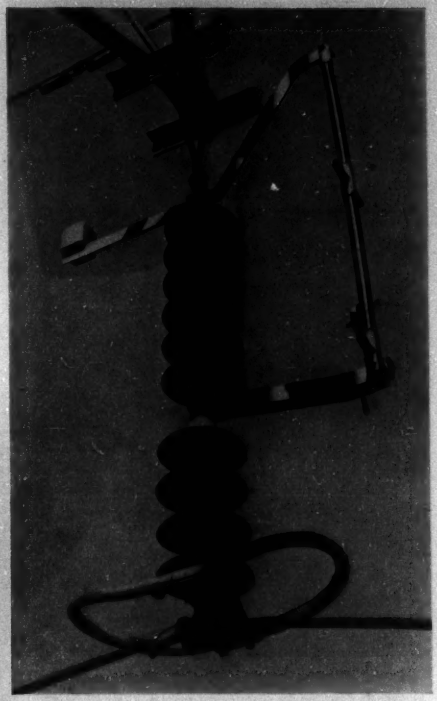

Fig. 3. Parallel mounting. 132 kv expulsion protective gap mounted on suspension insulator string on Glenlyn-Roanoke line

Note flexible indicating targets in bottom tube vents, also adjustable external gap to ring

h. Finally, considering the present limited expansion in the utility industry, it was felt that if the device was to be of any appreciable service over the next 5 years or so, it would have to be fully adaptable to existing transmission line structures, and that very little benefit would be gained if the physical form of the device could be utilized only on new tower designs, and then only with difficulty.

Design Developments and Application

The expulsion protective gap (here called "the tube" for brevity) as applied to a 132 kv line, consists essentially of 2 "internal" gaps inside 2 fiber tubes. These 2 tubes in series are placed in series with an external gap, and the whole assembly connected from line wire to ground close to the insulation (here the insulator string) to be protected.

Tube Designs (Physical). The first design proposed for 132 kv steel tower service is the so-called 30 degree mounting (mounted about 30 degrees from the vertical) composed of a single mechanical assembly of 2 fiber tubes. This tube was designed to be fastened rigidly to the tower. The length of

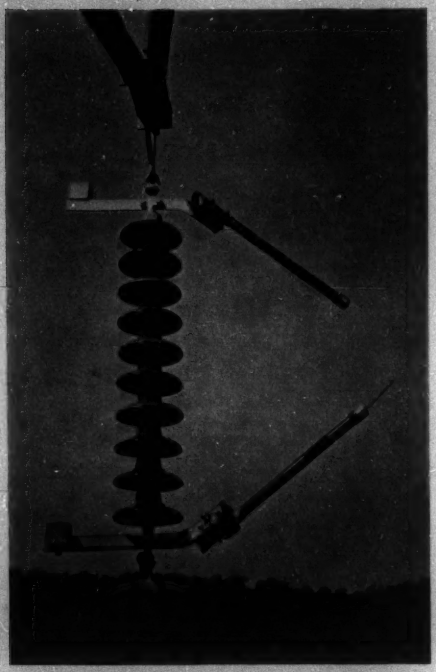

Fig. 4. "V" mounting. Expulsion protective gaps installed on single suspension insulator assembly on Glenlyn-Roanoke 132 kv line

this tube made it necessary to brace it to the tower at the middle point, as can be seen in figure 1. This rigid mounting to the tower made necessary the use of a curved top horn to maintain the external gap separation between the tube and conductor during conductor swing. The first developmental tests, subsequently referred to, were made on this design. However, after obtaining sufficient test data to indicate the probable successful operation of the device, it was realized that the 30 degree design failed to meet the fundamental requirements of *e*, *f*, and *g* enumerated above, and after considering a number of other possible designs, 2 were decided upon, each of which seemed to meet all the requirements as nearly as could be predicted; field installations of each of these designs were made to obtain operating experience.

Table I—Salient Line Characteristics

	Glenlyn-Roanoke	Roanoke-Danville
Number of circuits	2	1
Bottom conductor above ground	64 feet	64 feet
Conductor vertical spacing	13 feet	13 feet
Conductor horizontal spacing	21.8/26.8 feet	21.8/28 feet
Number of ground wires	1	1
Vertical height of ground wire above top cond.	10	10
Tower type	both 2 circuit steel, vertical configuration	
Number and spacing of insulators, single suspension	10—4³/₄	10—5¹/₈
Impulse flashover (see ref. 4) (1 × 5 microsecond pos. wave) of suspension string	910 kv	1,050 kv
Same except (1¹/₂ × 40 microsecond pos. wave)	750 kv	865 kv

The first of these designs, the so-called parallel mounting, consisted of a tube assembly mounted parallel to and on the insulator string with the 2 tubes still assembled as one unit. An installation of this assembly on a single suspension insulator string is shown in figure 3 and a full tower installation is shown in figure 2. It will be noticed that very little new hardware was required in this assembly and that no previously existing clearances on the tower were in any way affected by the installation. The second of these designs is the so-called *V* mounting and is also mounted on the insulator string; it is shown in figure 4 for a single suspension assembly, in figure 5 for a double suspension assembly, and in figure 6 for a double dead-end assembly. Here the tube is broken up into 2 parts, with the gap at the center instead of at the end as in the case of the parallel and 30 degree assemblies.

Preliminary Tests of Tubes. After the possibilities of the tube were indicated by field experience of Pittman[6] in 1930 on a 110 kv line, some laboratory work was done in exploring the device in lower voltage fields. In the 132 kv field little had been done. Before the installation of the tubes on the lines of the American Gas and Electric Company, considerable experimental work was done to determine the electrical suitability of the device under the particular conditions imposed by this 132 kv system.

In September 1932, experimental tubes were tested[1] on this 132 kv system, and performed successfully. The above mentioned *V* and parallel assemblies having been decided upon after these initial field tests, further laboratory tests were made in March 1933 with tubes mounted on actual insulator assemblies to determine the tube protective features with impulse and 60 cycle voltages, under both wet and dry conditions. The tubes finally designed, as a result of the above tests, were again tested at Glenlyn on the 132 kv system in March 1933, with satisfactory results. In summary, these preliminary tests showed: That the tube was capable of interrupting the maximum 60 cycle current it was possible to obtain on test at the proposed location, namely, 6,700 amperes crest; and that the tube, by normal functioning, would protect the minimum line insulation consisting of a 10 unit insulator string of 4³/₄ inch units, under 60 cycle voltage wet and dry conditions, and also under the fast and slow positive impulse waves obtainable in the laboratory, likewise under wet and dry conditions. The few negative impulse tests made at the time did not indicate that the tube performance would be materially different under negative impulse voltages.

Field Installation of Tubes. One circuit of the Glenlyn-Roanoke 65 mile, 2 circuit line was equipped with tubes in 1933, the installation being completed July 1. Tubes were placed on each of the 3 phases at every tower of 1 circuit (number 1) only. The

installation of tubes on the Roanoke-Danville 68 mile, single circuit line (actually broken into 2 line sections—Roanoke-Fieldale and Fieldale-Danville) was completed on April 10, 1934. Here also tubes were installed on each phase at each tower. Some of the salient characteristics of both lines which have been presented before[5] are summarized in table I.

Types of Tube Mounting. The types of tube mounting—*V*, parallel, and 30 degree—used on these lines in the actual field installations are given in table II. Of the 1,713 assemblies, 54 were 30 degree assemblies merely to obtain some operating experience with this type, 831 were parallel assemblies, and 828 were *V* assemblies. In all cases *V* assemblies were used exclusively on double suspension and double dead-end insulator strings.

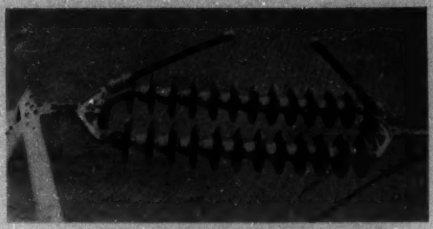

Fig. 6. Expulsion protective gaps on a dead-end assembly after external flashover

Note burned spots on tube where attached to tube fittings. The tube is still serviceable although showing burning of hardware and tube exterior finish

Operating Experience With Tubes

Procedure for Determining Tube Operation. After the installation of the expulsion protective gaps, close attention was given to their operation in service. On the Glenlyn-Roanoke line, surge crest ammeters[2] were installed on all tower structures, and on counterpoises, where used, to determine, in so far as possible, the character and severity of lightning conditions to which the line was subjected. Indicating targets over the vents of the tubes themselves gave information as to whether or not a tube had functioned in service. In addition, during the past lightning season, a crater lamp oscillograph[3] was in operation at the Roanoke station, and was connected to measure the 3 line currents in the Glenlyn-Roanoke number 1 tube-equipped line, 2 line currents in the Roanoke-Danville line, and the voltage from one phase to ground. This instrument, which is initiated in about 20 microseconds, in combination with the permanent magnetic oscillograph at Glenlyn (which initiates in about 0.5 cycle), and the other test and measuring facilities mentioned above, has given much valuable data on tube performance in service under lightning conditions. Periodic physical inspections of each tower made by climbing the tower also were made throughout the season.

Fig. 5. "V" mounting. 132 kv expulsion protective gap assembly on double suspension insulator string on Glenlyn-Roanoke line

Tube Operations. The record of tube operations, as indicated by the targets over the vents, is given in table III. Targets indicated by reason of tower vibration, wind, or other extraneous causes have been excluded. A total of 262 normal tube operations was found, 246 of which occurred during 1934 when both lines were in service for practically the entire lightning season. During 1934, which was considered a heavy lightning year in the territory where these tubes were installed, approximately 15 per cent of the tubes were found to have functioned once. In only 5 cases were tubes found by targets to have functioned twice during the year, and none more than twice. Based on the 1934 record of both lines, the tube operations found by targets averaged 1.85 per mile of line per year, and were observed on 28 per cent of the towers.

External tube arc-over was found on 17 tubes,

Table II—Types of Tube Mounting Used on 132 Kv Lines

	Glenlyn-Roanoke	Roanoke Danville	Total
30 degrees to vertical—single suspension	54	0	54
V—dead end	249	150	399
V—single suspension	48	234	282
V—double suspension	78	69	147
Parallel—single suspension	381	450	831
Total assemblies	810	903	1,713

Fig. 7. 132 kv expulsion protective gap operations during multiple lightning stroke on Roanoke-Danville line

11 tube discharges resulted from 8 repeated strokes occurring within 26.5 cycles

Tube discharges from last stroke not shown in this part of record

Crater lamp oscillograph record number 73

Recorded at Roanoke

which is 1 per cent of the tubes in service, and 7 per cent of the tube operations indicated by target. These arc-overs involved 14 towers and are believed to have caused 12 line tripouts, 9 on the Glenlyn-Roanoke line and 3 on the Roanoke-Danville line. The reason for these external tube flashovers has not as yet been fully explained, although in one case at least it is known that a tube flashover took place under rain conditions far more severe than any generally accepted wet test prescribed by A.I.E.E. standards. It is hoped that the study now being carried on to improve the impulse flashover characteristics of the tube will completely overcome this difficulty, the absence of which would probably have resulted in a 100 per cent lightning-proof line on these 2 trial lines during their first complete year of tube operation.

Power Current Interrupted by Tubes. A determination of the actual power current interrupted by the tubes in service was attempted by analysis of the oscillograph records. The maximum estimated currents which any tube was called upon to interrupt are given in the third column of table IV. Of some 120 current records obtained on the crater lamp oscillograph, the above are typical and include those of highest magnitude observed. Since interpretation of the data requires not only coincident oscillograph records at both ends of the line, but also a knowledge of the location on the line where a tube has operated, whether more than one tube on a given phase has operated, and other detailed information, an exact statement of actual currents interrupted is impossible. From the records available, however, it appears the tubes have successfully interrupted power currents as high as 3,500 amperes crest (2,500 amperes root mean square) which is 25 per cent in excess of the rating of the affected tube, assuming a single tube interrupted this current. This record is interesting in view of the fact that no tube has failed mechanically due to its inability to interrupt the current it has been so far called upon to handle.

Table III—Tube Operations in Service

By Target Indication

	Number of Tube Operations		
	Glenlyn-Roanoke[1]	Roanoke-Danville[2]	Total
1933			
30 degree tower mounting	0		0
V mounting	14		14
Parallel mounting	2		2
Total, 1933	16		16
1934			
30 degree tower mounting	0		0
V mounting	51	55	106
Parallel mounting	39	101	140
Total, 1934	90	156	246
Towers affected	56	104	160
Tubes externally arced over	12	5	17
Towers with external arced-over tubes	11	3	14
Total towers on line	270	300	570

1. Tubes on this line in service July 1, 1933.
2. Tubes on this line in service April 10, 1934.

Multiple Lightning Strokes. Although a detailed discussion of the theory of multiple lightning strokes is outside the scope of this paper, some data along this line have been obtained in the investigation of the performance of the expulsion protective gaps during the past year which have considerable bearing upon judgment of the tube performance. Some of the oscillograph records obtained indicate multiple strokes varying in number from 2 to 8, within a period of 2 to 26.5 cycles. These records are summarized in the last 4 columns of table IV. The record of 8 separate strokes obtained on the crater lamp oscillograph at the Roanoke end of the line during one lightning disturbance is shown in figure 7. The simultaneous record, not shown, on the magnetic oscillograph at Glenlyn indicated that the eighth lightning stroke occurred 26.5 cycles after the first stroke. While the records show as many as 8 discharges, it is, of course, not certain that any one tube is subjected to all the discharges, in some cases the tube passing current being on a different phase, or phases, at successive strokes. Again, it must be remembered that it is impossible to conclude definitely from the records obtained whether or not the stroke initially contracted the line at or near one tower and finally ceased at or near another tower. This might be possible within a period of 26.5 cycles. At any rate, such multiple strokes indicate that a given tube may actually be functioning a greater number of times than will be shown by the target indication on the tube. This point should be kept in mind when considering the limitation of tube life from internal erosion.

Another interesting record of a multiple stroke

which produced an outage of the tube equipped Glenlyn-Roanoke line is shown in figure 8. This record was obtained on the magnetic oscillograph, and therefore fails to show the power current at the start of the stroke. However, 3 separate strokes are clearly shown, occurring from 3 to 10 cycles after the first stroke which apparently initiated the oscillograph. On the occurrence of the second stroke, phases 1 and 2 of the number 1 tube equipped line faulted to ground, the tube clearing the fault on phase 1 in a half cycle, but the fault on phase 2

Table IV—Power Current Interrupted by Tubes, and Multiple Lightning Stroke Characteristics

From Crater Lamp Oscillograph Record

	60 Cycle Crest Amps.		Multiple Stroke Record			
Ref. No.	Measured at Roanoke	Estimated through Tube	Successive Strokes	Max. No. per Tube[1]	Cycles First to Last Discharge	Cycles Between Strokes
23	850	3,500	2	1	9	9
40	1,150	1,500	2	2	9	9
43	1,550	2,000	2	2	2	2
48	1,130	1,500	4	3	12 1/2	2 to 7 1/2
49	1,900	2,500	2	2	3	3
51	2,600	3,000	2	2	2 1/2	2 1/2
57	1,650	2,000	3	2	9	2, 6
72	1,720	2,000	2	2	3	3
73	2,100	2,500	8	6	26 1/2	1 1/4 to 9 1/2
80	600	750	3	3	20	3, 16

1. Assuming one tube interrupted all currents indicated by the oscillograph on a given line conductor.
No tube failures or line trip-out during above tube operations.

developed into a short circuit which was finally cleared by the line circuit breakers. However, before the circuit breakers opened, a third stroke took place to phase 1, which was cleared by the tube, and after another 4 cycles, the fourth stroke faulted phases 1 and 3, clearing on phase 3 but developing into a short circuit on phase 1. This record shows the type of service to which a tube may be subjected in service and indicates that actual tube operations may considerably exceed those indicated by targets.

Lightning Currents in Tube and Stroke. A

Table V—Lightning Currents Through Tubes and in Lightning Stroke:

Calculated From Field Records of Lightning Currents in Tower Legs

		Crest Amperes			Tube Operations	
			Calculated[1] in			
Ref. No.	Tower Foot Resist. (Ohms)	Measured in Tower Legs	Each Tube	Lightning Stroke	Location (Top, Mid., Bot.)	Successful or Not
2	85	−28,000	11,000	38,000	TM-	Yes
7	24.5	−29,000	12,000	33,000	-B	Yes
8	11.0	−38,000	15,000	45,000	-M-	Yes
10	35.0	−30,000	12,000	40,000	-MB	Yes
11	39.5	−26,000	12,000	40,000	TMB	Yes
14	10.0	−64,000	26,000	86,000	TM-	Yes
24	28.5	+28,000	11,000	32,000	-M-	Yes
25	14.0	+64,000	29,000	100,000	TMB	Yes
26	14.0	−38,000	17,000	59,000	TMB	Yes
28	27.5	+29,000	12,000	39,000	TM-	Yes
33	6.5	−40,000	16,000	54,000	-MB	Yes
35	12.5	−83,000	37,000	130,000	TMB	Mid. flashover
40	8.0	−52,000	23,000	80,000	TMB	Mid. flashover
43	12.3	−57,000	26,000	88,000	TMB	Yes
45	41.5	−30,000	12,000	35,000	T-	Yes
52	16	−34,000	15,000	53,000	TMB	M. & B. flashover

1. Based upon traveling wave theory.

knowledge of the actual current conditions imposed on a tube in service is important in determining whether or not the tube is performing as expected, and also serves as a basis for determining its performance limits. It is known that if an impulse current of sufficient magnitude is passed through a tube, the tube will fail mechanically without the presence of 60 cycle follow current. To determine the range of lightning currents which the above tubes probably handled—and from the records passed successfully—a group of lightning currents obtained on tower legs by surge crest ammeter readings has been analyzed as shown in table V.

In this analysis, only tower currents above 25,000 amperes have been taken, and it has been assumed that these currents are the result of direct strokes to the tower top or to the ground wire close to the tower. The stroke current is assumed to travel to the tower where it seeks various paths, over the insulator strings to line conductors—where tube operations were indicated—through the tower to ground, and continuing along the ground wire, all according to the laws of traveling waves.

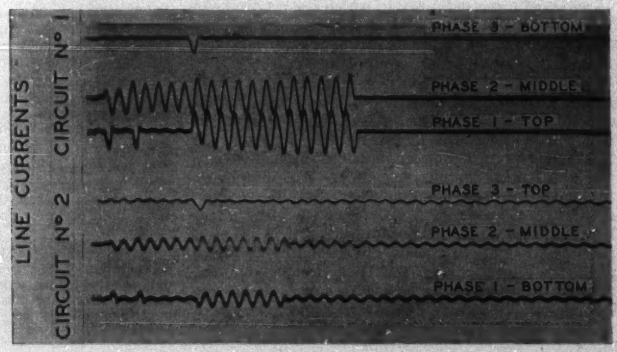

Fig. 8. Single circuit outage due to lightning

Glenlyn-Roanoke 132 kv double circuit line, June 26, 1934, 3:35 p.m. Automatic oscillograph record number 888. Recorded at Glenlyn plant

The results of this analysis (table V) indicate that an individual tube may have passed as high as 37,000 amperes of lightning current; and the probable stroke current was as high as 130,000 amperes.

While the type of data available does not warrant precision calculations, general considerations of lightning wave shapes and points of inception on the line permit the conclusions that the tube currents may be only about $^1/_2$ the values given, and the stroke current some 60 per cent above the values given in table V. The general order of currents involved in the stroke itself, therefore, is in agreement with more recent theory and with more recently reported field results.

Table VI—Outages Caused by Lightning, Glenlyn-Roanoke and Roanoke-Danville Lines

Year	Glenlyn-Roanoke No. 1[1]	Glenlyn-Roanoke No. 2	Glenlyn-Roanoke Nos. 1 and 2	Glenlyn-Roanoke Total	Roanoke-Fieldale[1,3]	Fieldale-Danville[1,5]
1926	6	6	4	16		
1927	13	8	3	24	9.5	7.9
1928	2	3	2	7	7.6	6.3
1929	13	6	10	29	12.1	10.1
1930	5	1	5	11	17.5	14.5
1931	7	8	15	30	13.7	11.3
1932	2	2	2	6	4.5	3.8
1933	1[2]	3	2[2]	6	9.7	8.1
1934[4]	8	7	1	16	1	2[4]

1. Prorated for these line sections from 1926 to 1933 when part of Roanoke-Roxboro line.
2. These occurred before tubes were installed on number 1 line.
3. Record to October 15. Tubes on all 3 lines.
4. Three additional trip-outs apparently caused by trouble on 33 kv side of power transformer.
5. Expulsion protective gaps on this line during part of 1933 lightning season and all of 1934.

Line Outages. As the main purpose of the tubes is to prevent line flashovers and resulting outages, the operating record of the 2 lines is perhaps the most pertinent factor. This is given in table VI. Since the Roanoke-Fieldale and Fieldale-Danville lines were originally a continuous part of the Roanoke-Roxboro 98 mile line, the outage records from 1927 to 1933 have been prorated on a length of line basis. While this procedure is open to criticism, it is practically the only way in which the relative performance of the Roanoke-Danville line can be compared before and after the tubes were installed. Line outages on the tube equipped (number 1) Glenlyn-Roanoke line in 1933 were eliminated, as were also the double circuit outages. Previous to 1933, the single circuit outages on this line averaged 6.8 yearly, and the double circuit outages 6 yearly. In 1934, the corresponding single circuit outages were 8 and the double circuit outages 1. All outages on the tube equipped line this year, 1934, have been attributed to external flashover of the tube under lightning conditions, a situation which it is believed possible to improve vastly, and probably to eliminate, by alterations in the tube design. On the number 2 line, not equipped with tubes, there were 7 single circuit outages against an 8 year average of 4.6 previously.

On the Roanoke-Fieldale line there was one outage in 1934 against a 7 year previous average of 10.6; and on the Fieldale-Danville line there were 2 outages in 1934, against a 7 year previous average of 9.0. Here again, the 3 outages this year were attributed to external flashovers of tubes under lightning conditions.

Thus it is seen that while the expulsion protective gap, in its present stage of development for use on 132 kv lines, has not rendered the line lightning-proof, it has very materially reduced service outages without deleterious effects on the system as a whole, or on any part of the line itself.

Tube Maintenance. The maintenance work so far done on the tubes installed consists of a complete repainting of all tubes on the Glenlyn-Roanoke line after about one year's operation. Since the performance of fiber subjected to voltage stresses and leakage currents of the order existing on the tubes as actually installed is not known, it was considered desirable to recoat the exposed surface of the fiber. The exterior finish of the Roanoke-Danville tubes, which is an improvement over the Glenlyn-Roanoke tubes, has not as yet shown sufficient deterioration to consider refinishing. More experience is needed to determine the maintenance problems which will be encountered during the life of the tubes.

Summary and Conclusions

From the record presented and other data not given here, the following features of the expulsion protective gap and its application to 132 kv lines are outstanding:

1. The expulsion protective gap appears to be an effective device for preventing lightning flashover of a line and reducing line outage.

2. In service it has successfully interrupted power currents within its rating, without any signs of weakness or distress. In practically every case, where records were obtained, it has interrupted the power current in one cycle or less.

3. A practical method of applying the tube to vertically configurated 2 circuit lines has been worked out which avoids cluttering up the tower structure, and still maintains normal clearances.

4. The present design of tube can be applied to existing high voltage steel tower lines without structural or insulation changes, unless the present line insulation is abnormally low.

5. In its present form and state of development, the tube will doubtless require some maintenance to keep it in the best operating condition. The weathering qualities of the tube are still unknown and may have to be improved.

6. The impulse flashover characteristics of the tube must be improved if it is to render a line lightning-proof. This improvement seems at present feasible, although it may require considerably more data on the characteristics of natural lightning before it is fully attained.

7. Close watch on the tube performance in the field, combined with a detailed study of lightning conditions under which the tubes operate, will doubtless result in more rapid development of the tube as a practical device for mitigation of lightning troubles on lines and equipment.

8. Multiple lightning strokes may have to be considered in estimating the expected life of the tube; as many as 8 successive discharges were recorded in one stroke within a period of 26.5 cycles. Only 2 per cent (5) of the tubes which functioned, as evidenced by the targets, operated on more than one occasion (multiple strokes not included).

9. Tubes have successfully discharged lightning currents, according to calculations based upon field data, of an order as high as 37,000 amperes. Lightning stroke currents in the order of 200,000 amperes have been indicated.

10. The lightning outage record of the 2 lines equipped with expulsion protective gaps has shown a vast over-all improvement; there were no 2-circuit outages on one line in 1933, and only one in 1934.

11. Although the tubes have not given 100 per cent perfect performance in their first full year of operation they have really performed as well as was expected. It is believed that, considering their present trial stage of development, they have, on the whole, performed creditably.

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Transient Voltages on Bonded Cable Sheaths

Field experience and tests show that unexpectedly high transient sheath voltages occur during the switching of charging current in single-conductor cable-type bus leads and in underground single-conductor power transmission cables bonded to eliminate sheath losses. No sheath troubles from these voltages have been found. Theoretical analysis of these voltages is presented together with suggested methods for protection of equipment, when the latter is necessary.

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IN ORDER to eliminate sheath losses on single-conductor lead-sheathed cables on 3 phase circuits, it is common practice to interrupt the continuity of the metallic sheath at intervals by the use of sheath insulators and to bond the sheaths in a variety of ways.[1] This procedure results, first, in reduction of cable size or installation cost, and second, in reduction in operating line losses or charges. Several years of successful operation in Chicago and elsewhere with Kirke-Searing cross-bonding, or H & M series transformer bonding, or other types of bonding, failed to reveal any evidence of transient voltages appearing on the sheaths, or any harm therefrom. Although theoretical considerations had indicated the possibility of such transient sheath voltages, no operating experience had shown the need for an investigation. The existence of such voltages was first indicated by the flashover of sheath insulators on 3,000,000-circular-mil lead-covered armored cable used as part of the metal clad switching bus at the Waukegan station of the Public Service Company of Northern Illinois during switching, and later by the failure in service of a few sheath-bonding transformers, which had less insulation than transformers previously used elsewhere, on one 66 kv line of the Commonwealth Edison Company, Chicago. Field tests were made at both locations to determine the cause and nature of such transients, and how to render them innocuous. F. O. Wollaston of the Commonwealth Edison Company was of considerable assistance in the preparation of the paper.

In the tests made in Chicago on 66 kv lines and at Waukegan station on the 132 kv switchgear, it should be noted that the data are incomplete and very rough because (*a*) the voltages were random; (*b*) measurements were made with roughly approximate devices; and (*c*) little data were obtained on conductor surges. For these reasons and because field conditions are too complex for any but a qualitative theoretical analysis, the following conclusions must be considered as tentative:

1. Surge voltages as high as about 30 kv across insulators or about 15 kv to ground may be produced on underground cable sheaths by the switching of charging current, particularly on deënergizing the line. Sheath voltages are highest near the switching end of the line. They are substantially less at distances of a few thousand feet from the switching end, and are negligible at the far end of the line. On short cables forming part of switching structures the sheath voltages may be considerably higher.

2. High transient sheath voltages can be caused by either traveling waves or oscillations on the cable conductor. Both are usually present, the disturbance starting as a traveling wave on the conductor but quickly changing to a damped oscillation. The latter contains most of the surge energy since it may last several hundred microseconds and is fed constantly by the switching arc.

Full text of a paper recommended for publication by the A.I.E.E. committee on power transmission and distribution, and scheduled for presentation at the A.I.E.E. winter convention, New York, N. Y., Jan. 22–25, 1935. Manuscript submitted Oct. 6, 1934; released for publication Nov. 5, 1934.

1. For all numbered references see list at end of paper.

3. Oscilloscope data obtained 1 mile from the switching end of one line showed that about 90 per cent of the sheath surges were oscillatory; the surge recorders, many of which were near the switching end, on several lines showed that nearly half of the surges were unidirectional or highly damped oscillations.

4. Field experience and tests indicate: (*a*) that these potentials do *no* harm to cable sheaths or sheath insulators; and (*b*) that where necessary for equipment, they may be reduced to harmless proportions by the use of simple protective devices or adequate insulation may be provided to withstand them at little expense.

5. Voltages at any given point for a particular type of bonding are dependent to a large extent on the bonding connections existing elsewhere on the line.

6. Because of the diversity of bonding connections and the physical differences in the several lines tested, the measured sheath voltages for the different types of bonding are not directly comparable.

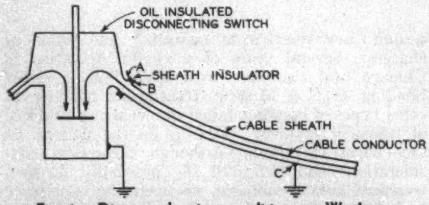

Fig. 1. Diagram showing conditions at Waukegan station bus; cable lengths were 30 to 85 feet

However, if the normal bonding connections are opened at 1 or 2 points on a line, then the transient sheath voltages may increase a few-fold at such points.

7. During switching of underground lines damped oscillations were observed having the following characteristics on the conductors and sheaths: (*a*) frequencies from 2,000 to 80,000 cycles per second, i. e., from 1 to 17 times the resonant frequencies of the conductors involved; (*b*) durations of from 100 to more than 800 microseconds; (*c*) maximum voltages on the conductors up to 3 times normal 60 cycle crest; and (*d*) associated calculated maximum conductor currents of 2,000 to 6,000 amperes.

8. Theoretical analysis indicates that transient sheath voltages resulting from conductor voltage oscillations would tend to increase as the line operating voltage increases and as the line length decreases, other conditions being equal.

9. Possible damage to equipment from sheath surges may be prevented by the following methods: (*a*) For high tension cable having lengths of a few hundred feet or less, shunt capacitors of 10 microfarads or more may be connected across sheath insulators; (*b*) for underground lines it appears preferable to provide adequate insulation for the insulators, the gaps in the sheath inside the insulators, and the bonding equipment to withstand transient sheath voltages. Protective shunts or arresters, if used, should be connected between sheath and ground.

10. No tests were made with impressed traveling waves known to be essentially unidirectional, so that no information was obtained as to the sheath voltages that might result from lightning surges entering cables with specially bonded sheaths.

Table I—Effect of Shunting Sheath Insulator at Waukegan Station

Switch Used: Oil Breaker	Switch Used: Oil Disc.	Shunt Across Insulator	Maximum Volts Across Insulator	Measured by
x		None	30,000	Flashover
	x	None	30,000	Flashover
x		1/2 ohm res.	<1,000	Surge recorder (Lichtenberg figure type)
	x	1/2 ohm res.	16,000	Surge recorder (Lichtenberg figure type)
x		1 ohm res.	<1,000	Surge recorder (Lichtenberg figure type)
	x	1 ohm res.	12,000	Surge recorder (Lichtenberg figure type)
x		14 μf	<45	Glow lamp
	x	14 μf	<45	Glow lamp
x		1 ohm & 14 μf	<45	Glow lamp
	x	1 ohm & 14 μf	<45	Glow lamp

Field Investigation on Waukegan Station Bus

The essential conditions encountered on the Waukegan Station bus are shown in figure 1. The circuit was interrupted either by an oil circuit breaker or by an oil insulated disconnecting switch. Inspections had shown that visual flashovers usually occurred only with the operation of the disconnecting switch. The distance from *B* to *C* along the cable was about 15 feet, while the distance from *A* to *B* around through the grounds and ground bus was about 45 feet. The flashover distance over the insulators was about $1^1/_4$ inches. The effect of bridging the sheath insulators with resistors or capacitors or both in parallel is shown in table I. In these tests, only charging current was interrupted, because the interruption of load currents had caused no high sheath voltages.

Tests with a magnetic type of oscillograph in the sheath circuit gave no voltage indications, showing that the transients were too short or the oscillation of too high a frequency to be measured. The resistors, when bridging the gap alone, became red hot.

Field Investigation on 66 Kv Lines in Chicago

The existence of high sheath voltages on specially bonded 66-kv lines in Chicago was indicated when internal short circuits were found in a few bonding transformers. Since the lines have no overhead con-

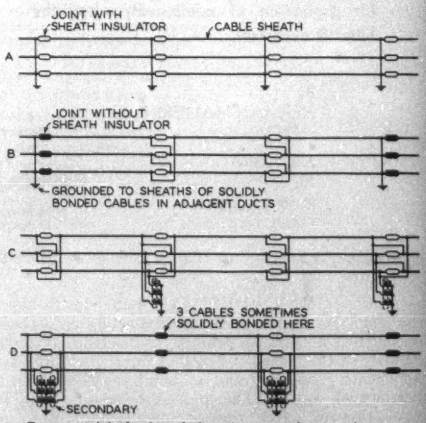

Fig. 2. Methods of bonding single conductor cables

A. One-end bonding. B. Kirke-Searing cross-bonding
C. Star bonding. D. H & M series transformer bonding

Table II—Surge Voltages Measured on Cable Sheaths of 66 Kv Line 6341 at 32d Street and Hamlin Avenue

Test location 3,480 feet from Crawford station. Adjacent bonding transformers were 1,000 and 992 feet toward Crawford and Northwest stations, respectively. Switching at Crawford end of line with Northwest end open (except in test 3). Line is H & M series transformer bonded throughout except for 2 Kirke-Searing cross-bonded sections adjacent to Crawford station and 1 one-end bonded length adjacent to Northwest Station

Test Conditions in Manhole					Surge Voltage Recorder Data, Highest Voltage Recorded in Kilovolts Crest*									Range of Approximate Data Obtained by Cathode Ray Oscilloscope Connected From B-Phase Sheath to Ground on Crawford Side			
			Capacitance, Microfarads		Northwest Side			Across Insulator			Crawford Side			Duration, Microseconds			
Test No.	No. of Switching Cycles	Series Transformer Connected	Resistance, Ohms Sheath to Grd.	Sheath to Grd.	Across Insulator	A ϕ Grd.	B ϕ Grd.	C ϕ Grd.	A ϕ	B ϕ	C ϕ	A ϕ Grd.	B ϕ Grd.	C ϕ Grd.	Kilovolts Crest	Front	Entire Surge	Frequency, Kilocycles
1	3	No.	None	None	None	6.3	9.3	7.6	17.8	15.4	12.7	7.2	8.4	7.2				
2	2	No.	None	None	None	7.2	8.9	8.0			12.7							
3	1†	Yes	None	None	None										0	—	—	—
4	3	Yes	None	None	None	—	6.3	—	3.0	12.7	—	—	8.0	—				
5†	2	Yes	None	None	None	—	—	—	2.6	6.8	—	T	8.9	—	½-3	20-190	100-750	Unidir. 20
6†	2	Yes	None	None	None	4.0	—	7.2	8.9	—	11.2	4.9	—	6.8	0-1¼	100-200	500-650	2
7	2	No.	33	None	None	5.3	4.4	5.6	14.2		14.2	4.9	5.6	5.3				
8	2	No.	None	2.0	None	3.7	2.5	2.6	7.2		9.3	2.6	—	2.8				
9†	2	No.	None	4.0	4.0	—	—	T	—		T	T	—	T				
10	3	Yes	17	None	None	—	—	—	2.8		—	—	2.6	—				
11	4	Yes	33	None	None	—	—	—	3.3		—	—	4.4	—				
12**	1	Yes	33	None	None	—	—	—	4.9		—	—	2.8	—				
13	3	Yes	None	2.0	None	—	—		2.6		—	—	2.5	—				
14	1	Yes	None	None	4.6	T	T	T	—	—	T	—	T	T	1	20	250	13
15†	2	Yes	None	None	6.9	—	—	—	—	2.6	—	T	T	—	1½-2	10-150	450-550	3-6
16	1	Yes	None	None	9.2	T	—	T	T	2.6	T	T	T	T	1½-2½	50	200-250	4.5-11
17	1	Yes	None	2.3	2.3	T	T	T	T	2.5	T	T	2.5	T	1½-3	50-60	200-400	5.7-6
18†	3	Yes	None	4.0	4.0	T	—	T	T		—	T	—	T				
19**‡	2	Yes	None	4.0	4.0	T	—	T	T		T	—	T	T				
20	1	Yes	None	4.6	4.6	—	—	T	—	—	—	T	T	—	½-3	30-40	200-350	Unidir. 10
21†	2	Yes	None	4.6	4.6	—	—	—	—	2.5	—	—	T	—	1½-3	40-50	350-600	4-8
22‡	2	Yes	None	4.6	4.6	—	—	—	2.5		2.5	—	—	—	0-1¼	40-50	500	3-23

* Where more than one surge was recorded on the same set of films, only the highest voltage is shown here. The letter "T" indicates a trace, less than 2.5 kv; a dash, no indication on film; and blank, no recording device connected.

** In tests 12 and 19, the 3 cable sheaths were bonded solidly together and to ground at a point 300 feet from the test location toward the Crawford end of the line.

† In these tests, observers heard audible discharges at each switching operation, indicating that external flashovers may have held some of the voltages to lower values than otherwise would have been the case.

‡ Switching small load.

nections except at the terminal bus structures, the possibility of these failures being caused by lightning was considered negligible. Examination of the transformers disclosed that there had been failures through layer insulation between approximately the end of the winding connected to the cable sheath and the end connected to ground. The puncture path was bridged with pitted and melted copper, short-circuiting the winding. The transformers that failed were of a relatively small lot of new design with less insulation than the much larger number of transformers that had operated successfully. All transformers were built to operate at a normal potential of 12 volts to ground.

Line 6341. The failures of the bonding transformers occurred on line 6341 between Crawford and Northwest Stations. The bonding is of the H & M series transformer type (see figure 2) except that one-end bonding is used for the Northwest terminal length and 2 complete sections of Kirke-Searing cross-bonding are adjacent to the Crawford terminal.

In the tests, the oil switch was opened and closed with the line open at the far end, except for a few such cycles of switching with load on the line. The sheath voltages were measured at a few locations by surge voltage recorders, supplemented by a cathode ray oscilloscope and neon glow lamps calibrated for surge voltages. The oscilloscope figures were watched by several observers, immediately drawn from memory by each man, compared, and a final figure agreed upon. Surprisingly good agreement was found between observers on the various characteristics of the figures.

Each glow lamp was coupled with a resistance voltage divider so that the lamp would glow when the applied voltage exceeded a certain definite minimum. A bank of lamps connected in parallel was used for each measurement each lamp being calibrated to glow at a different surge voltage. The approximate magnitude of voltage was indicated by the calibration of the lamps that glowed, if any. The surge voltage recorders were of the stationary film type used in the lightning investigation work in Chicago.[2] Each device contained 2 films for recording the direct and reverse polarity Lichtenberg figures of a unidirectional surge, combination figures being obtained for oscillatory surges.

Data are shown in table II for only one test location, but with different sheath connections and various protective apparatus. Data obtained at other locations on the Crawford half of the line during these tests were essentially similar.

Before attempting to draw comparisons between different connections and types of protection, it should be mentioned that the series bonding connections adjacent to the test locations in both directions were left undisturbed throughout the tests. For the open-end bonding tests 1 and 2 and also for tests 4, 5, and 6 of table II, as well as similar tests mentioned but not tabulated, the remote end of the sheath may not be considered as solidly grounded either in response to applied traveling waves or os-

Table III—Tests on 66 Kv Line 6313, Crawford Station to Fisk Street Station

Length of line 27,960 feet. Line is Kirke-Searing cross-bonded throughout except for 3 tunnel lengths at scattered locations having solid bonding. The 2 test locations were at the manholes with cross-bonding nearest the Crawford station end of 2 Kirke-Searing cross-bonded sections. The original bonding was not disturbed for these tests

			Voltages (Kv) Indicated by Surge Voltage Recorders and Glow Lamps†											
			Manhole No. 841, 170 Ft From Crawford Terminal (Lengths in Section Were 170, 366, and 146 Ft)						38th Street and Spaulding Ave., 5,280 Ft From Crawford (Lengths in Section Were 338, 338, and 366 Ft)					
			Crawford Side		Across Insulator		Fisk Side		Crawford Side		Across Insulators		Fisk Side	
Test No.	Switching Location	No. of Switching Cycles*	A ϕ Grd.	C ϕ Grd.	A ϕ	C ϕ	A ϕ Grd.	C ϕ Grd.	A ϕ Grd.	C ϕ Grd.	A ϕ	C ϕ	A ϕ Grd.	C ϕ Grd.
1	Crawford	3	6.8 (2) 6.0	8.0 (2) 12.0	22.0 15.4	18.2 25.0	7.2 10.4	8.9 8.0	3.3(2) 2.5	2.6 (2) 2.6	6.3 2.7	4.0 7.2	2.6 2.8	2.6 2.6
2	Crawford	3	8.0 (2) 6.8	8.0 (2) 8.9	19.7 20.4	12.3 20.4	8.9 7.2	7.2 8.0	2.7 (2) 2.8	2.5 (2) 2.6	4.0 5.3	3.3 4.0	2.5 2.6	2.6 3.3
3	Fisk	3	— —	(—) —	— —	— —	— —	— —	— —	(1) (1)	— —	— —	— —	— —
4	Fisk	3	— —	(—) —	— —	— —	— —	— —	— —	(—) —	— (0.5)	— —	— —	— —
5	Fisk	2			— —	(—) —	— —	(—)			— —	(1) —	(1)	

* Switching charging current only.
† Top figure represents voltage indicated by line side film; bottom figure is voltage indicated by ground side film. A dash indicates that no record was obtained; a blank, no recording device connected. Glow lamp voltages, shown in parentheses, are minimum surge voltages necessary to cause lamp to glow; in these tests the range of voltage that could be indicated was 0.5 to 2 kv.

cillations because of inductance and unknown "carry-over" voltage in the half coil induced from the other 5 half coils on the same core.

The test results must be accepted with caution because of the random nature of the voltages produced by the switching arcs, large inconsistencies in some of the data, probable reduction of some of the voltages by flashover (which voltages otherwise would appear with larger values in the tabulation), and the very rough methods used for measurements. Examples of inconsistencies are: (*a*) where the voltages across the insulators in tests 1, 7, and 8 exceed by a large percentage the sum of the voltages to ground on both sides—an impossible result; and (*b*) in test 5 where the surge recorder and oscilloscope data disagree greatly.

Complications such as unsymmetrical cable spacing, the position and nature of other cables in the conduit, the presence of sheet iron bands around the ducts, and the degree of wetness of the ducts and especially of the fireproofing material covering the insulators, have all been ignored. Similar remarks apply to data recorded in other tables and test results cited.

Subject to these limitations, table II presents several points of interest. A comparison of test 3 with other tests indicated that negligible sheath voltages appeared when switching was done with the line closed to the power transformer at the far end, whereas appreciable voltages generally appeared when switching charging current only. Table II also indicates that the highest voltages appeared when the series bonding transformer connections were open at the test location. With the transformer connected, the average voltages to ground and across insulators were reduced by about $^1/_2$ and $^2/_3$, respectively, although maximum voltages were decreased to a much lesser extent. In similar tests at other locations, not tabulated, the reduction of average and maximum voltages was more pro-

Table IV—Tests on 66 Kv Line 6342, Crawford Station to Northwest Station

Length of line is 55,600 feet. Line is star bonded throughout, except for 5 Kirke-Searing cross-bonded sections at scattered locations, 3 of which are adjacent to each other. The test section is the middle 1 of the 3 sections, and consists of 470, 473, and 395 foot lengths. Measurements of voltage were made at locations normally having cross-bonding

			Voltages (Kv) Indicated by Surge Voltage Recorders and Glow Lamps†											
			Elston and Warsaw Avenues (3,680 Feet From Northwest Station)								Elston and Wellington Avenues (4,150 Feet From Northwest Station)			
				Northwest Side		Across Insulators			Crawford Side			N.W. Side		
Test No.	No. of Switching Cycles*		Sheath Bonding Connections	B ϕ Grd.	C ϕ Grd.	A ϕ	B ϕ	C ϕ	A ϕ Grd.	B ϕ Grd.	Sheath Bonding Connections	A ϕ Grd.	B ϕ Grd.	Across Insulator of B ϕ
1	2		Open	2.7 (1)	7.2	6.3	6.8	12.7	2.7	3.3	Normal	2.6	—	—
2	1		Open	3.3 (2)	7.2	7.2	8.0	29.0	3.0	3.7	Normal	2.8	—	—
3	2		Normal	— (0.5)	—	—	2.5	—	—	—	Normal	—	—	—
4	2		Normal	— (0.5)	—	2.5	—	—	—	—	Normal	—	—	—
5	1		Normal	— (0.5)	—	—	2.5	—	—	—	Normal	—	—	—

* Switching charging current at Northwest Station.
† Glow lamp voltages shown in parentheses; a dash indicates no record obtained on surge recorder film.

Table V—Tests on 66 Kv Line 6314, Crawford Station to Fisk Street Station

Length of line is 27,990 feet. Line is series transformer bonded throughout, except for 1 one-end bonded length adjacent to Fisk Street Station and 4 Kirke-Searing cross-bonded sections at scattered locations. The test section is one of these latter sections and consists of 442, 461, and 490 foot lengths. Measurements of voltage were made at locations normally having cross-bonding

		Voltages (Kv) Indicated by Surge Voltage Recorders and Glow Lamps†												
		31st Street and Central Park Avenue (5,640 Ft From Crawford Station)								31st Street and St. Louis Avenue (6,100 Ft From Crawford Station)			
			Crawford Side		Across Insulators			Fisk Street Side			Crawford Side		
Test No.	No. of Switching Cycles*	Sheath Bonding Connections	A ϕ Grd.	B ϕ Grd.	A ϕ	B ϕ	C ϕ	B ϕ Grd.	C ϕ Grd.	Sheath Bonding Connections	B ϕ Grd.	C ϕ Grd.	Across Insulator of C ϕ
1	2	Open	2.5 (2)	2.6	6.3	4.9 (4)	3.3	2.6	2.5	Normal	—	—	—
2	1	Open	— (2)	2.5	5.6	7.2 (4)	6.3	3.0	2.6	Normal	—	—	2.5
3	2	Normal	— (1)	—	—	2.5 (2)	—	—	—	Normal	—	—	—
4	2	Normal	— (0.5)	—	—	— (1)	—	—	—	Normal	—	—	—
5	1	Normal	— (0.5)	—	—	— (2)	—	—	—	Normal	—	—	—

* Switching charging current at Crawford end.
† Glow lamp voltages are shown in parentheses. A dash indicates no record obtained on surge recorder film.
NOTE: The cathode ray oscilloscope data for conductor surges shown on figure 4 were obtained during tests 1 and 2, and during additional tests in which no sheath voltages were measured.

nounced. The voltages to ground across the transformer coils were restricted to values of about 9 kv or less even though the open circuit voltages reached values of 14 kv to ground or 33 kv across insulators (at test location near switching point). About the same reduction in voltage was secured by replacing the transformers with either resistors or capacitors alone of the values indicated in table II (see figure 3 for connections). Still greater reduction was obtained by using combinations of transformer and resistors or capacitors in parallel.

In one set of tests not recorded in table II, switching was done at both ends of the line. The average voltages to ground and across the insulators were about 10 kv and 20 kv, respectively, in manholes near the switching end, when the connections of the bonding transformer were open. The corresponding voltages with transformers normally connected were roughly 3 kv and 6 kv. In these tests, the transient voltages in manholes near the end of the line remote from the switching end were always less than the minimum (2.5 kv) that can be indicated on recorders.

Oscilloscope data indicated that a large majority of the sheath potentials were oscillatory, only 2 or 10 per cent being unidirectional. About 40 per cent of the recorder films indicated unidirectional surges; but this fact does not indicate that the remainder were definitely oscillatory, since for each film there were a few cycles of switching, and unidirectional surges of opposite polarity might have been recorded on the same film. At the same time, some of the indicated unidirectional surges may have been very highly damped oscillations, only the initial peak being indicated on the films.

The frequency of the oscillations observed on the sheaths of the 10 mile line 6341 varied from 2,000 to 23,000 cycles per second. The lengths of the wave fronts were from 20 to 200 microseconds, while the entire disturbances lasted from 100 to 750 microseconds. The highest voltage observed by oscilloscope from sheath to ground was 3 kv.

Line 6313. A series of tests was made on the 5 mile line 6313 which has Kirke-Searing cross-bonding *throughout* (see table III). Measurements were made on the terminal length at Crawford and about 1 mile away. The voltages at the latter location when switching at Crawford were about the same as those obtained at 32d Street and Hamlin Avenue for line 6341, which was about $^3/_4$ mile from Crawford.

When switching was done at the Fisk Street end of the line, the data confirmed the results obtained on line 6341, that is, the sheath voltages were higher near the switching end of the line and negligible voltages appeared at the far end. Likewise, when switching was done at Crawford, the sheath voltages for the cable length adjacent to the circuit breaker were 3 to 4 times as high as for the test location 1 mile from the Crawford end. The voltages for the terminal length at Crawford were, roughly, 10 kv to ground and 20 to 25 kv across the insulating sleeves.

Line 6342. Tests were made on 10 mile line 6342. (see table IV). The bonding is of the star type throughout, except for 5 sections of cross-bonding. The measurements were made at the middle one of

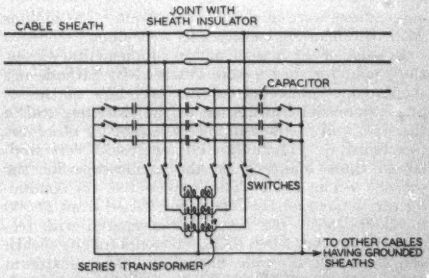

Fig. 3. Method of making connections to cable sheaths having H & M series transformer bonding

A typical test set-up is shown. In other tests, resistors were connected in place of, or in parallel with, the capacitors. Surge voltage recorders or other measuring devices were connected between various points in the circuit. Tests were made with switches open or closed

3 adjacent cross-bonded sections, about $^3/_4$ mile from the switching end. The sheath voltages with the cross-bonding connections in place were about $^1/_8$ as high as those for line 6313. The transient sheath voltages with the cross-bonding connections in place averaged about $^1/_4$ as high as with open bonding connections.

Line 6314. This line is 5 miles long and has series bonding, except for 5 scattered sections of cross-bonding. The sheath measurements were made on one of the cross-bonded sections about 1 mile from the switching end (see table V). The data show that the voltages to ground when the cross-bonding connections were in place, were about $^1/_2$ as high as when the bonding connections were open.

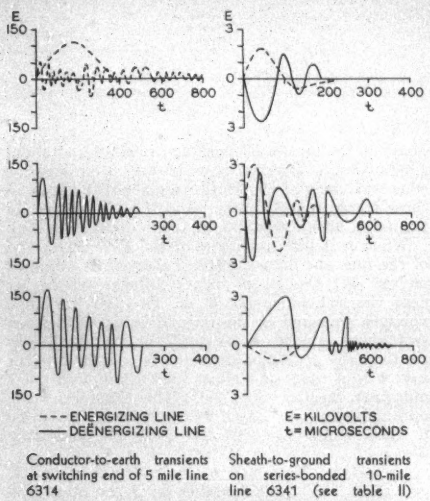

Fig. 4. Typical voltage transients on interrupting charging current of 66-kv underground cables

In some of these tests, and in supplementary tests, the conductor surges were observed by cathode ray oscilloscope connected to the secondary of the *C*-phase potential transformer at the switching end of the line, and oscillograms were drawn by observers (see figure 4). These show characteristics very similar to those observed on the oscilloscope for the sheaths of line 6341. The frequency of the conductor oscillations for the 5 mile line varied from 23,000 to 83,000 cycles per second as compared with frequencies of from 2,000 to 23,000 cycles for the sheath surges on the 10 mile line 6341. The maximum crest voltage was 165 kv from conductor to ground, or about 3 times normal. The oscillations produced by opening the circuit breaker tended to have higher frequencies and higher maximum values than those produced by closing the switch.

A few years ago tests were made of conductor voltage oscillations on a 5-mile 66-kv line similar to line 6314 with practically identical test connections and switching procedure. A magnetic type of oscillograph was used and oscillograms were obtained strikingly similar in general appearance to those reported by Berkey.[3] Damped oscillations of about 2,800 cycles occurred each time the arc restruck; this is about the natural resonance frequency of the line and power transformer. The magnetic type of oscillograph was too slow to record the higher frequency oscillations disclosed by the cathode ray oscilloscope in tests on line 6314. Probably both sets of frequencies, or a wide range, were present.

The data indicate that the sheath surges on line 6314 were of essentially the same nature as those on the other lines tested. Since the initiating surges on the conductor were predominantly oscillatory, it seems reasonable to conclude that the sheath surges on the specially bonded 66 kv lines in Chicago were caused mainly by the production of high-voltage high-frequency surges on the line conductors by switching charging current.

Sheaths and Sheath Insulators. Flashovers across the $1^1/_4$ inch outer surface of the Waukegan sheath insulators caused no perceptible damage. No flashovers or evidence of flashovers were observed during the tests or at other times on the Chicago insulators, which have external and internal leakage distances of $3^3/_4$ and $1^1/_2$ inches, respectively. Also, careful examination of lengths of single conductor cables removed from various lines has disclosed no perceptible damage to the sheaths from transient sheath potentials—a record confirmed by the power companies of New York, Philadelphia, and St. Louis, which have been using a great many sheath insulators. Similarly, no sheath damage has been found in Chicago from lightning potentials approximating 40 kv from sheath to ground.[2]

Theoretical Analysis and Discussion

Any disturbance initiated on a line having distributed electrical constants must be propagated initially along the line as a traveling wave. It can be shown (see appendix) that, regardless of the type of bonding, the transient sheath voltage for a traveling wave initiated on any one conductor will be highest at the first 1 or 2 bonding points. At these points the surge is divided into a multiplicity of surges on all conductors, sheaths, and "earth" (sheaths of other cables). In the ideal case for cross-bonding, or for series transformer bonding without solidly bonded points, the transmitted surges on the conductors can travel along the remainder of the line without either further reflection or further production of sheath voltages. In practice so many factors differ from those of the ideal case that residual sheath voltages will appear at every specially bonded point. The energy represented by these residual effects comes from the wave front of the conductor surge, and rapidly depletes the front as the wave travels along the line. Normal attenuation also is operative and the wave front becomes "stair stepped" and smoothed off to a long sloping front, which soon becomes a major fraction of the line length. Then the disturbance rapidly develops into a set of stand-

ing waves which are maintained by the sputtering arc and continue to oscillate at a variety of resonant frequencies natural to the line and connected apparatus.

This sequence of events becomes considerably more complicated when surges originate on all 3 phases. The cross-bonding or series transformer bonding connections couple the sheaths together and introduce a strong mutual effect between phases, although it would be much less for a line with open end or solid bonding throughout. Separate and nearly simultaneous arcs are drawn on the 3 line conductors. Different phase conductors and associated terminal apparatus probably have at least slightly different natural frequencies. The principal result of these circumstances is to introduce beat frequencies in the oscillations, an effect observed by Berkey.[3]

The action may be compared with the behavior of 3 similar violin strings linked together at unequal intervals by springs, and set in vibration separately and almost simultaneously. A wave first will travel down each string and then quickly develop into a complicated set of "standing waves" having natural and beat frequencies; in time the waves will die out because of the dissipation of energy. In the light of this analogy, the reasons for the following field observations become clearer:

1. In accordance with theoretical expectations, higher frequencies were observed on a short line than on a long line (see figure 4). The Waukegan bus leads were so short that the frequencies must have been about 1,000,000 or 2,000,000 cycles per second.

2. Switching load resulted in the smallest sheath voltages and energizing a line generally resulted in smaller voltages than deënergizing. When switching load at least one end of the line always is connected to terminal apparatus, which decreases the natural frequency and the sheath voltages and also introduces factors promoting rapid attenuation. When deënergizing a line the arc is more prolonged and both ends of the line are freed of terminal apparatus, resulting in higher frequencies and less dissipation of energy. It must be recognized, however, that these considerations may not hold when switching large loads, particularly if the power factor is low, since the switching arc may be more severe.

3. Sheath voltages measured by surge recorders in the first section adjacent to the switch and within a few hundred feet of the switch were larger than at locations a mile or so away and were negligible at the remote end of the line. Despite this the transformer failures in service and during tests were not confined to the first few sheath lengths adjacent to the switch, but were distributed somewhat uniformly along the 10-mile line; most of the switching was done at the Crawford end. Examination of the failures indicated pitting, melting, and bridging of copper across the puncture path, indicative of sustained large currents and not typical of surges.

Apparently the greater energy of the oscillating surges was responsible for the final breakdown of the windings. An internal flashover alone would have no effect on the serviceability of the transformer. The initial puncture might have been attributed to either traveling waves or oscillations. The former would be more probable near the switching end; the latter, however, might reach breakdown values almost anywhere except at the far end of the line. The locations of voltage maximums in the standing waves would depend on the frequencies of the oscillations, which varied widely.

4. Sheath voltages appearing at any given point on a line are determined by the kind of bonding on other portions of the line as well as at the point in question, just as in the analogy the amplitude of vibration of one string at any selected point is a function of the interlinkages along its entire length in addition to the interlinkage at the point in question. In particular, attention should be called to the fact that voltages measured at 1 or 2 points in the line with bonds removed as in these tests are not at all representative of the voltages to be expected on a line open-bonded throughout. So far as could be determined experimentally or theoretically, the behavior of the conductor and sheath circuits was consistent with theories advanced by Brinton, Buller, and Rudge[4] and discussion with reference to sheath potentials by Beck.[4]

5. Check calculations based upon the theory give numerical results of the right order of magnitude, which is all that can be expected. Definite checks with particular cases are not feasible, since each item of test data is a composite of 2 or more switching operations, making it impossible to distinguish between voltages resulting from oscillations and voltages resulting from traveling waves. It is reasonable to assume, however, that the sheath voltages at 32d Street and Hamlin Avenue on line 6341 (see table II) resulted mainly from oscillations, as indicated by the oscilloscope data. The frequencies averaged about 7,000 cycles per second. The crest voltage of the conductor oscillations may be assumed to have averaged about 60 kv, on the basis of the tests on line 6314 (see figure 4). The corresponding crest current from equation 4 (see appendix) would be about 2,000 amperes, since the surge impedance of the cable is about 30 ohms. The sheath voltage to ground for a 66 kv cable having one-end bonding is calculated (see appendix) to be 9 kv per 1,000 feet for 2,000 amperes and 7,000 cycles. In test 1, the sheath length was 1,000 feet and the measured voltages were 8.4 kv on B phase and 7.2 kv on A and C phases. The conditions were not strictly equivalent to one-end bonding, however, because of the presence of the transformer coil in the ground connection.

In the case of line 6313, where the sheath voltages adjacent to the switch were 300 to 400 per cent higher than at a location a mile farther away, it seems reasonable to assume that the surge recorder indications resulted mainly from the initial traveling wave. Although the crest voltage of the conductor surge might have been from 60 to 150 kv (1 to 3 times normal 60 cycle crest) only a small fraction of this would appear on the sheaths, even for the length adjacent to the switch, since the wave front of the surge would be quite slow. The measured sheath voltages to ground confirm this view, the values being about 10 kv for the terminal length, and 3 kv for the location 1 mile away from the switch.

In the case of the Waukegan bus, the traveling wave theory suffices to account for the occurrence of voltages high enough to cause insulator flashovers. The heating of the resistors to incandescence, however, was probably caused by sustained oscillations, since the initial traveling wave could hardly have contained the requisite energy.

Methods of Protection

In the light of the theoretical analysis, the results of the tests in which resistors and capacitors were installed to limit the sheath voltage may be discussed more intelligently. In the case of the Waukegan bus, the calculated mutual reactance between conductor and sheath is about 25 ohms. This in series with the impedance of the protective device shunted across the sheath insulator would be the major impedance of the sheath current circuit on which the impressed voltage was about 100 kv. The 1 ohm resistor probably had considerably higher resistance at the very high frequency under consideration, because of skin effect. If its effective resistance increased to about $3^1/_2$ ohms, which seems reasonable, then the calculated surge potential across the shunt resistor would check with the measured value of 12 kv (i. e., $100 \times 3.5/28.5 = 12$ kv). The 14 microfarad capacitor, however, would have an impedance of only 1/180 ohm at 2,000,000 cycles per second. When shunted across the insulator it would reduce the voltage to $100{,}000(1/180) \div 25$ or only 22 volts. The combination of resistor and capacitor in parallel would be slightly more effective. Tests showed that the potentials were less than 45 volts in these cases.

For conditions such as those at Waukegan, the insulators are protected most effectively by shunt capacitors of 10 microfarads or more. The method successfully adopted for reducing the transient sheath

potentials to safe values from the standpoints of personnel and equipment was to shunt each sheath insulator with a 15 microfarad capacitor in parallel with 2 1-ohm resistors.

The sheath circuits for the series and star connections used with bonding transformers in Chicago are much more complicated than the bus at Waukegan. To attempt to check theoretically the results obtained in the tests involving resistors and capaci-

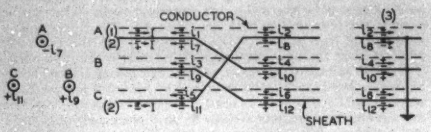

Fig. 5. Traveling wave at cross-bonded point

Numerals in parentheses refer to cases 1, 2, and 3 of text

tors on line 6341 would involve so many assumptions that the results would be worthless. However, it is easy to see in a general way why the shunt devices were much less effective than at Waukegan. In test 7, table II, a 33 ohm resistor was inserted between sheath and ground in the test manhole (bonding transformer disconnected) and the other end of the 1,000 foot sheath length was grounded through the bonding transformer coil. The average frequency of the induced sheath voltages was about 7,000 cycles and the calculated magnitude about 9 kv. Probably the resistor represented an appreciable fraction of the total sheath circuit impedance, since skin effect would increase its resistance and saturation would decrease the effective impedance of the transformer. The impedance of the unsaturated transformer coil would be about 120 ohms at 7,000 cycles (1 ohm at 60 cycles). Saturation would occur at about 1,800 volts. Thus a substantial part of the 9 kv impressed voltage would appear across the 33 ohm resistor. The 2 microfarad capacitor (test 9) would be more effective, having an impedance of only 11 ohms, but the voltage drop across it probably still would be a few kilovolts; tests indicated about 2.6 kv.

When the shunt devices are paralleled with the transformer, the combined impedance is appreciably less, thus reducing the voltage as indicated in table II. However, in order to reduce the voltages to satisfactory values, the impedance of the shunt protectors would have to be so small as to introduce undesirable characteristics, such as excessive heat losses at 60 cycles in the case of resistors or large physical dimensions in the case of capacitors. In addition, studies showed the installed cost of the shunts to be uneconomical.

The best solution of the problem of transformer protection appeared to be either some form of low voltage arrester or an increase in the strength of the layer insulation of the transformer windings. Suitable arresters or gaps could not be applied readily under Chicago conditions. The method of using ample insulation was adopted, since its feasibility and economy were demonstrated clearly by the satisfactory operating experience with the large majority of the bonding transformers which had sufficient insulation, and since the method did not require auxiliary equipment.

If external shunts are to be used for protecting the bonding transformers, they should be connected between phase and neutral rather than directly across the sheath insulator, since voltages may exist from sheath to ground even though none exists across the insulating sleeve.

Suggested Future Tests

Tests that might be made to supplement and check the results presented in this paper are as follows:

1. Determination of maximum sheath potentials adjacent to the switching end and some distance therefrom for short leads at terminals and for lines of various lengths that have various types of bonding.

2. Determination of the character of conductor and sheath transients by means of cathode ray oscillograms.

3. Determination of the nature and magnitude of surges on the conductors and on the sheaths of lines to which the following have been applied on 1 conductor and on all 3 conductors of a dead line: (*a*) d-c surge and (*b*) sustained oscillations of various frequencies from an oscillator. The sheath surges would be determined at several points along the line to see whether voltage or current nodes existed along the line. Also using the oscillator, resonant and beat frequencies as well as effective line impedance at such frequencies would be determinable for actual lines with all their complexities of sheath circuit conditions.

Table VI—Traveling Wave at Cross-Bonded Point

Ratio	Current and Voltage Ratios, Fig. 5: Cross Bond, Case 1	Cross Bond, Case 2	End of Section, Case 3
i_1/I	$2z/D$	$4z/D$	
i_2/I	$(8x + z)/D$	$-4z/D$	$(64x^2 + 3z^2)/D^2$
i_3/I	z/D	$2z/D$	
i_4/I	z/D	$2z/D$	$(24xz + 3z^2)/D^2$
i_5/I	z/D	$2z/D$	
i_6/I	z/D	$2z/D$	$(24xz + 3z^2)/D^2$
i_7/I	$4x/D$	$-3z/D$	
i_8/I	$4x/D$	$8x/D$	$64x^2/D^2$
i_9/I	0	0	
i_{10}/I	$4x/D$	$8x/D$	$-32x^2/D^2$
i_{11}/I	$4x/D$	$-3z/D$	
i_{12}/I	0	0	$-32x^2/D^2$
e_{AB}/I	$-2xz/D$	$4xz/D$	Bond Wire to Ground
e_{BC}/I	0	0	
e_{CA}/I	$2xz/D$	$-4xz/D$	
e_{AA}/I	$4xz/D$	$8xz/D$	Across Insulators
e_{BB}/I	$2xz/D$	$4xz/D$	
e_{CC}/I	$2xz/D$	$4xz/D$	

Note: $D = (8x + 3z)$.

Appendix

Traveling Waves on Cross-Bonded Lines

Let figure 5 represent a point on a line where the sheaths are cross-bonded. The cables are assumed to be equilaterally spaced and remote from earth. The surge impedance between conductor and sheath is x and between sheaths is z. For case 1, indicated by the solid-line arrow, the surge current I is assumed to be applied between A-phase conductor and sheath only and for case 2, indicated by the

dotted arrow, between sheaths of A- and C-phase cables. In either case the surge is split up into reflected and transmitted currents and voltages. Arbitrary signs are assigned to each pair of image charges. For example, the signs on the arrow for i_7 indicate negative charge on the sheath of A-phase cable, and the plus sign refers to that part of i_9 and i_{11} on the other sheaths corresponding to i_7.

The solutions for the currents i (see table VI) in cases 1 and 2 are obtained by use of Kirchoff's laws. These solutions show that the impact of the surge I cannot change the potential of the bond BC. The latter is taken as a reference point, and is considered to be at zero potential to earth. The voltage equations (see table VI) readily are obtained from the relation that the voltage of a surge is equal to the product of the current and the surge impedance.

With the solutions of cases 1 and 2 in hand, the progress of a surge I entering on A-phase conductor and traveling across a complete section of cross-bonding may be examined. The fractions of the original surge that finally reach the far end of the section (case 3, figure 5) are given in the right-hand column of table VI. Only the conductor currents i_1, i_4, and i_8 are transmitted into the next section, since the sheath currents i_9, i_{10}, and i_{12} are totally reflected at the solidly bonded point.

Numerical values for the currents are obtained by substituting values of 31.5 and 112 ohms for x and z, respectively The latter figure is approximate, since no data are available for the surge impedance of circuits in a medium consisting mainly of damp concrete and air. Upon substitution, i_2, i_4, and i_8 are found to be 30, 35, and 35 per cent, respectively, of the original surge current I. Thus only about 30 per cent of the energy of the original surge is transmitted

Table VII—Traveling Wave at Series Bonded Point

Current and Voltage Ratios, Fig. 6		
Ratio	Conductor Surge, Case (1)	Sheath Surge, Case (2)
i_1/I	$2xe'/3D$	$-ze'/D$
i_2/I	$1-2xe'/3D$	$-ze'/D$
i_3/I	$ze'/3D$	$-ze'/2D$
i_4/I	$ze'/3D$	$-ze'/2D$
i_5/I	$4xe'/3D$	$-(2xe'/D)+(1-e^{\prime\prime})$
i_6/I	$4xe'/3D$	$-(2xe'/D)+e^{\prime\prime}$
i_7/I	$2xe'/3D$	$-(xe'/D)+(1-e^{\prime\prime})/2$
i_8/I	$2xe'/3D$	$-(xe'/D)+e^{\prime\prime}/2$
i_9/I	$1-2e'/3$	$-2+(e'+e^{\prime\prime})$
i_{10}/I	$1-2e'/3$	$(e'-e^{\prime\prime})$
i_{11}/I	$e'/3$	$1-(e'+e^{\prime\prime})/2$
i_{12}/I	$e'/3$	$-(e'-e^{\prime\prime})/2$
e_{AA}/I	$4xze'/3D$	$-2xze'/D$
e_{BB}/I	$-2xze'/3D$	$xze'\ D$
e_9/I	$2xze'/3D$	$-(xze'/D)-ze^{\prime\prime}/2$
e_{10}/I	$-2xze'/3D$	$(xze'/D)-ze^{\prime\prime}/2$
e_{11}/I	$-xze'/3D$	$(xze'/2D)+ze^{\prime\prime}/4$
e_{12}/I	$xze'/3D$	$-(xze'/2D)+ze^{\prime\prime}/4$

NOTE: $D=(2x+z)$; $e'=e^{-2xz/3MD}$; $e^{\prime\prime}=e^{-z/3M}$.

into the second cross-bonded section, and is about equally divided between the 3 conductors.

The progress of the surge after it has become equally divided between the 3 conductors can be deduced from the equations by cyclical rotation of subscripts and additions. It is found that if dissipation is neglected the surge travels undiminished along the line, but the sheath potentials become zero everywhere. For cross-bonded lines under actual field conditions, therefore, it is concluded that:

1. A traveling wave (switching surge) starting between conductor and sheath of 1 phase of a 3-phase cross-bonded line would become about equally divided between the 3 cables in passing through the first cross-bonded section, equivalent to about 1,000 feet of line.

2. After passing the first cross-bonded section, only residual or differential voltages would appear on the sheaths, these being due to nonsymmetry of duct spacing, unequal cable lengths, unequal velocities of propagation inside and outside the sheath, etc.

3. Each cross-bonded section acts as a wave trap for the residual voltages and multiple reflections, and attenuation would cause a steep wave front to be "stair stepped" into a long sloping wave front in the first few thousand feet of line.

Traveling Waves on Series Bonded Lines

Analysis of the behavior of surges at locations having series transformer bonding (see figure 6) is complicated by the effects caused by the 3-phase iron-cored bonding transformer. Terms of the form $M\ di/dt$ are introduced to take account of the voltage drops across the transformer coils. The symbol M represents the flux linkage per coil, leakage flux being neglected. The internal and external surge impedances of the cable are represented as before by x and z. Solutions obtained by operational analysis are given in table VII for the following: case 1—rectangular surge applied between conductor and sheath of A-phase cable; case 2—rectangular surge applied between A-phase cable sheath and the sheaths of B- and C-phase cables in parallel.

The exponential terms in the current and voltage equations all reduce to 1 at time $t=0$ and to zero when $t=\infty$ so that investigation of particular cases becomes an easy matter. For equal surges on all 3 cables applied between conductor and sheath, it is found that no reflections occur at the transformers and the sheath voltages remain zero everywhere. For such a set of surges, therefore, the series transformer bonding is equivalent to cross-bonding. For surges not applied symmetrically, the transformer would become saturated rather rapidly and introduce substantial changes in the transients given by the equations in table VII, the principal result being a more rapid completion of the remainder of the transient.

Another interesting case is that of a surge between conductor and sheath of 1 cable accompanied by a surge only $^2/_3$ as large between the sheath of same cable and the sheaths of the other 2 cables in parallel. The combination is equivalent to (case 1 plus $^2/_3$ case 2). The front of the wave passes through the transformers without hindrance and at the first instant the potentials across all sheath insulators are zero. The potentials from sheath to ground, however, are not zero.

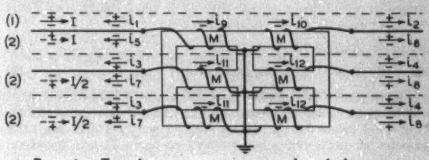

Fig. 6. Traveling wave at series bonded point

Numerals in parentheses refer to cases, 1, 2, and 3 of text

Hence, protective devices, if used, should be connected from sheath to ground. After the first instant a redistribution of potentials takes place.

These cases show the fallacy of the rather general impression that a concentrated inductance always completely reflects the front of a rectangular wave. In the bonding transformer the inductance is almost purely mutual, the self-inductance or leakage flux being

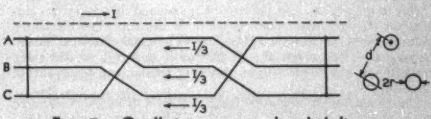

Fig. 7. Oscillation on cross-bonded line

negligible. Instead of the currents in the transformer coils being zero at the first instant, it is the energy stored in the magnetic circuit that must be zero. This is accomplished by the instantaneous occurrence of finite currents in the coils, having values governed by the external circuit except for the limitation that the magnetomotive force around each closed loop of the transformer core must be zero. The surge voltages across the coils likewise take up finite initial values depending on the initial distribution of currents in the external circuits. As the transient progresses, the voltages change in proportion to the rates of change of the currents in the coils. The expo-

nentials in table VII show that the initial conditions tend to persist longer for larger values of mutual inductance M.

The neglecting of the self-inductance of the transformers has been justified by considering the time constants of the transient effects that the self-inductance would produce. From test data on values of self- and mutual inductance it is found that transients due to the former would last only from $^1/_3$ to 2 microseconds, as compared with time constants of 40 to 2,000 microseconds for the transients in table

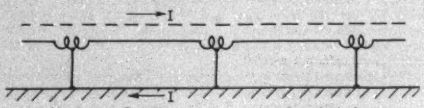

Fig. 8. Oscillation on series bonded line

VII due to mutual inductance. The only practical effect on surges of the closed secondary of the transformer is to reduce the self-inductance.

The solutions in table VII for currents and voltages readily are adapted for waves of any desired characteristics, as well as for those of simple rectangular form. Thus the progress of a surge passing through several transformers in succession may be investigated. It is found that regardless of the number of transformers encountered, no new exponentials enter the equations, so that the currents and voltages always may be expressed in terms of e' and e''.

Oscillations

An oscillating current on 1 conductor of a cross-bonded line is assumed to return about equally divided on the 3 sheaths (see figure 7). The induced sheath voltages are:

$$E_A = (^2/_3)2j\omega I \cdot \log_e(d/r) \quad (1)$$

$$E_B = E_C = -(^1/_3)2j\omega I \cdot \log_e(d/r) \quad (2)$$

The frequency reactance ω per 1,000 feet at 1,000 cycles is 0.192 and for 66 kv cables in Chicago the logarithmic term reduces to 1.71. Numerical values for the sheath voltages per 1,000 feet per 1,000 amperes at 1,000 cycles per second (see figure 7) are, therefore:

To Ground (Volts)			Across Insulators (Volts)					
			AA		BB		CC	
A	B	C	Left	Right	Left	Right	Left	Right
437	219	219	656	656	656	0	0	656

For any other cable length, frequency, or conductor current, the voltages may be found by direct proportion.

For series bonding (see figure 8) it is assumed that all return current for one conductor flows in earth or neutral. The calculated voltages per 1,000 feet per 1,000 amperes at 1,000 cycles per second become $E = 656$ volts, $E_A = 328$ volts, and $E_{AA} = 656$ volts, respectively, per sheath length, sheath to ground, and across sheath insulators.

The fundamental oscillation frequency for a cable short-circuited at one end is $f = 1/4\sqrt{LC}$. For cables having a permittivity (S.I.C.) of about 3.3, this reduces to

$$f = 25{,}000/L \quad (3)$$

where L is the length of the line in miles.

The maximum voltage and corresponding maximum current for each harmonic frequency of a standing wave or oscillation are related by the same expression as for traveling waves, that is:

$$E = IZ \quad (4)$$

where Z is the surge impedance. In the case of oscillations, however, the conductor current and voltage maximums are spaced alternately along the cable, whereas they are coincident for traveling waves.

From the foregoing data, the sheath potentials induced by oscillations may be calculated numerically for any underground line if the voltage of the oscillation is known or assumed.

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Application of Electron Tubes in Industry

Several of the circuits and principles of application of the various types of electron tubes in industrial control are considered in this paper. Principal consideration is given to the various types of photo-electric control, electron tube-reactor theater lighting control, electron tube motor control, and electron tube welder control. Principles intended as guides in the selection of the proper tube circuits are given.

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THE art of electron tube application is now several years old. During this period there have been evolved certain circuits and principles of application which, because of their peculiar fitness for the field, have almost come to be recognized as "standards." It is the purpose of this paper to discuss several of these circuits and to indicate typical applications in which they have found use. The observer will be impressed by the fact that electron tube control has made a place for itself in the industrial field by enabling things to be accomplished which are difficult or impossible to accomplish otherwise, and that as yet electron tube control has for economic reasons been unable to displace estab-

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lished apparatus except in a few instances. It is to be expected that electron tube control will encroach more upon the field of established apparatus when production volume has allowed unit costs to be reduced so as to meet competition with present methods.

Simple Photo-Electric Relay

The electronic device which has found the widest use up to the present time is the simple photo-electric relay. A device of this type utilizes the change in photo-electric effect caused by a substantial change in the light flux impinging upon its photo-electric tube to operate, through the proper amplifying equipment, a relay capable of handling the power required for the control function.

Since no power is required of an object to intercept a beam of light, and since the light beam cannot be damaged or worn out, this type of photo-electric relay is used in a large number of applications as a limit switch to control various electrical functions or as a production counter, responding to the presence of some object too light, or too fragile, or too heavy, or too hot, or too highly polished, etc., to permit satisfactory operation with ordinary mechanical switches.

These relays are used in automatic weighing processes; in steel mills to control automatic sheet catcher tables, conveyors in heat treating furnaces, the operation of rod or merchant mill shears, "kick-off" on "run-out" tables; in machines for grading ball bearings; for the automatic inspection of battery caps for vent holes and in many other applications.

A photograph of a typical relay of this type, removed from its case, is shown in figure 1, and its circuit diagram is shown in figure 2. This relay operates as follows: When terminal A of the transformer secondary is positive, both the triode amplifier tube and photo-electric tube anodes are negative, hence no current flows in either circuit inasmuch as electron tubes are inherently rectifiers. (No attempt is made in this paper to explain tube characteristics. The reader will find convenient the paper

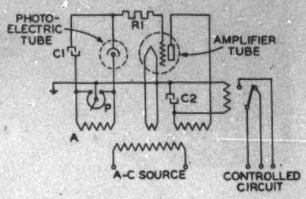

Fig. 2. Diagram of connections of the simple a-c photo-electric relay

"Electron Tubes in Industry" by W. R. King, A.I.E.E. Transactions, volume 50, 1931, pages 590–8.) However, if $C1$ be considered to have zero charge the grid of the amplifier tube will be positive when terminal A is positive and grid current, limited by grid resistor $R1$, will flow to charge grid capacitor $C1$ in the sense indicated on the diagram. Upon reversal of the a-c voltage, the amplifier tube and photo-electric tube anodes become positive, but the amplifier tube grid is negative by an amount equal to the charge of the capacitor plus the voltage from terminal A to the slider of potentiometer P, and, therefore, no current flows in the amplifier tube anode circuit. But if there be light on the photo-electric tube, current passes through it to the capacitor in the direction which tends to discharge the capacitor and charge it in the opposite sense. As the voltage across the capacitor decreases and finally reverses, the amplifier tube grid is made less and less negative with respect to the cathode and finally reaches a potential which permits current flow in the anode circuit. The current of the amplifier tube at first flows largely into the smoothing capacitor $C2$ inasmuch as the inductive effect of the magnetic circuit of the sensitive relay tends to maintain zero magnetic flux linkages in the relay coil at the beginning of current flow in the anode circuit. Shortly after anode current of the amplifier tube starts to flow the anode voltage of this tube again reverses and anode current stops. However, current flows in the local circuit composed of the capacitor $C2$ and the coil of the sensitive relay until the energy stored in that circuit is dissipated in the coil resistance. $C2$ is made sufficiently large that it is enabled to maintain continuous current through the coil of the relay between pulses of the amplifier tube anode current before the average value of the current in the relay coil reaches the value necessary to operate the relay. Hence, the relay has but small tendency to chatter at the critical average current value for pick-up. This complete series of events is repeated each cycle as long as there is light on the photo-electric tube.

With no light on the photo-electric tube, the action during the half-cycle when terminal A is positive is

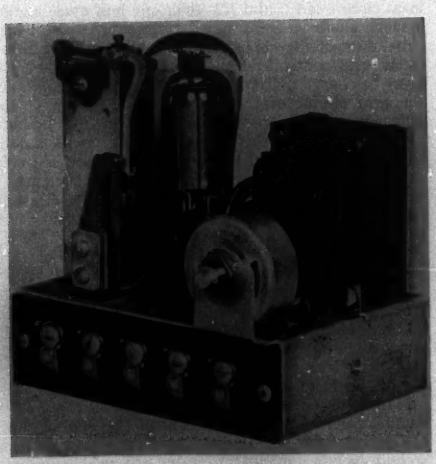

Fig. 1. Simple a-c photo-electric relay

the same as before. But in this case, when the a-c voltage reverses, practically no current flows in the photo-electric tube and therefore capacitor $C1$ is not discharged but maintains its negative charge and keeps the grid negative throughout the positive half-

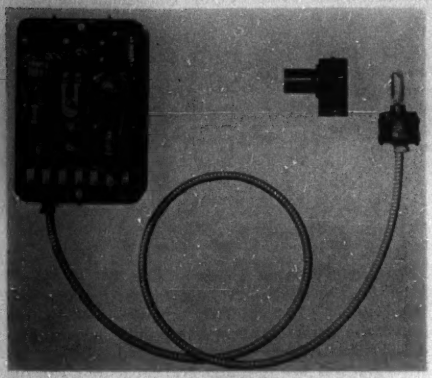

Fig. 3. Sensitive, high speed a-c photo-electric relay operating a grid controlled vapor discharge tube

cycle, thereby prohibiting flow of current in the amplifier tube anode circuit.

Adjustment of the circuit is accomplished by means of potentiometer P, the position of which determines how far capacitor $C1$ must be discharged by the photo-electric tube current to permit current to flow in the anode circuit of the amplifier tube. The average value of anode current of the amplifier tube is therefore determined by 2 factors: (1) The value of light flux impinging upon the photo-electric tube (the magnitude of photo-electric tube current is a function of the magnitude of the light flux); and (2) the potentiometer adjustment.

A relay of the type shown in figure 1 operates with a minimum illumination of 5 foot candles on the photo-electric tube and upon a 50 per cent change in light which lasts for not less than 0.066 second (assuming a 60 cycle source of power) and will operate up to 400 times per minute. Its contact tips are rated one ampere, noninductive, at 115 volts.

Sensitive High Speed A-C Photo-Electric Relay

Some applications require greater sensitivity or a somewhat greater speed of response than it is possible to obtain with the above relay. In these cases a relay of the type shown in figure 3 may be applied, especially if the device to be operated be a small solenoid or other small magnetic device which may be operated directly from the grid controlled vapor discharge tube in place of the contactor shown, thus saving the time required to operate the magnetic relaying contactor. That is, the relay of figure 3 employs the photo-electric tube amplifier circuit of figure 2 to operate a grid controlled vapor discharge tube. Hence, since an arc discharge of a grid controlled vapor discharge tube will establish itself within a few microseconds after its grid receives the tripping impulse, power is applied to the relaying contactor or operating solenoid in minimum time (for an a-c circuit).

Relays of this type are used in tooth paste tube machines to align properly the end crimp with the printing on the tube, in steel mills to respond to radiant energy from hot bodies, and in slow speed package wrapping machines to insure correct register of the printed matter upon the wrapper to the package.

The circuit of this relay, shown in figure 4, operates as follows: As before, an increase in light on the photo-electric tube causes an increased average

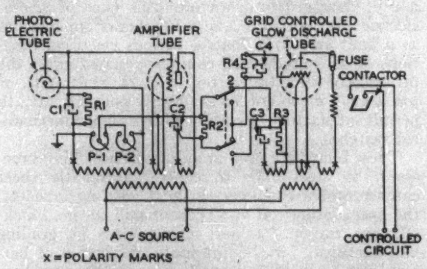

Fig. 4. Diagram of connections of the relay shown in figure 3

plate current flow through the amplifier tube, but due to the a-c circuit and to the time constant of the local circuit of $C2$ and $R2$ (over one-half cycle at 60 cycles) anode current flows through the amplifier tube in quarter-cycle pulses (while the anode voltage of the grid controlled vapor discharge tube is negative) to charge $C2$ and so produce a bias voltage in the grid circuit of this latter tube. Inasmuch as different applications demand that an adjustment be provided so that this tube in one case may be made to conduct upon light increase, and in another may be made to conduct upon light decrease, a change-over switch is provided between the photo-electric tube-amplifier circuit and the circuit of the grid controlled vapor discharge tube to allow the polarity of the tripping voltage introduced into the circuit of the latter tube by the amplifier to be reversed.

With the change-over switch in position 1 and zero current being passed by the amplifier tube, the voltage conditions in the circuit of the grid controlled vapor discharge tube are as shown in figure 5A; i. e., an a-c grid bias voltage 180 degrees out of phase with the anode voltage is used to charge $C4$ through the grid-cathode circuit of the grid controlled vapor discharge tube. The time constant of the local circuit of $C4$ and $R4$ is less than $^1/_8$ cycle at 60 cycles per second, yet is sufficient to carry the grid negative enough before the anode becomes positive so that

incidental shifts of anode voltage phase caused by current flow through the contactor coil are insufficient to cause the tube to fire erratically. With the relations of figure 5*A*, the anode current is zero.

If the amplifier tube is caused to pass more and more current, the conditions of figure 5*B* finally obtain; i. e., due to the a-c bias voltage superimposed on the difference in voltages existing on *C*4 and *C*2, the grid of the grid controlled vapor discharge tube is more positive than the critical grid voltage at the beginning of the half-cycle during which the anode of this tube is positive. Hence, full current is passed by the tube.

However, if the change-over switch be thrown to position 2 and there be zero anode current in the amplifier tube, the conditions of figure 5*C* obtain; i. e., an a-c voltage is introduced into the grid circuit of the grid controlled vapor discharge tube from the mid-tap of the bias winding and the junction of *C*3

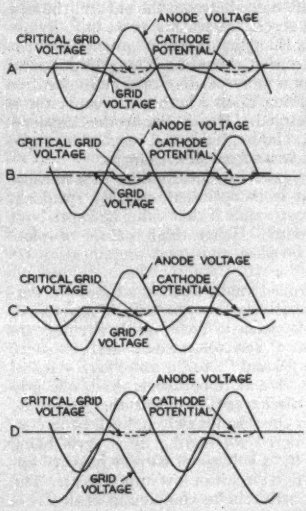

Fig. 5. Voltage relations of grid controlled vapor discharge tube of the relay shown in figure 3

and *R*3 which leads the anode voltage of this latter tube by slightly less than 90 degrees. This voltage charges *C*4 in a quarter-cycle pulse and holds the grid positive at the beginning of the half-cycle during which the anode is positive. Hence, full current is passed by the grid controlled vapor discharge tube.

If, under the latter conditions the amplifier tube is caused to pass more and more current, the conditions of figure 3*D* finally obtain; i. e., the increasing voltage across *C*2 shifts the axis of the 90 degree leading a-c grid voltage in the negative direction until the critical grid voltage is no longer exceeded, and the grid controlled vapor discharge tube ceases to conduct.

Particular notice should be taken of the care used in the above circuit to provide grid voltages for the vapor discharge tube of the correct phase and ample magnitude such that the tube cannot but pass full or zero anode current—a necessary condition to prevent erratic operation of the device controlled by the tube.

In contrast with the relay of figure 1, the relay of figure 3 will operate with a minimum illumination on the photo-electric tube of one foot candle and upon a 40 per cent change in illumination at this value, or upon a 10 per cent change in illumination at 10 foot candles, provided these changes last 0.05 second or longer (assuming a 60 cycle source of power). Hence the relay will operate up to 600 times per minute, assuming that the device operated by the grid controlled vapor discharge tube will follow at that speed.

Ultra-High Speed Photo-Electric Relays—D-C Operated

Both of the above photo-electric relays require the light impulse to last an appreciable length of time for proper operation, due to the direct utilization of a-c voltages on the tube elements. Many modern processes, however, require a photo-electric relay which will respond to a light impulse lasting but a few microseconds. For example, many wrappers for packaged articles first have printing applied in a rotary press, then are removed to a machine which cuts the wrapper in register with the printing and applies it to the package. Here it is necessary, for accurate

Fig. 6. Scanning head of the ultra-high speed photo-electric relay, d-c operated

high speed work, for photo-electric control apparatus to provide the synchronizing tie between the cutting knife and the printed matter on the web, because factors such as slip of the web in the machine and variations in stretch of the web preclude successful operation otherwise. And because it is essential that the photo-electric apparatus work on some small part of the printed design which may give but small photo-electric contrast with its background (or on some small mark printed specifically for the purpose)

and at the high web speeds possible in modern machines, an extremely sensitive and fast photo-electric device is required.

The type of relay shown in figures 6 and 7 has been found to be adapted to meet the exacting requirements of this type of service. Its virtues may best be understood, perhaps, from the following description of the operation of its circuit, shown in somewhat simplified form in figure 8. In order that the tubes may operate at any instant and be as free as possible from the transient voltage disturbances common on industrial power distribution lines, power is usually taken from the a-c power source used for incandescent lighting, modified in voltage by an electrostatically shielded transformer, rectified and carefully filtered by a full wave rectifier tube and pi filter. The practically pure d-c voltage thus derived is applied across voltage dividers from which are tapped the voltages required by the various tubes. Because of the high impedance of the photo-electric tube and the extreme speed at which this circuit must work, the photo-electric tube and amplifier are placed as close together as possible in a shielded enclosure known as the "scanning head." Usually the light source is mounted on the scanning head by a bracket, thus providing a unit which operates from change of reflected light which is relatively free of troubles due to moisture, dirt, electrostatic interference, or variations in focus. Sometimes, dependent upon the installation and upon the web material, the light source is mounted on the opposite side of the web from the photo-electric tube housing, thus providing a unit which operates upon transmitted light, which may allow a larger value of light flux to fall upon the photo-electric tube.

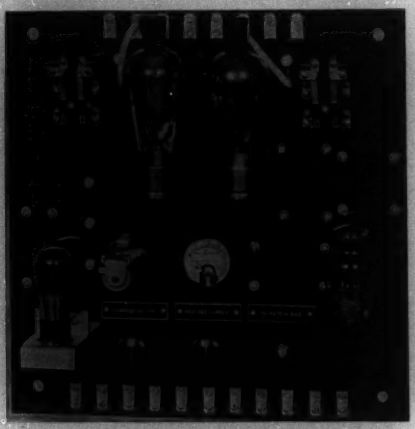

Fig. 7. Control panel of the ultra-high speed photo-electric relay, d-c operated

Due to the relatively high level of power output from the scanning head, however, the grid controlled vapor discharge tubes, control contactors, and rectifier may be mounted in a separate enclosure several feet from the scanning head in such a manner as to allow easy access, and in a position free from vibration.

Particular notice should be taken of the method of circuit coupling. Referring to figure 8, the photo-electric tube-amplifier circuit operates as follows When there is no change of light on the photo-electric tube, capacitor $C1$ assumes the potential existing across the photo-electric tube resistor, there is zero current flow in $R5$ and the amplifier tube grid is at ground potential, negative with respect to its cathode. However, upon change of light on the photo-electric tube, since the response of the tube is instantaneous, a new potential value exists across the photo-electric tube resistor. The voltage across $C1$ must finally equal the new voltage across the resistor but, since a capacitor cannot change its charge instantly, the difference between the old and the new voltage existing across the resistor must initially appear across $R5$, changing the grid potential of the amplifier tube by that amount. The grid potential will be carried in a more positive or a more negative direction, depending upon whether the capacitor is charged or discharged. Hence, due to the "capacity coupling" effect, the amplifier will respond to rapid changes of light but not to slow changes.

The pentode is used for the amplifier tube because its plate current is independent, roughly speaking, of the plate voltage value, if that value be kept above a certain minimum. Hence, high values of plate resistance may be used and great amplification secured.

The grid controlled vapor discharge tubes are normally biased negatively through hold-off resistors of moderately high value. Their grid circuits are carried through a selector switch and capacity coupled through $R6$ and $C2$ to the amplifier. Hence, if TR be closed, A and R be deënergized, one grid controlled vapor discharge tube or the other, according to the position of the selector switch,* will be in condition to be rendered conducting by its grid being carried positive by a voltage of correct polarity appearing across $R6$ (a circuit of low impedance). The tube, once fired, will remain conducting until TR is opened, even though the potential across $R6$ may have become zero meanwhile, or the selector switch contact opened, carrying the grid negative. A and R are the operating coils of contactors which operate to produce the required correction; while TR opens, then recloses after the desired correction period has passed, rendering the tube nonconducting again and putting it in condition to operate on the next proper impulse.

Relays of the type of figure 6 will operate on a minimum light change of 0.02 lumen occurring at an average rate of between 2 and 200 lumens per second.

* In applications such as the print-on-paper register control, 2 indications of position are required; one from the print itself, one from the cutting knife. The photo-electric tube obtains the indication from the print, while the selector switch which is geared in proper fashion to the cutting knife is the means of indicating in the tube circuits the position of the knife, and is also the means of choosing which of the grid controlled vapor discharge tubes should conduct.

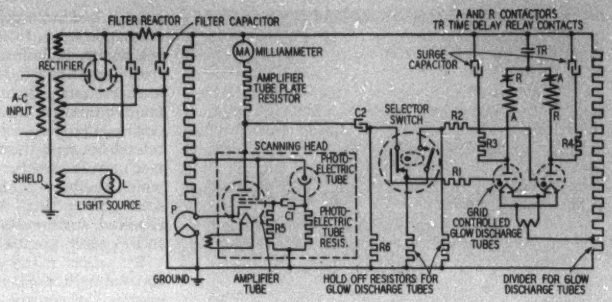

Fig. 8. Ultra-sensitive high speed d-c register control using photo-electric tube and grid controlled vapor discharge tubes

Electron Tube-Reactor Theater Light Control

In the field of theater light control, electron tube-reactor dimming has come to be recognized as most efficient and most flexible. The saturable reactor is a device consisting essentially of 3 windings wound upon a multilegged iron core. Two of the windings are used to produce impedance in the a-c circuit, but are so placed upon the iron core and so connected that zero voltage is induced by them into the third, the d-c winding. The d-c winding is so wound upon the iron core that flux due to it tends to saturate the whole iron structure, causing the impedance offered by the a-c coils to decrease as the d-c saturating current increases. The saturable reactor losses may be kept at a value of roughly 2 to 3 per cent of the connected lamp load value at any lamp voltage in the dimming range (which represents a great advantage over resistance type dimmers). The tube units, reactors, and magazine circuit distribution panels may be located at the most economical distribution point and remotely controlled from a very small unit located in the position to give the operator maximum visibility; and due to the very small size of the control device at the operator's position several of these per lighting circuit may be provided by which complete lighting scenes may be set up in advance and brought into use as desired by the operator from a single control.

The lighting control circuit shown in figure 9 is of particular interest due to the so-called "feed-back" feature. For convenience and clarity the diagram has been divided into several parts.

A-C Power Circuit. The lamp load current passes through the line contactor, through a line fuse, through the several individual magazine circuit fuses, through the lamps, through the a-c winding of the saturable reactor *SR*, then to the neutral line. Since the a-c impedance of the reactor varies as a function of the d-c current flowing in its d-c winding, it is necessary to control the value of this d-c current in order to control the value of the voltage across the lamp load.

D-C Power Circuit. The direct current for saturating the reactor is obtained through the medium of a grid controlled vapor discharge tube *T* and a 2 electrode gas filled tube *P*. Power from the line is taken in pulses through the d-c winding of *SR* and *T*, the latter governing the average value of power taken. The energy caught in *SR* due to its inductance forces current through *P* and *R* during the half-cycle when *T* cannot pass current, being a rectifier. Thus, full wave rectified current flows in the d-c winding.

Grid Circuit of T—Turn On. The network located remotely in the master control board can be represented, as in figure 9, by a resistance type potentiometer *MCB* which produces a voltage whose magnitude may be varied but whose phase is of no consequence since the 2 electrode vacuum tube *K* rectifies this voltage and charges capacitor *FI*. The voltage across *FI*, for any given input from *MCB*, is practically constant because of the long time constant of the local circuit of capacitor *FI* and resistor *A* in comparison to the supply system frequency. If, at the instant under discussion, capacitor *FB* be assigned a zero charge, the voltage existing across *FI* carries the grid of *T* positive and *T* tends to pass maximum current.

Turn Off. However, the increase of current through the d-c winding of the reactor increases its saturation and causes its impedance to decrease, thus causing the lamp voltage to rise and the control transformer *CT* connected across the lamp, to charge capacitor *FB*. But the polarity of the voltage across capacitor *FB* is opposite to that across capacitor *FI*, and if the voltage of capacitor *FB* rises too high the net voltage applied to the grid of *T* is negative and *T* will cease to pass current, which would cause the lamp voltage to drop. However, the time constant of *FB* and its discharge resistor *A* is made more

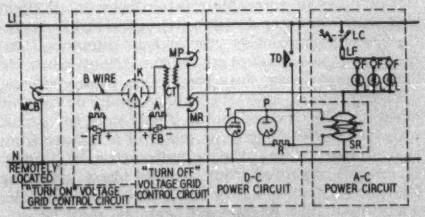

Fig. 9. Theater type electron tube-reactor control for light intensity

nearly comparable to a half-cycle of the system frequency, thus producing, in effect, an a-c voltage superimposed upon the difference of the 2 d-c voltages. The phase of this a-c voltage is such that as its axis is shifted by change in value of the d-c difference voltage, the phase angle at which it intersects the critical grid voltage of T is shifted, thus producing phase control of T. Hence, as the lamp voltage nears the correct value, T regulates and finally passes the correct value of current to hold the lamp voltage at the desired value.

Adjustments. Two adjustments are provided to compensate for conditions of the customer's installa-

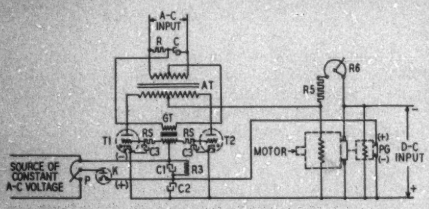

Fig. 10. Electron tube motor control

tion and for variations due to manufacture of the parts. MR is provided so that T may be rendered completely nonconducting when MCB is in the zero intensity position, and MP is provided to adjust the lamp voltage to the correct value with MCB in the maximum intensity position. These adjustments are made quickly at the time of installation and thereafter are fixed.

Particular heed should be paid to the comparison or "feed-back" feature of the circuit of figure 9 in which the result is compared to the cause. The general use of this principle in those applications in which the tubes are used to regulate power flow to devices provides accuracy, flexibility, and consistency. In the particular case of figure 9 in which the comparison feature is used to compare the lamp voltage directly to the voltage from MCB, the control operates to hold constant lamp voltage for a given setting of MCB. Hence: (*a*) The lamp load may be changed through wide ranges without affecting the lamp circuit voltage—a great advantage in stage pocket circuits into which bunch lights of various sizes are plugged; (*b*) the variations of characteristics of tubes or saturable reactors have small effect upon lamp voltage; (*c*) the a-c circuit is fast in operation compared to other reactor type dimmers, inasmuch as T passes full or zero current except when the lamp voltage is near the correct value, thus producing a forcing action; and (*d*) a voltage of any or variable phase may be received on the B wire since the circuit responds to the magnitude, only, of a voltage from that source. Thus, the potentiometer MCB may be entirely operated from a single phase while the loads are distributed over the 3 phases. Also, solenoids, involving no moving contacts, may be employed as potentiometers.

Due to the fact that but minute power quantities are required in the grid circuits of grid controlled vapor discharge tubes to affect control of these tubes, all apparatus, including "unit controls," "master controls" and the "fader" (if used) mounted upon the master control board at the operator's position, remain miniature in size. Also, since the tube unit responds only to a change in voltage magnitude received between the B wire and the neutral, any device may be used in the master control board network which produces a change in voltage. Hence, when scene "presetting" and scene to scene "fading" are required, small voltage regulators, one for each scene to be preset, are used as "unit controls."

By proper manipulation, through the "fader," of the voltages applied to the voltage regulator primaries, the control of the single tube unit may be transferred from one voltage regulator to any other as desired at any rate determined by the operator. That is, as the "fader" control is operated, the lighting circuit "fades" proportionately from its previous intensity to the intensity required in the selected preset scene. Obviously, there are no mechanical interconnections between any controls; the "mastering" and "fading" are accomplished through the same simple electrical network.

Electron Tube Motor Control

Control for d-c motors obtained by the application of grid controlled vapor discharge tubes has found use

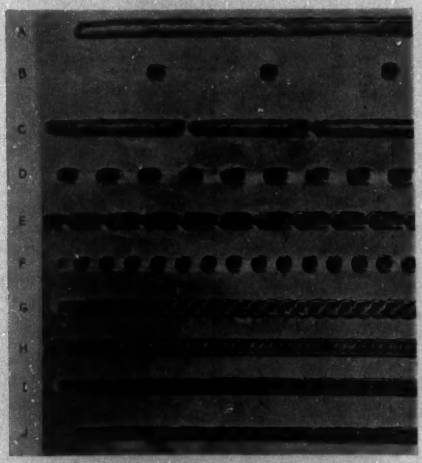

Fig. 11. Resistance welds made at approximately 7 feet per minute by line welder controlled by a control panel using grid controlled vapor discharge tubes

A. 21 spots per inch
B. Long off period, short on period
C. Short off period, long on period
D. Intermediate speed and ratio
E. Intermediate speed and ratio
F. $1^3/_4$ spots per inch
G. 3 spots per inch
H. $4^1/_2$ spots per inch
I. 6 spots per inch
J. 14 spots per inch

in many applications where stepless, accurate control of motor speed is sought, or where peculiar or unusual conditions prevent the ready adoption of rheostatic control. It is used for maintaining the correct tension during the reeling of the wire output of wire drawing machines, for correlating the speeds of the various sections of rubber process conveyors to maintain a given loop of rubber sheet between conveyor sections, for varying over wide ranges the speed of d-c motors driving frequency changers which supply power to high speed textile motors, and for maintaining the speed of the motors within narrow limits at any given setting in spite of wide load changes, etc.

Field or armature control may be used depending upon the application. However, armature control by electron tubes, except for highly specialized cases, has not been developed for reversing or regenerative applications, and field control is therefore used unless an unusually wide speed range is required.

A typical diagram for speed control of d-c shunt motors through the use of grid controlled vapor discharge tubes to control field strength is shown in figure 10. This simple circuit is applicable in those cases in which the mechanical and electrical circuit constants of the motor and load provide a system which is not particularly susceptible to hunting. As the diagram indicates, it is the practice only to boost to the required maximum value, with power from the grid controlled vapor discharge tubes, that value of field current (obtained in the orthodox manner from the regular d-c supply) which limits the motor speed to its rated maximum value, since this connection prevents the motor overspeeding if the tubes should fail. Here also, as in the case of the theater light control circuit of figure 9, a feed-back circuit compares, in the grid circuit of the tubes, voltages from the controlling potentiometer and from the pilot generator directly driven by the motor whose speed is being controlled. Hence, under any load conditions in the rated range of the motor, and in spite of possible variations in characteristics of these tubes, in d-c line voltage (the pilot generator field runs well saturated) or in motor field resistance, the tube circuit regulates the motor speed to a value which produces a pilot generator voltage which compares closely in value to the voltage from the controlling potentiometer.

In particular, the circuit of figure 10 operates as follows: The controlling potential from potentiometer P is used to charge capacitor $C1$ through the 2 electrode vacuum tube K. Inasmuch as the time constant of the local circuit of capacitor $C1$ and resistor $R3$ is made large in comparison to the time value of one cycle at the supply system frequency, P introduces practically a pure d-c voltage into the grid circuit of the grid controlled vapor discharge tubes. There this voltage opposes in polarity the voltage introduced into the grid circuit by pilot generator PG across filtering capacitor $C2$. Since GT superimposes upon the difference of these d-c voltages an a-c voltage, obtained from the bridge consisting of the primary of the power transformer, resistor R and capacitor C, lagging by 90 electrical degrees the anode voltage applied to the grid controlled vapor discharge tubes, effective phase control of these tubes may be obtained by varying the d-c difference voltage through small positive and negative values. Hence, the circuit regulates to produce a pilot generator voltage to compare closely in value in the grid circuit to the grid circuit voltage from potentiometer P, irrespective of load or circuit characteristic changes. Circuits of this nature may normally be expected to improve the regulation of a shunt motor to less than 2 per cent at any load or speed setting in the rated range of the motor.

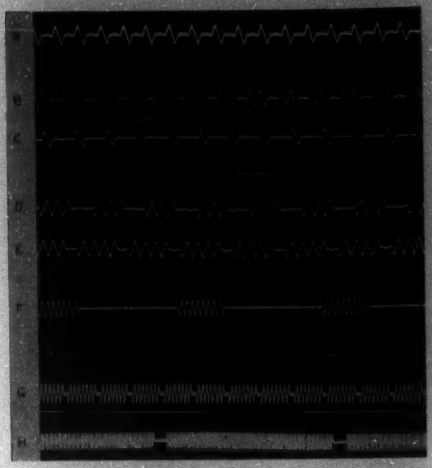

Fig. 12. Oscillograms illustrating range of control with electron tube control for resistance welding machines

A. 1 cycle on, 1 cycle off
B. 2 cycles on, 1 cycle off
C. 1 cycle on, 2 cycles off
D. 3 cycles on, 2 cycles off
E. 4 cycles on, 1 cycle off
F. 9 cycles on, 19 cycles off
G. 7 cycles on, 1 cycle off
H. 97 cycles on, 7 cycles off

Electron Tube Welder Control

A good example of the flexibility of electron tube control is that provided by using grid controlled vapor discharge tubes for the control of power flow to resistance welders. The development of this useful control has revolutionized the methods of fabrication of many high production units such as refrigerators, cans, small metal spools, etc., and has made it possible to weld metals consistently which were previously considered too difficult to weld for commercial practice. This control, used with line welders, produces, at high speed, gas and oil tight seams of excellent strength. Used with spot welders it produces consistently good welds as fast as the operator can handle the work. Figures 11 and 12 illustrate the flexibility and consistency of the control shown in figure 13, operated as a line welder.

In describing the operation of this control whose complete circuit is shown in figure 14, it is convenient

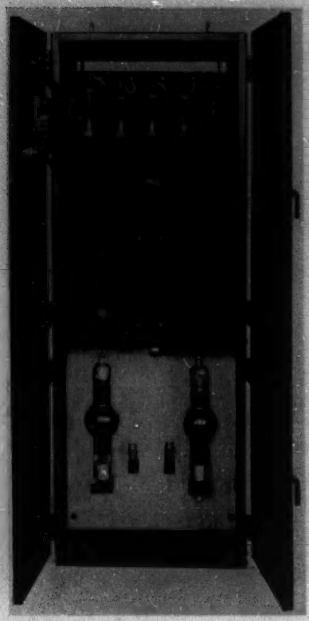

Fig. 13. Control panel for electron tube spot - welder and line - welder

to divide the circuit into several parts and describe the operation of each separately, from which the operation of the whole will become apparent.

Power Circuit. Because hot-cathode electron tubes are inherently low current, high voltage devices, a series transformer is interposed between the power tubes and one of the lines used to supply the welder; which line is, in effect, to be opened and closed to control the power flow to the welder. The use of the series transformer allows a small (exciting) current to flow when the power tubes are held nonconducting and introduces a small (leakage) reactance in the circuit when the power tubes are caused to short circuit the series transformer secondary, but these effects are generally negligible. To insure that the power tubes, $T1$ and $T2$, may be rendered completely nonconducting, a d-c bias is provided for each of the power tubes through the medium of full wave rectifier tubes $T7$ and $T8$ and filters composed of the local circuits of $C3$ and $R3$. Resistors $R7$ are provided to limit the grid current when the grid is carried positive with respect to the cathode. To protect the tubes from losing control due to voltage surges caused by the bouncing of contacts during the closing of circuits on either the primary or secondary side of the welder, a material having a negative resistance-current characteristic is placed across the series transformer secondary, and the grid cathode capacity of the power tubes is increased by the addition of capacitors $C2$. Hence, with the primary of the grid transformer TG open circuited the power tubes are held nonconducting, but upon the closing of power to TG a-c voltages of large value in phase with the anode voltages of $T1$ and $T2$ are superimposed upon the d-c biases and the tubes are rendered conducting, and power is applied to the welder.

It is clear that at the beginning of the "power on" period of a welding cycle that the grid controlled vapor discharge tubes must be rendered conducting at that instant during the a-c supply voltage cycle which produces minimum current transient in the supply lines. Otherwise, excessive peaks of line current due to saturation of the transformer iron and inconsistent welding results may be obtained. In the case of line welders, it is also clear that even numbers of half-cycles of the a-c line power must consistently be applied to the welder to insure that d-c line current components are not built up to saturate the transformer cores and cause high line current peaks to be drawn. Hence, the control circuit section of the circuit of figure 14 has been designed with the above limitations in mind.

Control Circuit. Actually, the control circuit controls the power supplied to the grid transformer TG of the power tubes in the same manner that the power

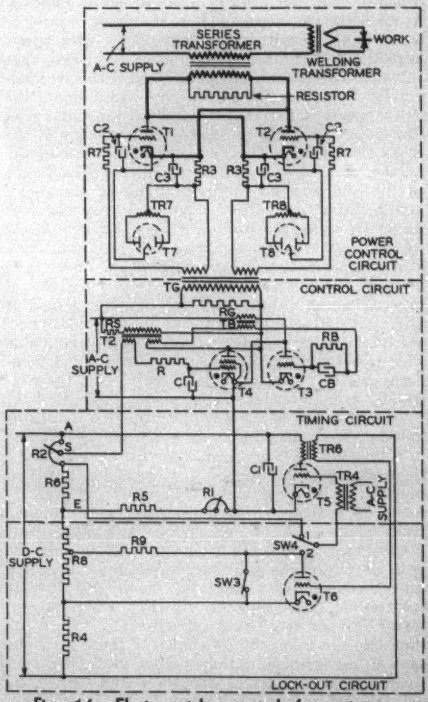

Fig. 14. Electron tube control for resistance welding

tubes control the power flow to the welder, except that the power required by TG is of such value that small grid controlled vapor discharge tubes, $T3$ and $T4$, may be placed directly in one lead of the a-c supply to TG, obviating a series transformer. The grid of tube $T3$ is normally biased negatively with respect to its cathode by the charge upon CB produced by grid cathode current flow due to voltage from TB during the time the anode of tube $T3$ is negative. Tube $T4$ is also normally held nonconducting by a negative bias from the timing circuit. However, should $T4$ be caused to pass a quarter of a cycle of current or more, transformer $T2$ will be energized simultaneously with the power tube grid transformer TG, and $T2$ will introduce into the grid circuits of both tubes $T3$ and $T4$ voltages which lead their anode voltages and are of sufficient magnitude to render $T3$ and $T4$ conducting. Hence, tubes $T3$ and $T4$ will continue to pass current until a negative bias again is introduced into the grid circuit of tube $T4$ of greater magnitude than the peak of the voltage from transformer $T2$. When this occurs tubes $T3$ and $T4$ will each finish out the remainder of the half cycle allotted to them and again become nonconducting, but ready to begin a new welding cycle. Tube $T3$ is a simple 3-element grid-controlled vapor-discharge tube, for ample power is available to control it, but tube $T4$ is a 4 element tube (a shield grid vapor discharge tube) containing argon instead of mercury vapor. This type of tube is used because it may be positively controlled with a minute amount of power, thus allowing the value of the current limiting resistor R to be high to reduce the load upon the timing circuit, and because its characteristics change but little over wide temperature ranges. As in the case of the power circuit, resistor RG and capacitor C are used to minimize voltage surges and their effect. It is obvious that the control circuit could be dispensed with if power tubes $T1$ and $T2$ could be positively controlled with the power values supplied to the grids of tubes $T3$ and $T4$.

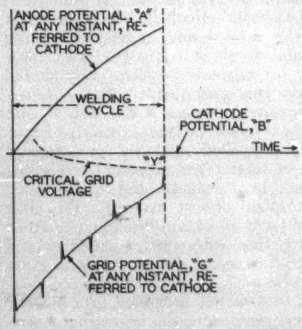

Fig. 15. Voltage relations of grid controlled vapor discharge timing tube, T-5, of figure 14

Timing Circuit. For the moment, let switch $SW4$ be thrown to position 1, disconnecting the lockout circuit, and let the operation of the timing circuit under line welding conditions be considered. Its action may be most easily understood, perhaps, by considering that $C1$ has zero charge at the first instant. Under this condition, the d-c voltage A-E appears across $R1$ and $R5$, the anode voltage of the grid controlled vapor discharge tube $T5$ is zero and its grid is negative by the value of the voltage A-E less the drop across $R6$. However, capacitor $C1$ immediately starts to charge at a rate dependent upon the setting of $R1$. But the voltage across $C1$ is applied to the anode-cathode circuit of tube $T5$ and also directly reduces the value of the negative grid-cathode bias. Hence, when the value of the voltage across $C1$ has increased to a certain critical value, the sharply peaked a-c voltage superimposed upon the reduced d-c bias, through the medium of the saturating transformer $TR4$, renders tube $T5$ conducting, whereupon capacitor $C1$ discharges through it and the commutating reactor-feedback transformer $TR6$. (The transformer feature is used with the lockout circuit and will be discussed later.) The reactor $TR6$ is used to limit the peak value of discharge current to a value within the peak current rating of tube $T5$ and to trap enough magnetic energy to overdischarge capacitor $C1$ and carry the anode-cathode voltage of tube $T5$ negative for a sufficient period of time to deionize this tube so that the grid bias, now grown again to a large negative value, may prevent the tube from passing current as capacitor $C1$ starts to charge in the normal sense. At the instant the capacitor charge becomes zero, this inverter, used for the timing circuit, has completed one pulse, and the sequence of events already described begins again. Figure 15 graphically illustrates the rise of anode voltage, the decrease of the d-c component of the grid voltage with the peaked voltage a-c component superimposed upon it, and the point Y at which the grid potential exceeds the "critical grid voltage" in the positive direction and renders the tube conducting. Figure 16 illustrates the variation of grid voltage and critical grid voltage over several cycles of operation. It is to be observed that the pulsing of the inverter is controlled by the peaked a-c voltage and is thus exactly synchronized with an even number of half-cycles of the a-c power supply. Hence, since one pulse of the inverter is defined as one welding cycle, and the instant of starting of the welding cycle with respect to the phase of the a-c supply voltage may be varied by varying the phase of the peaked a-c component of grid circuit voltage with respect to the line voltage, it is seen that only an even number of half-cycles of line voltage frequency may con-

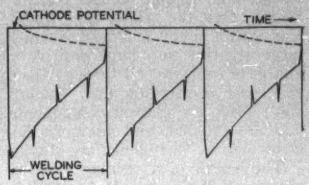

Fig. 16. Variation of grid voltage and critical grid voltage of T-5 over several cycles of operation

stitute a welding cycle; and that power may be switched to the welder only at that instant during a line voltage cycle determined by the phase position of the peaked a-c voltage wave in the grid circuit of tube $T5$, since the varying d-c bias to control tube $T4$ in the control circuit is obtained from the timing circuit and applied to the control circuit in such manner that the grid of the "leading" tube ($T4$) of the control circuit is almost instantly carried from a large negative to a large positive value by the discharge of capacitor $C1$ through the timing tube ($T5$) to render conducting the "leading" control tube, $T4$. Thus, d-c current components in the line circuit are avoided, and minimum line current transients due to "switching" are obtained.

The length of a welding cycle is determined by the length of time required to charge capacitor $C1$ of the timing circuit to the critical value; while the ratio of time during which power is allowed to flow to the welder to the time during which power is prevented from flowing during the welding cycle is determined (assuming that the critical grid-cathode potential of tube $T4$ is zero volts) by the ratio of time that the grid of tube $T4$ is positive during the welding cycle to the time that it is negative. Inasmuch as the setting of the variable resistor $R1$ determines the rate of charge of capacitor $C1$, and the setting of the tapping arm S of potentiometer $R2$ determines the length of time that the grid of tube $T4$ may be positive during a welding cycle, it is seen that 2 very simple control devices provide complete flexibility as to required welding adjustments. Notice also that no moving parts are required except for setting up for new welding conditions.

Lockout Circuit. It is obvious that the above circuit combinations can be used for spot welding if an additional circuit be added to allow but one pulse to be made by the timing circuit. Such a circuit is connected to the timing circuit if switch $SW4$ be thrown to position 2. The normal set of conditions under which the circuit is ready to apply and time the power flow to the welder is: welder's control switch $SW3$ closed, placing grid of timing tube $T5$ at a large negative potential; timing tube $T5$ nonconducting; capacitor $C1$ fully charged, thus holding the leading control tube $T4$ nonconducting; anode voltage of lockout tube $T6$ zero, being short-circuited by $SW3$; and grid of $T6$ considerably negative. To initiate a power pulse to the welder, the welder's control switch $SW3$ is opened, thus reducing to a small negative value the d-c bias applied to the grid of the timing tube $T5$. Simultaneously d-c voltage from the voltage divider appears across the anode-cathode circuit of lockout tube $T6$ but, due to its negative bias, this tube remains nonconducting for the moment. At the next positive pulse of peaked a-c voltage, superimposed through transformer $TR4$ upon the now small negative d-c bias in the grid circuit of the timing tube $T5$, the timing tube will be rendered conducting, starting the welding timing cycle and power flow to the welder. The discharge of capacitor $C1$ through commutating reactor-feedback transformer $TR6$, however, induces a voltage into the grid circuit of lockout tube $T6$ which overcomes in the positive voltage direction the negative d-c bias always existing there and renders $T6$ conducting. With $T6$ conducting, the large negative d-c bias is reestablished in the grid circuit of the timing tube $T5$, which prevents anode current in $T5$ from restarting after having been stopped by the anode voltage of $T5$ being carried negative by the electrical inertia of $TR6$. The lockout tube $T6$ being a grid controlled vapor discharge tube and having a d-c voltage applied to its anode, will continue to carry current to keep $T5$ nonconducting until switch $SW3$ is again closed, in spite of the fact that the grid of $T6$ was but momentarily carried positive by the pulse from $TR6$. Observe that practically no time is wasted in "resetting" the circuit for the next welding cycle, and that high speed spot welding introduces no problems.

Many of these controls, operating with line welders, are in constant (24 hour) use making gas tight seams in stainless steel at the rate of 72,000 welds per hour. The power controlled in this instance amounts roughly to 50 kva.

Principles Useful in Choosing Tube Circuits

Due to their unique properties, electron tubes have already proved themselves to be very useful tools in many industrial applications. However, as might be expected, these tubes have certain characteristics which become faults when used with apparatus for the industrial field. Nevertheless, experience has shown that most of these faults may be largely eliminated, in so far as their practical effect upon a desired result is concerned, by a careful choice of the circuit in which the tubes are used. As guides in helping to choose such circuits, the following few principles have been found useful: (a) If possible, but one tube should be used as the controlling element; (b) a "feed-back" circuit in which the result is compared to the cause should, in general, be used whenever the tube circuit is to regulate power flow to some device; (c) wherever possible, steps should be taken to insure that grid circuit voltages change at a high rate over wide ranges at the instant that control of the tube is required (thus, saturating transformers providing peaked voltages or capacity coupled circuits or some other expedient, according to the need, should be provided); and (d) inasmuch as tubes may respond almost instantly, the most careful layout of parts to obtain minimum intercircuit coupling, together with careful shielding and filtering is essential to avoid difficulty due to stray transient voltages.

Electron tube control has expanded in a healthy manner in the few years since the beginning of serious effort to apply it in the industrial field, in spite of the fact that it has had to contend both with the difficulties attendant to the introduction of apparatus of radically new concept and the fact that industry in general has been reduced to straits in which it has tended only to buy parts for the necessary upkeep of existing apparatus. It is believed that the return of industry to normal will cause a rapid expansion in the use of electron tube control, and that the above circuit principles will be found in general use.

Use of Vacuum Tubes in Measurements

For the benefit of those who may wish to use vacuum tubes in meeting specific problems in the field of measurement, the comprehensive bibliography contained in this paper has been prepared. Some 600 references are included in this list, selected from a total of about 1,500 papers or books published since approximately 1920. The first portion of the bibliography contains publications dealing with the characteristics of vacuum tubes, and the second portion contains references to specific applications to measurement problems.

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A CURIOUS situation exists with respect to the application of the vacuum tube to measurement problems. On one hand it is found that of all the various types of vacuum tube circuits which have been devised a very considerable proportion have been intended solely for use in measurements. On the other hand an extensive measuring technique, for both electrical and nonelectrical quantities, rests almost entirely upon the vacuum tube. Many measurements, including the fundamental measurements of length, mass, and time, have been carried to greater precisions by means of the vacuum tube. In other cases the tube has been instrumental in extending the range of measurable magnitudes.

In spite of its importance as an element in measuring apparatus there are relatively few cases in which a tube has been designed expressly to meet the requirements of a given measurement problem. The history has generally been that a tube, designed originally for use as a telephone repeater or as a radio broadcast detector, has been found to possess characteristics which could be utilized to advantage in an ultra-micrometer or in a fractional millisecond chronograph. The usual procedure in designing measuring apparatus involving the vacuum tube is to examine the characteristics and constants of existing tubes and then to adjust the associated equipment in such a way as to utilize as effectively as possible the most suitable tube. It must be noted, however, that this technique may at times prove a serious handicap and that a tube of special design may in certain cases be the best, or even the only, solution to a given problem. As a matter of fact, one suspects that the usual practice of adjusting the circuit to the tube is largely a question of the environment of the experimenter, and would be considered absurdly awkward by tube design engineers. The present material, however, is not prepared for tube design engineers, but has been collected at the request of the communications and electrophysics committees of the A.I.E.E. for the benefit of those who may wish to use vacuum tubes in meeting their own specific measurement problems. The more common practice is therefore adhered to and the utilization of those characteristics possessed by tubes already in existence is considered.

So much has been written regarding the behavior and use of the vacuum tube that a description of the innumerable applications of the tube to measurement problems is quite outside the scope of a paper of limited length. Even if it were possible such a discussion would be largely a repetition of what has already been said many times. It appears, therefore, that the present purpose may best be served by devoting the space available to a classified bibliography of those papers which are most likely to contain information of value to one contemplating the use of vacuum tubes in some problem of his own.

In preparing this bibliography it has been recognized that the vacuum tube is a functional element having fairly complex performance characteristics. One or several of these characteristics may be pertinent to a given application. The first portion of the bibliography has, consequently, been devoted to a survey of those publications which deal with the various characteristics of vacuum tubes or which discuss the theoretical aspects of their behavior. The second portion contains references to specific applications where these characteristics are utilized in representative types of measurement.

The bibliography goes back to approximately 1920, the date of publication of "The Thermionic Vacuum Tube" by van der Bijl. This book includes both a thorough treatment of the performance characteristics of the 3 element tube and a detailed analysis of the various uses to which this tube had been put up to that time. There is also an excellent general survey of prior art to be found in R. W. King's paper, "Thermionic Vacuum Tubes and Their Applications," published in 1923 (see reference 329). Since the time of these publications multigrid vacuum tubes and tubes with indirectly heated cathodes have come into extensive use. There have also been developed a number of special purpose tubes of particular interest in measurement work. These include the low grid current, or electrometer tube, the variable-mu tube and others. The demands of ultra-short wave radio have stimulated the design of tubes the geometry of which permits their use at frequencies beyond the range of the more familiar types. The gas filled tube, with its remarkably fast trigger action, has also found numerous uses in measurement work. In addition

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to having now available an increased variety of performance characteristics from which to make a choice, a greatly improved knowledge of the fundamental relations associated with these characteristics is also available. The references in the present bibliography were selected from a total of about 1,500. The choice has been governed primarily by a desire to include papers which should constitute a collection covering broadly that information which forms the basis of the utilization of the vacuum tube in measuring apparatus. All titles have been translated into English.

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Constant-Current D-C Transmission

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High voltage d-c electric power transmission has been envisioned for many years, but numerous obstacles have prevented its use to any great extent. Most of these obstacles appear to be overcome in the system described in this paper; this system comprises conversion of constant-potential a-c power to constant-current d-c power, transmission of constant-current d-c power, and reconversion to constant-potential a-c power. The promising features of this system are its unusual stability and reliability; as an example, the high-voltage constant-current d-c line may be short-circuited without damage to line or equipment.

ADVANTAGES of direct current for high voltage power transmission have been recognized for many years, but general use of this method of power transmission has been prevented by numerous obstacles. In the Thury system, as developed in Europe, rotating machines are employed to convert the high-voltage d-c power into a-c power. The difficulties associated with this sytem are well recognized.

Development of the hot-cathode grid-controlled vapor-discharge electron tube has promised a satisfactory solution for the problem of transforming the d-c power into a-c power, but the performance of high-voltage constant-potential inverters never has been entirely free from difficulties.

A paper recommended for publication by the A.I.E.E. committee on power transmission and distribution, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 22–25, 1935. Manuscript submitted Oct. 4, 1934; released for publication Nov. 14, 1934.

The authors have conducted a series of developmental studies on a d-c transmission system employing a constant current inverter and rectifier. The transmission was over an artificial line at 10 amperes and 15,000 volts. The line was supplied from a 3-phase full-wave 10-ampere constant-current delta-wye rectifier, operating from a 150-kw 3-phase 550-volt motor-generator set. At the receiving end the power was fed into a 3-phase full-wave 10-ampere constant-current delta-delta inverter operating on the 550-volt 3-phase shop service of the General Electric Company at Schenectady, N. Y. The circuit is shown in the single line wiring diagram of figure 1.

The promising features of these developmental studies center largely around the equipment employed for converting constant-potential a-c power into constant-current a-c power, and conversely.

Monocyclic Network

Some 45 years ago, Paul Boucherot invented the use of a series resonant circuit, as shown in figure 2, for transforming constant voltage into constant current for arc light circuits. Later, this type of circuit was studied thoroughly by Steinmetz. In "Alternating Current Phenomena," published in 1905, Steinmetz analyzes the simple resonant circuit of figure 2 for converting constant potential into constant current, or conversely. In "Theory and Calculation of Electric Circuits," published in 1897, he analyzes a bridge arrangement of 2 inductive and 2 capacitive reactors, as shown in figure 3. This arrangement Steinmetz calls a monocyclic square.

The term "monocyclic," as used by Steinmetz,

("Theory and Calculation of Electrical Apparatus," first edition, second impression, 1917, page 214) is applied to a polyphase system of voltages (whether symmetrical or unsymmetrical) in which the flow of energy is essentially single phase. It is thus well known that this circuit operates as a phase balancer, when supplying a single-phase constant-current load, and draws balanced power from a quarter phase system.

This paper is not concerned primarily with the phase balancing property of this circuit. However, all arrangements for converting constant potential into constant current, or the converse, that employ inductance and capacitance will be referred to as monocyclic networks.

In "Theory and Calculation of Electric Circuits," Steinmetz describes several polyphase arrangements of monocyclic networks. One of these arrangements, which is particularly valuable because of the wide use of 3 phase power, is shown in figure 4. If lines A, B, and C are supplied with constant potential, lines A', B', and C' will supply constant current. However, the network is perfectly symmetrical and reversible.

In the following discussion, Z' will represent the load impedance of one phase to the neutral, I' the constant current through this impedance, and I_a the current in phase A on the constant potential side; Z_1' and Z_2' will represent impedance branches of the monocyclic network and E_a, E_b, and E_c, the phase voltages of the constant voltage supply. These quantities are shown diagrammatically in figure 5.

It is easy to show that the following general vector equations describe this circuit for all conditions of operation:

$$I' = \frac{E_a Z_2' + E_b Z_1'}{Z_1' Z_2' + Z'(Z_1' + Z_2')} \tag{1}$$

$$I_1' = \frac{(E_a - E_b)\, Z' + E_a Z_2'}{Z_1' Z_2' + Z'(Z_1' + Z_2')} \tag{2}$$

$$I_2' = \frac{(E_b - E_a)\, Z' + E_b Z_1'}{Z_1' Z_2' + Z'\,(Z_1' + Z_2')} \tag{3}$$

$$I_a = \frac{(3Z' + Z_1' + Z_2')\, E_a}{Z_1' Z_2' + Z'\,(Z_1' + Z_2')} \tag{4}$$

Balance

The quantities Z_1' and Z_2' are preferably pure imaginaries. At the resonant frequency these 2 quantities are equal. The operation of the monocyclic circuit is, however, in no way critical at the resonant frequency, and satisfactory operation may be obtained with considerable variation from the resonant frequency. Since the frequency of power systems is usually very nearly constant, the variation in relative magnitudes of Z_1' and Z_2' will be referred to as the balance of the monocyclic network.

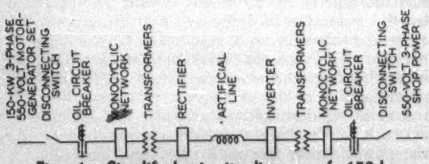

Fig. 1. Simplified circuit diagram of 150-kw 15,000-volt 10-ampere constant-current d-c transmission system

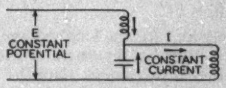

Fig. 2. Resonant circuit for transforming constant voltage to constant current

A circuit in which Z_1' equals Z_2' at the operating frequency will be referred to as a balanced monocyclic network. When the inductive reactance exceeds the capacitive reactance, the circuit will be described as inductively unbalanced, and conversely.

Phase Rotation

When a rectifier is operating from a monocyclic network, one phase rotation gives the best economy, whereas the reverse rotation is preferable for an inverter. The phase rotation shown in figure 5 is the preferred one for an inverter. The reason for this difference in phase rotation between the rectifier and inverter arises from the fact that in the circuit of figure 5 there is a constant voltage of half the phase voltage effectively in series with the constant current. When this series constant voltage is in such a direction as to increase the current, the condition is best for the rectifier. In an inverter it is best if this constant voltage is in such a direction as to absorb power.

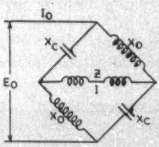

Fig. 3. Circuit known as a monocyclic square

This condition may be demonstrated mathematically by a consideration of equations 2 and 3. In a rectifier the load impedance Z' has a positive real component, whereas in the inverter the load impedance has a negative real component. If the load impedance Z' has a positive real component, then Z_2' should be a negative and Z_1' a positive imaginary to give the smallest currents I_1' and I_2' and therefore the lowest inductive and capacitive kilovoltamperes for a given load.

Power Factor

If a balanced monocyclic network be assumed, as shown in figure 4, equation 4, which gives the line current of phase A on the constant potential side, becomes:

$$I_a = \frac{3E_a Z}{Z_1' Z_2'} \tag{5}$$

Since Z_1' and Z_2' are pure imaginaries of opposite sign, their product is a positive real quantity, and the line current I_a leads the phase voltage E_a on the constant potential side by the angle of Z', the load impedance of the constant current side. On the constant current side,

$$E' = I'Z' \tag{6}$$

where E' is the load voltage, and the current lags the voltage by the angle of the load impedance. It is therefore evident that the monocyclic network reverses the power factor angle.

Steinmetz in his work states that the power factor is the same on the 2 sides of the monocyclic network. He fails, however, to point out that the power factor angle is reversed.

This reversal of power factor is of the greatest importance in the use of a monocyclic network in connection with inverters using grid-controlled vapor-

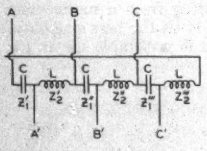

Fig. 4. A 3-phase monocyclic network

discharge tubes. It is well known that commercial loads ordinarily are lagging in phase, whereas an inverter using phase commutation will supply only loads that are leading in phase. By interposing a monocyclic network between the inverter and the load, it is possible to supply lagging loads and yet operate the inverter by means of phase commutation. This greatly simplifies the inverter circuit, and appears to avoid the necessity for using "harmonic

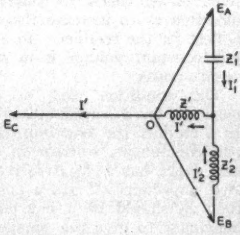

Fig. 5. Vector diagram for a 3-phase monocyclic network

commutation (see "Harmonic Commutation for Thyratron Inverters and Rectifiers" by C. H. Willis, *General Electric Review*, volume 35, 1932, page 632).

Utility

Assuming a balanced monocyclic network, as shown in figure 4, it readily may be shown that the ratio of output kilovoltamperes to monocyclic kilovoltamperes is highest, or the utility is greatest, when the absolute values of the load impedance and monocyclic impedances are in the relation:

$$Z' = \frac{Z_1'}{\sqrt{3}} = \frac{Z_2'}{\sqrt{3}} \tag{7}$$

This condition is independent of the power factor, but the value of the utility depends on the power factor. The load impedance as obtained by equa-

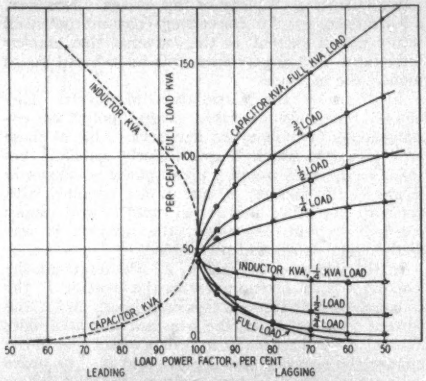

Fig 6. Capacitor and inductor kilovoltamperes in monocyclic network versus load power factor, with constant current inverter supplying power through the network to a constant potential load

tion 7 is the correct impedance for full load. Since the current is constant, half load will obtain with half this impedance, and no load will occur at short circuit. It is this response of the constant current circuit to the short-circuit condition that promises the greatest advantages over the constant potential system.

The curves of figure 6 give the capacitive and inductive kilovoltamperes for several values of load impedance with varying load power factors. These curves apply to a constant current inverter when operating through a monocyclic network to supply an inductive load at constant potential. It is evident from these curves that the capacitive kilovoltamperes required rises rapidly as the power factor of the load decreases. This rise in the capacitive kilovoltamperes by no means is fully compensated by the reduction of inductive kilovoltamperes because the capacitor must supply the kilovoltamperes necessary to reverse the power factor angle of the load in passing from the constant current to the constant potential side of the monocyclic network. For this reason it is desirable to operate the monocyclic network at the highest possible power factor. As the power factor increases, the time available for commutation and deionization of the inverter tubes is reduced. The 150 kw developmental apparatus has operated satisfactorily at about 95 per cent power

Fig. 7. Oscillogram for inverter operating on short circuit without commutating voltage

D-c line volts 0; d-c line amperes 9.8; capacitance volts 352; load 550 volts, shop

A. Line voltage, constant potential lines
B. Line current, constant potential lines
C. Line voltage, constant current lines
D. Line current, constant current lines
E. Monocyclic capacitance voltage
F. Monocyclic inductance voltage

factor. It would seem safe to assume that operation at power factors as high as 90 per cent readily may be attained. With lower power factors the time available for commutation and deionization is increased at the expense of greater capacitive kilovoltamperes.

Operating Characteristics

A constant potential inverter requires a grid phase shift of approximately 180 degrees to change from inverter to rectifier operation. A constant current inverter operating through a monocyclic network requires no grid phase shift to change from inverter to rectifier operation. The monocyclic network operates as a current regulator; when there is no impressed voltage, this network swings over and supplies a voltage to circulate the current, and the inverter tubes operate as rectifiers. If, now, a voltage be applied to the d-c circuit in such a direction as to tend to increase the current, the voltage of the monocyclic network reverses thus holding the current to the normal value. The apparatus thus automatically swings from rectifier to inverter operation, with the application of voltage. No change or adjustment of the grid phase is necessary in passing from inverter to rectifier operation. In this respect the constant current inverter operating through a monocyclic network is the only tube circuit known at this time that will regenerate or reverse power flow automatically.

In order to begin operation the d-c circuit is short-circuited and full potential is applied to the constant potential side of the inverter. Under these conditions the inverter begins operation as a rectifier and establishes full load current circulating through the short-circuited line. The voltage of the rectifier supply then is reduced somewhat below normal and the rectifier monocyclic network is excited. The rectifier then circulates a reduced current through the short circuit in the direction opposite to that of the current from the inverter. When rectifier and inverter are adjusted to give the same current, the short circuit, which carries the difference of the 2 currents, carries no current and the short-circuiting device may be opened. A further small rise in the current supplied by the rectifier causes the inverter to take load because the inverter monocyclic network tries to hold a constant current. In this way the voltage of the d-c line and the corresponding load may be established.

The load flow is controlled in a manner quite closely analogous to the control of load flow between 2 d-c constant-potential shunt generators operating in parallel. A small change in voltage of either shunt generator is sufficient to cause a large transfer of load. Similarly, in a constant current circuit, a small change in current is sufficient to cause a large change in voltage and, therefore, in load. A 5 per cent change in current is sufficient to effect a change in load from no load to full load.

A 2-electrode rectifier tube has been found to be a very satisfactory device for short-circuiting the d-c line when starting. This tube is connected in the proper direction to carry the current from the inverter. As the rectifier current is raised, the current through the short-circuiting tube decreases. When the rectifier current tries to exceed the inverter current, the tube ceases conduction and the system takes load. The short-circuiting tube then acts as an automatic reverse power relay and prevents the inverter from feeding back power if the rectifier voltage decreases. The circuit automatically is short-circuited if the inverter tends to reverse the power flow.

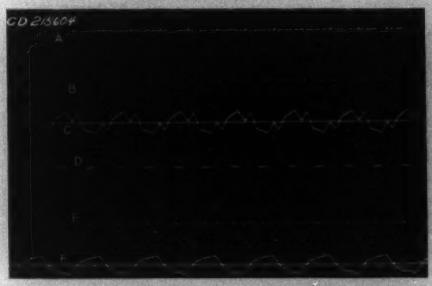

Fig. 8. Oscillogram for inverter operating on short circuit with full commutating voltage

D-c line volts 0; d-c line amperes 9.4; capacitance volts 448; load 550 volts, shop

A. Line voltage, constant potential lines
B. Line current, constant potential lines
C. Line voltage, constant current lines
D. Line current, constant current lines
E. Monocyclic capacitance voltage
F. Monocyclic inductance voltage

In case of an accidental short circuit on the line

connecting a constant current inverter and rectifier, the current through the short circuit is much less than the line current, because only the difference between the no load currents of the rectifier and inverter is available for the short circuit. The short-circuit current may be of the order of 10 per cent

Fig. 9. Oscillogram for inverter operating at full load

D-c line volts 14,000; d-c line amperes 10.1; capacitance volts 395; load 550 volts, shop

A. Line voltage, constant potential lines
B. Line current, constant potential lines
C. Line voltage, constant current lines
D. Line current, constant current lines
E. Monocyclic capacitance voltage
F. Monocyclic inductance voltage

of the line current. In the 150 kw developmental apparatus a 2 ampere fuse would not be blown when used to short-circuit the 10 ampere lines operating at 15,000 volts. A 1-ampere 250-volt cartridge fuse, however, would be blown and would successfully rupture the short circuit on a 15,000 volt circuit. It is also possible to short the 15,000 volt d-c circuit with a standard knife switch, and then open the switch; no appreciable arc is formed across the switch blades when opening a circuit normally operating at 15,000 volts. The reason for this lies in the fact that the monocyclic network requires an appreciable time to restore the voltage after operating at short circuit. This will be discussed more fully later. Opening and closing a knife switch across a 15,000-volt constant-current circuit makes a very impressive demonstration because of the absence of any sign of distress, of either a transient or steady nature.

Commutation

In a constant potential inverter it is necessary to advance the phase of the grid excitation and therefore of the current by the angle desired for commutation. In a constant current inverter operating through a monocyclic network the amount and phase position of the current in the inverter is determined by the voltage on the constant potential side of the monocyclic network and cannot be shifted. In order to obtain a commutating voltage the phase of the grids of the inverter tubes is retarded slightly. This causes the monocyclic network to advance the phase of the voltage on the constant current side in order to prevent a shift of the current in response to the change of the grid excitation.

In this manner any desired phase advance of the voltage may be obtained on the constant current side of the monocyclic network for commutation purposes. This grid phase adjustment to obtain commutation may readily be made while the inverter is operating as a short-circuited rectifier. The commutating voltage is rather sensitive to a phase change of the grid excitation of the inverter tubes, but once this adjustment is made it need not be changed unless a different operation is desired. The grid phase adjustment for commutation, of course, determines the power factor at which the inverter operates, because the phase relation of the current on the constant potential side of the monocyclic network shifts in response to the phase shift of the voltage on the constant current side.

When the inverter is supplying a load of definite impedance characteristics such as induction motors or lamps, no adjustment of the grid phase is necessary. This adjustment is necessary only when the inverter is operating in parallel with synchronous generators of appreciable size.

When the inverter is operating as a short-circuited rectifier and there is no commutating voltage, the current on the constant potential side of the monocyclic network is small. This current would be zero were it not for losses in the monocyclic network and the harmonic currents introduced by the inverter tubes. An oscillogram of this line current at short circuit is shown in figure 7. As the grids are shifted to obtain a commutating voltage, the voltage across

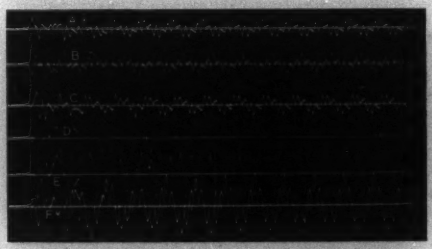

Fig. 10. Starting transients in inverter when full voltage is applied to the monocyclic network with the d-c lines short-circuited; full commutating voltage

D-c line volts 0; d-c line amperes 9.5; capacitance volts 475; supply, short circuit

A, B, and C. Line current, constant potential lines
D, E, and F. Line current, constant current lines

the monocyclic capacitances rises and the voltage across the monocyclic inductances decreases. These voltages serve as a convenient measure of the commutating voltage.

With the rise in the commutating voltage, there

appears a wattless component of current of fundamental frequency on the constant potential side of the monocyclic network. This condition is shown in the oscillogram of figure 8 where the inverter was operating as a short-circuited rectifier, but was adjusted for full commutating voltage. It is evident from an inspection of the oscillograms of figures 7 and 8 that there is a large harmonic component of current in the constant potential supply lines.

A glance at figure 4 shows that the harmonic component of the currents in lines A', B', and C' must pass through the capacitance and into the constant potential lines A, B, and C, while the fundamental component of the constant current at no load may be supplied by the inductance and capacitance. As the reactor voltage decreases and the capacitor voltage rises, to furnish commutation, an increasing component of wattless current of fundamental frequency is circulated in the supply lines of the constant potential side. When the load on the inverter is increased by raising the d-c supply voltage, a power component of current of fundamental frequency appears on the lines on the constant potential side of the monocyclic network. This power component of current on the constant potential side corresponds to a power component of voltage on the constant current side of the monocyclic network. This condition is illustrated in figure 9, which is an oscillogram of the inverter operating at full load.

A comparison of the oscillograms of figures 8 and 9 shows that there is an approximately constant component of harmonic current in the constant potential lines. These harmonic currents are not affected appreciably by the load, and are affected only slightly by the commutating voltage.

The wide variation of wave shape is attributable

Fig. 11. Starting transients in inverter when full voltage is applied to the monocyclic network with the d-c lines short-circuited; inverter adjusted to seize full load

D-c line volts 14,200; d-c line amperes 10.1; capacitance volts 538; supply, rectifier
A, B, and C. Line current, constant potential lines
D, E, and F. Line current, constant current lines

to varying components of the fundamental wave. It is unfortunate that so large a harmonic current exists at no load, but this is not a normal operating condition. At full load the wave shape has the same harmonics and the same telephone interference factor as a 6 phase rectifier, although the appearance of the wave is quite different because of the phase displacement of the harmonics with respect to the fundamental caused by the monocyclic network.

Transient Conditions

It is very fortunate and somewhat surprising that the presence of the large inductive and capacitive

Fig. 12. Starting transients in rectifier when a-c supply circuit was closed; inverter operating through short circuiting tube and adjusted to seize full load

D-c line volts, 14,100; d-c line amperes 10.0; capacitance volts 360; load, inverter
A, B, and C. Line voltage, constant current lines
D, E, and F. Tube voltages, positive side

reactances in the monocyclic network causes no undesirable transient conditions. A thorough oscillographic study of the transient conditions does not reveal any conditions under which the current or voltage of any portion of the circuit approaches twice normal value.

When voltage is applied to a monocyclic network connected to a 3-phase full-wave inverter short-circuited on the d-c side, the circuit behaves as an ohmic resistance during the period when the fields of the reactances are building up.

Figure 10 shows the current transients in both the constant potential lines and in the primaries of the transformers on the constant current side of the monocyclic network when full voltage is applied to the monocyclic network with the d-c lines short-circuited. The inverter grids were adjusted to give full commutating voltage, and the transformers were connected delta-delta.

The oscillogram of figure 11 shows the same currents when the inverter is switched on to the constant potential system, when adjusted to seize full load. Oscillograms taken at other points show that the steady state condition is established quickly and that no abnormally large currents or voltages occur. It should be noted in connection with figures 10 and 11 that these oscillograms were taken when the monocyclic network was switched on to a comparatively large system and that the connecting cables had no appreciable impedance.

The oscillogram of figure 12 shows the potential

across the constant current lines and across the tubes when the power was switched on the rectifier monocyclic network, with the inverter operating through a short-circuiting rectifier tube and adjusted to seize full load when the rectifier was connected. It is evident from figure 12 that the first 5 cycles are required to charge the monocyclic reactor fields and establish a commutating voltage. During this time the voltage of the d-c line is zero (the displacement of the straight portion of traces D, E, and F from the zero line is a measure of the voltage of the d-c line). An additional 3 cycles after the initial 5 are required to establish full load.

This slow response of the system to load changes is very favorable to the suppression of arcs formed on the d-c circuit. It is undoubtedly this characteristic that permits a knife switch short-circuiting the d-c lines to be closed and opened without causing an appreciable arc, although the d-c lines are operating at 15,000 volts.

The oscillograms of figures 13 and 14 show the same currents and voltages as figures 11 and 12, but under the transient conditions of switching a 1-ampere 250-volt cartridge fuse across the d-c lines. The fuse blows and successfully interrupts the 15,000 volt arc, although rated for only 250 volts. It is particularly interesting to note that the inverter output current in the constant potential lines does not decrease very greatly even during the time the d-c line voltage is considerably reduced. During the time of this disturbance the energy stored in the reactances of the monocyclic network serves as a reservoir to maintain the operation. It has not been possible to determine how well the inertia of the monocyclic network would have maintained the output during the transient disturbance if the load had been an ohmic impedance rather than an inverter feeding into a large system.

Fig. 13. Transients occurring when d-c line is short-circuited through a 1 ampere fuse

D-c line volts, 13,100; d-c line amperes 10.1; capacitance volts 440; load 550 volts, shop
A, B, and C. Line current, constant potential lines
D, E, and F. Line current, constant current lines

The traces shown as D, E, and F of figures 12 and 14 must be interpreted with some care because these tube voltages were taken with potential transformers, using a series capacitor to block the d-c component of the voltage. It is possible for this arrangement to introduce extraneous transient effects, but other sources of information indicate that the phenomena shown in figures 12 and 14 were present, although the time lag as shown on traces D, E, and F may have been exaggerated.

This inertia of the monocyclic network serves a very useful purpose in maintaining the inverter operation in case of tube failure. Unfortunately, high voltage rectifiers and inverters have been subject to occasional tube failures. In constant potential equipment this results in a serious condition and usually causes the protective equipment to disconnect the apparatus from the line and thereby results in an interruption. In a constant current rectifier or inverter employing a monocyclic network, a tube failure of a transient character does not cause the apparatus to be disconnected from the line, does not produce any harmful condition, and may not cause an appreciable interruption of service.

Fig. 14. Transients occurring when d-c line is short-circuited through a 1 ampere fuse

D-c line volts 12,200; d-c line amperes 10.1; capacitance volts 425; load 550 volts, shop
A, B, and C. Line voltage, constant current lines
D, E, and F. Inverter tube voltages, positive side

It has not been possible to catch a tube arc-back or loss of control on an oscillogram, but it has been possible to produce these conditions many times by the use of defective tubes. Almost invariably the apparatus will run through these tube failures with no appreciable interruption of the output.

Losses

The losses involved in converting constant-potential a-c power to constant current d-c power, or conversely, are about 1 per cent. It would appear possible, therefore, to convert an a-c transmission system to a d-c constant-current system and incur only a 2 per cent increase of the losses as based upon the power transmitted. A greater saving than this probably can be effected by the elimination of the wattless component of the current by the d-c transmission system.

In conclusion the authors would emphasize the stability and reliability promised by this new system of power transmission employing constant current rectifiers and inverters.

A Carrier Current Relay Installation

Operating experience obtained during 2 lightning seasons with an installation of carrier current relays on a New England power system is presented herewith. A résumé of the reasons for the choice of this type of protection also is given, and the relay and carrier current equipment is described.

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DURING the spring and early summer of 1933, the Turners Falls Power and Electric Company, together with the United Electric Light Company and the Western Massachusetts Electric Company, subsidiaries of the Western Massachusetts Companies, installed a system of carrier current controlled relay protection on approximately 105 miles of double circuit tower lines comprising that part of their 69 kv transmission system which is between the Cabot power station and the Agawam substation. The relays and associated equipment were installed on a total of 28 line terminals at 10 various stations, including one of the Holyoke Water Power Company's stations. A geographic sketch of the system involved is shown in figure 1, and in figure 2 is a schematic layout of the system.

The system involved is continuously interconnected with that of the New England Power Company on the north at Cabot station, by means of a 115-kv double line tap to the Harriman-Millbury line; and on the south to the Hartford Electric Light Company and other Connecticut companies, by a double circuit 69-kv line.

The relay scheme previously in use was a combination of balanced line power directional relays and balanced line directional ground relays, with relays for single line or double line operation. This scheme had several serious drawbacks, chief of which was the long time delay in clearing the line sections due to the high current and long time settings required for normal operation. The results of such long time settings were serious damage to the lines, and long interruptions to equipment when the lines were subjected to flashovers from lightning or other causes.

For the purpose of eliminating this recurring damage, several schemes were proposed:

1. Rebuild the lines to increase the insulation; or
2. Decrease fault currents; or
3. Reduce circuit breaker time by improvements in relays and methods of operation. The lines had already been equipped with high speed circuit breakers.

Of these 3 possible remedies, changing the relay scheme seemed to offer the most improvement for the money invested.

Two general schemes of relay protection were studied:

1. The application of distance type and high speed balanced line relays.
2. The application of high speed power directional relays with pilot wire or differential type of control.

Whatever scheme of relays was used, it would have to provide quick clearing time for both single line and double line faults, as past experience indicated that approximately 75 per cent of all lightning flashovers would involve both circuits.

Due to the peculiarities of the system in question, i. e., the combination of long lines and short lines with tap stations at various points, distance relays would not function entirely satisfactorily. During fault conditions instantaneous tripping of the circuit breakers at both ends of any line section could not be

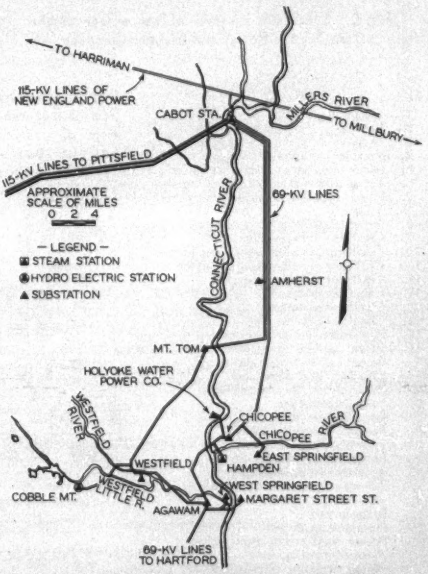

Fig. 1. The 69-kv system of the Turners Falls Power and Electric Company

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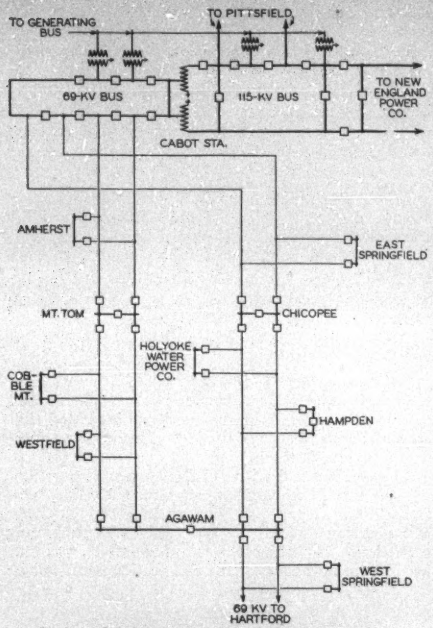
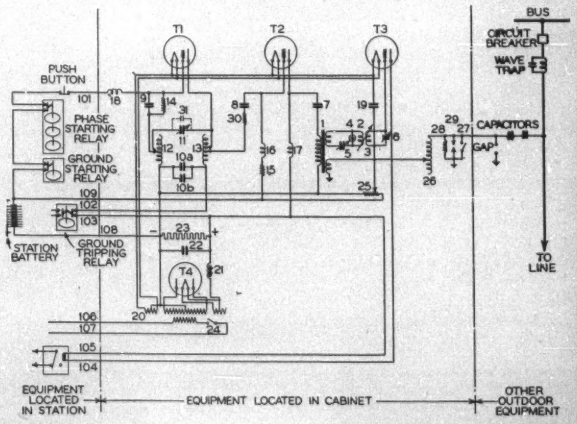


Fig. 2. Schematic diagram of the system of the Turners Falls Power and Electric Company

ITEM NO.	NAME
1.	Output transformer
2.	Receiver primary coupling coil
3.	Receiver secondary coupling coil
4.	Receiver protective neon glow lamp
5.	Receiver primary variable condenser
6.	Receiver secondary variable condenser
7.	Power amplifier plate blocking capacitor
8.	Power amplifier grid coupling capacitor
9.	Oscillator grid capacitor
10a.	Oscillator plate blocking capacitor
10b.	Oscillator plate blocking capacitor
11.	Oscillator variable capacitor
12.	Oscillator grid coil
13.	Oscillator plate coil
14.	Oscillator bias resistor
15.	Power amplifier grid resistor
16.	Power amplifier grid-choke coil
17.	Power amplifier plate choke coil
18.	Oscillator grid choke coil
19.	Receiver bias by-pass condenser
20.	Power transformer
21.	Rectifier filter reactor
22.	Rectifier filter capacitor
23.	Rectifier voltage divider
24.	Power supply switch
25.	Receiver bias potentiometer
26.	Tuning inductance
27.	Grounding switch
28.	Drainage coil
29.	Protective spark gap
30.	Power amplifier excitation resistor
31.	Auxiliary tank capacitor
T-1	Master oscillator tube, type 210
T-2	Power amplifier tube, type 210
T-3	Receiver tube, type 210
T-4	Full wave rectifier tube, type 83

Fig. 3 (below) Schematic diagram of carrier current equipment



obtained. With distance relays in use on the Cabot-Mt. Tom lines, for instance, the minimum time for the clearing of a fault would be between 50 and 60 cycles and, for a fault in the vicinity of a tapped station, this time delay would occur at both ends. Conditions would be even worse were these relays applied to some of the other lines.

Carrier Current Equipment Proposed

A study of the pilot wire or differential type of protection indicated that the straight pilot wire type of control was, due to the length of pilot wire conductors required, out of the question. Conductors owned by the communication companies were considered but it was decided to use apparatus under the control of the power company. By using carrier-current equipment, the pilot wire conductors themselves could be omitted and the conductors of the high voltage line used instead. The transmission of a carrier current signal would be required only during the existence of a fault on the system; and then only on those lines not involved in the fault. That is, the carrier current signal would be used to provide a locking-out of tripping relays on the good line rather than for the tripping of the faulted lines.

The relays in use on each line terminal would consist of special over-current relays coördinated with high speed power directional relays so connected that tripping would be obtained only for the condition of power flow into the line with no power flow out of the line. If, at any station, the flow of power was from the line to the bus, the relays would start a carrier signal which would be received practically instantaneously at the other terminals on the line and would operate relays to open the tripping circuits of all the oil circuit breakers on that line, thus preventing the opening of such breakers.

The relays, both phase and ground, at both ends of the lines and at all tap stations would be set for the same time, approximately 8 cycles. This time setting would depend entirely upon the time required

for the carrier sending relays and the lock-out relays to operate.

No extensive calculations would be required for determining the setting for the carrier current relays. Distance relays, however, involve extensive calculations which become quite complicated if ground fault protection is required.

Potential for directional relays on carrier current equipment is required only for indicating direction, not reactance or distance measurement, and may be taken from low voltage sources. Thus, high voltage potential transformers are not needed except where required for directional ground protection.

After extensive studies of the general schemes mentioned above, the scheme of carrier current pilot control, with the line conductors supplying the carrier channel, was adopted. High speed power directional and directional ground relays were selected for the relay equipment.

A description of the schemes finally selected for use at the various stations is naturally divided into 2 parts, as follows:

1. Carrier current equipment
2. Relay equipment

The equipment will be described in this order.

Carrier Current Equipment

The carrier current set is divided into 3 parts, as follows (refer to figures 3 and 4):

1. Rectifier shelf (bottom of cabinet).
2. Transmitter and receiver shelf.
3. Line tuning panel and protective devices (top of cabinet).

Rectifier. The 500 volt d-c power supply, for operation of transmitter and receiver, is obtained from a full wave tube rectifier, using a step-up transformer and a type 83 rectifier tube, operating from a constant source of a-c potential, 115 volts, and approximately 60 cycles, obtained from a small dynamotor operating on the station battery. Each dynamotor is capable of supplying the power requirements for 2 carrier current sets. A spare unit with proper throw-over relays is provided for emergency use in the event the regular set fails.

Transmitter. The master oscillator of the transmitter uses one of the standard oscillating circuits in which the frequency calibration is obtained by a variable air condenser. The oscillator is started by removing the 125 volt negative bias which is normally applied to its grid. One step of amplification is used to increase the output of the transmitter.

Receiver. The receiver consists of 2 loosely coupled tuned circuits using only one tube as a grid biased detector.

General. The protective devices located in the outdoor cabinet of the carrier current set consist of grounding switch 27, drainage coil 28, and spark gap 29. The line tuning panel, 26, is used to tune the inductance of the antennae system for maximum output at any frequency.

One phase coupling and ground return is used for the transmission of the carrier signal. The connections between the outdoor cabinet and the capacitors consist of a high grade rubber insulated number 6 solid copper wire, mounted on a minimum number of vertical insulators. Two 46 kv, 0.001 microfarad capacitors connected in series are used on the 69 kv circuits. They are mounted adjacent to each other on 46 kv insulators. These capacitors are similar to others already in use for ground relay potential.

In addition to using the capacitors for carrier current relaying, at some locations they are also used in conjunction with potential devices to obtain a line potential for synchronizing purposes. For this use, an auxiliary capacitor, 0.002 microfarad, and a carrier frequency choke are required.

A carrier frequency line trap consisting of an inductance coil and condenser is installed in series with the phase wire used for the carrier current channel, and is located between the tap to the coupling capacitors, and the bus at each station. This trap is necessary to keep the high frequency current in the section of line where it belongs, and to prevent external faults from short-circuiting it.

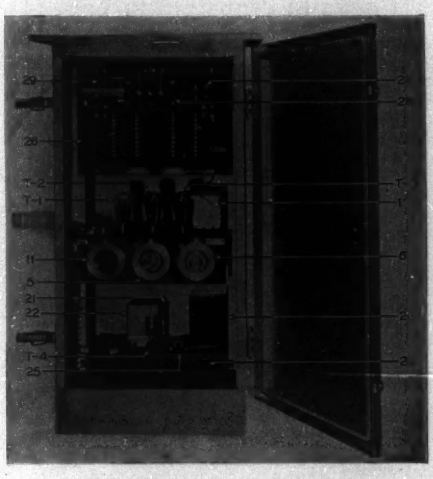


Fig. 4. Outdoor carrier current cabinet

Relay Equipment

The relay equipment proper has 2 functions to perform, as follows:

1. To start transmission of blocking signal when power flow is from line to bus.
2. To trip the oil circuit breaker for line faults.

Two different schemes were finally chosen for use, one scheme being used at the sectionalizing stations, Cabot, Mt. Tom, Chicopee, and Agawam, while the second scheme was used at the remaining stations,

namely, Amherst, Cobble Mountain, Westfield, Hampden, Holyoke, and East Springfield. The difference between the 2 schemes is in the type and connections of the phase relays used for tripping.

In general, 2 phase relays and 2 ground relays are used, one relay of each having normally closed contacts that open on power flow from the line into the bus. Another set of relays of the conventional type are used to complete the tripping circuit to the oil circuit breaker. The connections from the current transformer to the various relays in use at a sectionalizing station are shown in figure 5. The 3 pole,

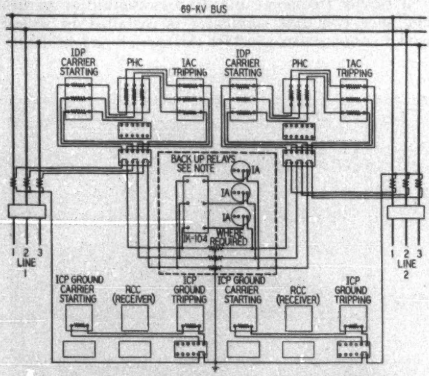


Fig. 5. Connection diagram for current transformers and relays controlling carrier current equipment

Note: Back-up relays and midpoint autotransformer located on separate panel

type *PHC* plunger relay contacts are used to remove voltage restraint from the power directional type *IDP* relay, which is used as the carrier current starting relay.

The tripping of the oil circuit breaker is accomplished by the type *IAC* relays through the contacts of the type *IDP* relay. The control connections are shown in detail in diagram of figure 6. The circuit for the carrier starting relays is through the contacts of the phase *IDP* relay and ground *ICP* relay in series.

Provision is made for manual test of the complete carrier apparatus by means of a push button in the circuit to the grid of the master oscillator tube. This provides a complete test of all sending and receiving apparatus, including a check of the tripping circuit.

The receiver relay is of the d-c polarized type, operating on approximately 2.5 milliamperes in the operating coil. The polarizing coil is constantly energized at 125 volts direct current. The contacts are of the single pole double throw type. A holding coil is provided to hold the contacts in the normally closed position in case tripping current is flowing, thus preventing operation of the relay by a stray carrier signal and burning of the contacts. The normally closed contacts of this relay are in the tripping circuit and operation of this relay by a received carrier signal prevents tripping of the circuit breaker. Suitable connections through the normally open contact provide for a visible and audible signal when the relay is in the operated position.

The scheme at the tap stations substitutes a type *IDP* for the 3 pole *IAC* relay, to provide for the tripping functions through circuit closing contacts, when the power flow is into the line. The phase carrier starting relay operates to open its contacts when the power flow is into the bus in either case.

The ground relay protection functions in a similar manner, except that the tripping relay has an additional set of contacts which are normally closed. This set of contacts is in the plate circuit of the master oscillator tube and prevents operation of the transmitter when the tripping ground relay operates, even though the phase power directional relay indicates a resultant power flow into the bus.

Back-up overload relays are installed at certain locations, namely, Cabot, Mt. Tom, Cobble Mountain, Agawam, Hampden, Chicopee, and East Springfield. They are connected as shown in the dotted insert of figure 5.

The photograph in figure 7 shows front view arrangements of the panels as finally used. The relays for one line are on the top section and the second line on the bottom section of the panel.

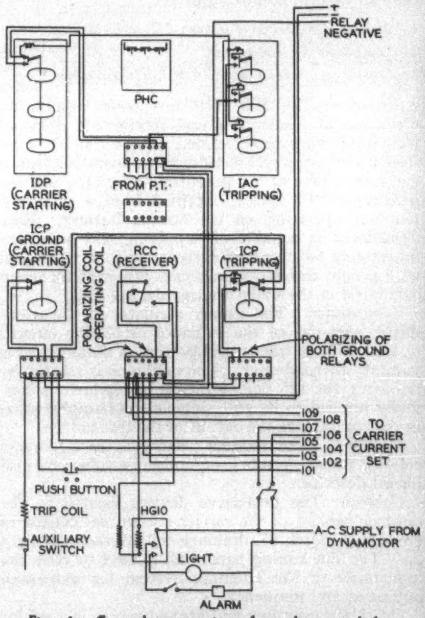


Fig. 6. Control connections for relays used for carrier current protection

Installing and Adjusting

The procedure followed in installing and adjusting the carrier current equipment is described briefly as follows.

The carrier current apparatus was set up and put in working order, and all adjustments and settings made before the relays controlling this equipment were connected to the current transformers.

On this system, 2 parallel circuits were available in each section of line. The carrier current equipment on one line was used by the testing crew for communication purposes between the several stations on the section while final adjustments were being made on the equipment of the remaining line. For this purpose a small telephone unit, consisting of a telephone hand-set and some auxiliary equipment was used to modulate the transmitted signal by talking. All of the preliminary adjustments, except setting the carrier frequency traps, were made with the line in service.

Final tests and adjustments on the remaining line were made as follows.

An arbitrary value of frequency was selected for trial. The line was removed from service, but not grounded. Having the section of line open at all points was the equivalent to having perfectly tuned traps at these locations for all frequencies. Thus, the effects of the wave traps were neglected on these preliminary tests. A signal was transmitted, the frequency of which was varied in steps of 1 kilocycle, over a range of approximately 10 kilocycles either side of the selected value. The value of frequency was determined by a wavemeter located at one station.

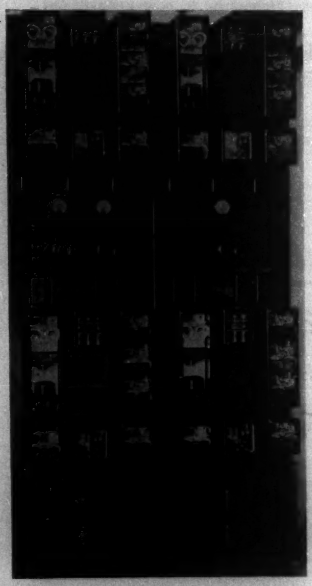


Fig. 7. Front view of relay panels

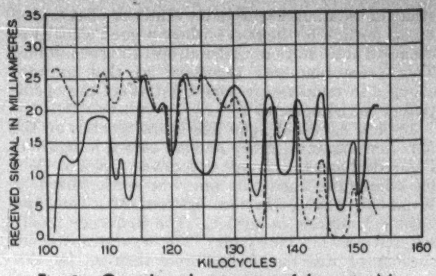


Fig. 8. Open line characteristics of the entire Mt. Tom-Agawam line; signal sent from Mt. Tom

Solid line—Signal received at Westfield substation
Dash line—Signal received at Agawam substation

The sets at the remaining stations on the line section under test were tuned to the frequency of the first set, by having both sets transmit a signal at the same time. With a telephone receiver connected to the receiver circuit of the second set, a beat note was audible. The frequency of the second set was

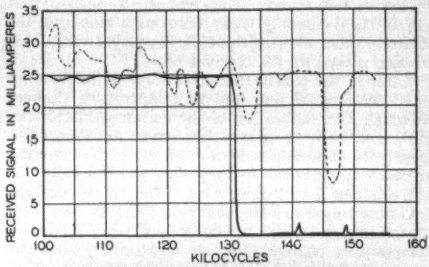


Fig. 9. Open line characteristics of the Mt. Tom-Agawam line; signal sent from Mt. Tom

Solid line—Signal received at Cobble Mountain, Agawam tap open at Westfield
Dash line—Signal received at Cobble Mountain, Agawam tap closed at Westfield

brought into synchronism with the first by lowering the pitch of the beat note until it disappeared. The output was tuned to a maximum value by changing taps on the tuning inductance coil. The receivers were tuned for a maximum received signal. Complete readings were recorded for each value of transmitted frequency.

These data, when plotted, gave a curve of the open line characteristics for transmission of the high frequency currents over the entire line. It was also necessary, in order to obtain proper relaying under certain operating conditions where transmission lines may be sectionalized, to obtain a similar curve for various portions of the line.

The final frequency which was selected from a

study of these curves was in the center of a flat topped broad portion of the curve where a good signal was obtained at all stations under all operating conditions. This precaution was necessary so that extreme changes in temperature would not affect the operation of the equipment.

Typical curves of open line characteristics on the Mt. Tom-Agawam entire line are shown in figure 8. Figure 9 shows the change in received signal at Cobble Mountain when this line was sectionalized at Westfield, leaving the line between Mt. Tom and Cobble Mountain in service. The frequency finally selected was 116 kilocycles. The wave traps at all stations on this line section were then set for this frequency.

Additional data were taken with the line still out of service, but with the phase to which the carrier current equipment was coupled grounded on the station side of the wave trap; and also, with the line in service.

When this equipment was ready for service, the temporary telephone equipment was changed over to the finished line, and a similar set of tests made in the line which had been used for communication.

Difficulties

A continuous signal was received at just one station on one section of line. This was due to a faulty fuse clip in the d-c supply leads removing a bias from the detector tube, allowing this tube to pass current, which in turn picked up the receiver relay.

Later in the season there was some difficulty on 1 or 2 sections of line due to temperature changes affecting the calibration of the master oscillator circuit, and shifting of the line characteristics sufficiently to eliminate reception of the carrier current signal. These shifts in frequency were probably in the order of 1 to 2 kilocycles. The carrier current sets were tuned to a frequency on the edge of a peak on the line characteristics curve, and the shift due to temperature changes, though slight, were sufficient to cause trouble. In most cases, the tuning band of good reception was broad enough to allow slight shifts in frequency, and still get good reception at all temperatures. In one case, it was necessary to shift to an entirely different frequency band.

Trouble was caused by very heavy rain storms or sleet causing sufficient leakage on lead-in wires and supporting insulators so that no signal was received. The original lead-in connections were bare copper wire. By using an insulated lead-in conductor, vertical mounting of supporting insulators, and rain shields, these conditions were improved and no further trouble is expected.

Maintenance

The carrier current sets are checked at 7:15 a.m., 3:15 p.m., and 10:30 p.m. by each station operator sending a signal in a predetermined order. Failure to receive a signal at any point is immediately checked by the operators themselves. They are instructed how to change tubes in the carrier current sets, check relay contacts for proper position, and, in general, to note whether the set is failing to send out the signal or the set at the other end failing to receive the signal. Cases which require more knowledge than this are reported at once to the proper parties for investigation.

As a further assistance to the operators, and for use in checking the operation of the carrier current equipment, ammeters with a 50 milliampere range and mounted on test plugs are available for measuring the received signal. The operators are instructed to take readings when the routine tests are made, or to observe that the received signal does not drop below a minimum of 10 milliamperes. This is considered the lowest desirable value, although the receiver relays will operate at 2.5 milliamperes.

The sets are given a general inspection late in the fall and a more detailed inspection in the spring just before the lightning season.

Normally, tubes are allowed to run until failure takes place, except on the inspection just before the lightning season when all tubes of a doubtful nature are replaced. Tube replacements have not been excessive and therefore it has not been considered necessary to keep individual tube records any more than one would of the Mazda lamps in his house. The type 210 tube life, as far as can be determined, is about a year. These tubes have a rated life of 1,000 hours, but last approximately 8,000 hours. This is due to the fact that while the tube filaments are lighted at all times, they only pass plate current intermittently. The type 83 tubes are somewhat shorter lived, probably averaging 6 to 8 months. A complete replacement of tested type 83 tubes and a 50 per cent replacement of type 210 tubes are kept

Table I—Number of Relay Tripping Operations

	1933	1934 to Oct. 1	Total
Total number of correct operations	113	164	277
Incorrect operations	10	22	32
Failures to operate	9	2	11
Total operations, including failures	132	188	320
Per cent correct operations	85.6	88	86.6

Table II—Single Line and Double Line Operations

Cause and Type of Fault	1933	1934 to Oct. 1	Total
Lightning			
Double line faults	14	17	31
Single line faults	9	8	17
Total faults	23	25	48
Total line sections in trouble	37	42	79
Other Causes			
Double line faults		2	2
Single line faults	6	9	15
Total faults	6	11	17
Total line sections in trouble	6	13	19
Total—All Causes			
Double line faults	14	19	33
Single line faults	15	17	32
Total faults	29	36	65
Total line sections in trouble	43	55	98

at each station at all times. Tubes removed are gathered into central points and tested every 2 to 3 months.

Operation and Results

In 1933, the relays on the first section of line went into service about the 15th of May, and the last about the first of August.

Since that time, the following number of relay tripping operations shown in table I have occurred.

A total of 8 causes for the incorrect operations and failures to operate have been located and corrected. To date, the causes of only 2 incorrect operations are listed as unknown.

The faults causing these circuit breaker operations were divided between single line and double line interruptions as shown in table II.

Out of 79 line sections tripping out due to lightning flashovers during the 1933–34 seasons, only one developed trouble which prevented the line from being immediately returned to service. This interruption was caused by a mechanical failure of an insulator which allowed one conductor to fall to the ground. The fast relay and circuit breaker clearing time prevented the copper conductor from being damaged.

Tripping of the oil circuit breakers during surging between this system and the systems of adjacent companies, has, up to the present time, been prevented with the installation of this equipment.

The fast relay tripping time, together with the high speed oil circuit breakers, has materially reduced the extent of the damage to the transmission lines, and has reduced the extent of voltage disturbances and surges to a minimum.

This installation of relay equipment has operated in an entirely satisfactory manner and has justified its cost in the results so far obtained.

Ultra-Short Waves in Urban Territory

This paper extends a previous paper on the investigation of ultra-short wave propagation, to include transmission within a built-up region together with a consideration of the additional problems introduced by man-made interference. Tests were made using both a fixed transmitter with mobile receiver, and a mobile transmitter with a fixed receiver.

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EXPERIMENTAL data on the propagation of ultra-short waves in urban territory obtained within the city of Boston, Mass., at a frequency of 34.6 megacycles per second are presented in this paper. The paper is a sequel to an earlier paper "Ultra-Short Wave Propagation,"[1] which dealt mainly with transmission across open country. Mass plots of the field strength as a function of distance both for transmission from a fixed location to a mobile receiver and from a mobile transmitter to a fixed location show that the mean field strength varies inversely as the square of the path length, which is the same variation as would be expected for level terrain in the absence of buildings. The same data are presented also in the form of field strength contour maps. Some effects of local conditions that cause deviations of individual points from the mean curve are discussed on the basis of experimental evidence here presented. The data presented were obtained during the summer of 1933.

These data are interpreted on the basis of the same physical picture that has been established for open country. The present data preclude interpretation upon the basis employed by earlier investigators of ultra-short wave propagation through urban areas. Types of interfering noise are discussed. For reception at the mobile terminal, automobile ignition noise was found to be the most objectionable.

Apparatus

Both terminals employed vertical half-wave antennae which were connected to balanced circuits by means of symmetrical 2-wire transmission lines. At the fixed locations unloaded antennae were used; at the mobile terminal, in order to limit their heights to 8 feet above the ground, the antennae were loaded so that their lengths were reduced to about a quarter wave length (see figure 1).

The transmitter consisted of an electric oscillator employing 2 75-watt tubes operating in push-pull relationship. At the fixed location where ample power was available, the transmitter was capable of producing 1 ampere (measured by a Weston type 425

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1. For all numbered references see list at end of paper.

thermoammeter at the current maximum) of 100 per cent modulated carrier in its antenna without undue distortion. The mobile transmitter, which used a dynamotor for tube plate supply, was capable of producing the same current in its antenna. This corresponds to about 6 decibels less power because of the shorter antenna length.

The measuring set was of the double detection type with balanced high frequency circuits, push-pull first detector, and calibrated intermediate frequency attenuator. The set was similar to that described previously by Friis and Bruce.[2] This receiving equipment was calibrated in absolute units by the method described in the appendix. A mechanism for recording the field strength was attached to the measuring set; this consisted of a roll of paper that could be driven either by clockwork or by the rear wheels of the truck. The position of the recording pen was controlled by the setting of a manually operated variable attenuator. Samples of the type of record obtained are shown in figures 6 and 7.

Locations

The radiator for the fixed transmitter was supported by a 50-foot pole above the roof of a 7 story building at the corner of Berkeley and Stuart streets in the business section of Boston. The building is about 90 feet high, making the center of the antenna about 130 feet above the ground. Thus, the antenna was higher than most of the buildings of the city though it was lower than a few buildings nearby.

The antenna for the fixed receiver was supported by a 20 foot pole from the middle of the highest ridge of a gabled building, making the center of the antenna about 80 feet above the street level. This building is situated on the side of a slight slope in a fairly heavily wooded territory, on Seaverns Street near Center Street.

Field Strength Measurements: Transmitter at a Fixed Location

With a current of 1 ampere in the half-wave antenna above the building at Berkeley and Stuart

Fig. 1. Mobile receiving equipment

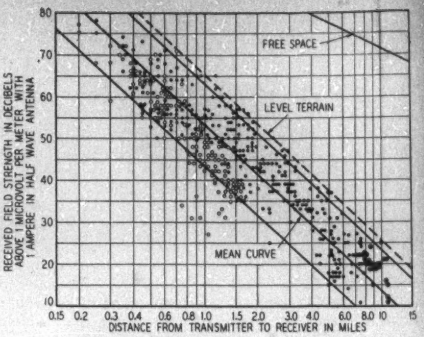


Fig. 2. Mass plot of field intensities measured at various distances from the transmitter at Berkeley and Stuart streets in Boston

The values corresponding to distances less than 2 miles represent field strengths averaged over $^1/_{10}$ mile intervals, while those for greater distances represent averages over $^1/_2$ mile intervals. The open circles indicate fields in the high building area; the solid circles indicate fields in the residential district. Residential points outside the city limits have been enclosed in circles

streets and with the receiver in the truck, field strength measurements were made along various routes throughout Boston. Since the antenna was in free space in so far as radiation resistance is concerned, this current corresponds to a radiated power of 73 watts. The data thus obtained have been averaged by $^1/_{10}$-mile intervals when the average radial distance was less than 2 miles and by $^1/_2$-mile intervals for greater average distances. A plot of these data is shown in figure 2. The points lie approximately on an inverse-square-of-distance line with deviations ranging up to about ±10 decibels. An effort has been made to separate the points taken in the high building area. These points (shown as open circles) lie somewhat below the others with a few particularly low field strengths. The lowest field strengths in the business district were measured along the shore near Charles River Dam and near State Street on Atlantic Avenue. The field strengths in the business district would be expected to be lower because of the presence of the high buildings. The lower residential field strengths correspond to the region beyond Chestnut Hill.

When attempting to interpret the results of the mass plot of figure 2 a natural method would be to assume transmission as in free space plus an additional attenuation due to the proximity of the earth and obstacles above the earth's surface. The simpler case of transmission over level terrain in the absence of obstacles will be considered first.

It has been determined experimentally that the propagation of ultra-short waves over unobstructed paths follows the laws of optics[1,2] so that the resultant field is composed of a well defined reflected wave superposed upon a direct wave. Consequently for propagation over level terrain, the explanation is as follows (figure 3): Energy is propagated from a

transmitter at A, at a height of h_1 above the ground, to a receiver at B, at a height of h_2 above the ground, both directly, as represented by r_1, and by reflection at G, as represented by r_2, the distance between transmitter and receiver being represented by d. For the practical case where h_1 and h_2 are small compared with d, the reflected wave impinges upon the ground at nearly grazing incidence, so that a negative reflection coefficient, the magnitude of which is unity for ordinary ground (not water) is obtained. This results in the field at B being the difference between 2 vectors of equal magnitude and differing in phase by an amount corresponding to the difference in path lengths, r_2 and r_1. For the case under consideration,

$$r_2 - r_1 = 2h_1h_2/d \tag{1}$$

and the angle between the vectors is

$$2\pi(r_2 - r_1)/\lambda = 4\pi h_1h_2/\lambda d \tag{2}$$

Except in the immediate proximity of the transmitter, this angle is small and the resultant field is

$$E = E_0\,(4\pi h_1h_2/\lambda d) \tag{3}$$

where E_0 is the free space field.

To be more exact, the magnitude of the negative reflection coefficient of the ground is $1 - 2\epsilon\,(h_1 + h_2)/d\sqrt{\epsilon - 1}$ for vertical polarization and $1 - 2(h_1 + h_2)/d\sqrt{\epsilon - 1}$ for horizontal polarization, making the corresponding values for the received fields,

$$E_0\,\frac{(4\pi h_1h_2)}{\lambda d}\sqrt{1 + \frac{\epsilon^2(h_1 + h_2)^2\lambda^2}{(\epsilon - 1)\pi^2h_1^2h_2^2}} \tag{3a}$$

$$E_0\left(\frac{4\pi h_1h_2}{\lambda d}\right)\sqrt{1 + \frac{(h_1 + h_2)^2\lambda^2}{(\epsilon - 1)\pi^2h_1^2h_2^2}} \tag{3b}$$

respectively, instead of as in equation 3. When the lower of the 2 antennae is more than a couple of wave lengths off the ground, the radicals are substantially unity. For the case under consideration it would be more accurate to refer to expression 3*a* as the theoretical formula, but lack of knowledge of the magnitude of the dielectric constant and antenna heights that apply would introduce unnecessary uncertainty if the results were referred to this formula. It might be remarked that neglecting the presence of buildings and referring all heights to the local street level, the radical represents an increase of 13 to 20 decibels for vertical polarization in the cases under consideration.

Now since

$$E_0 = 60\pi HI/\lambda d \tag{4}$$

the resultant field becomes

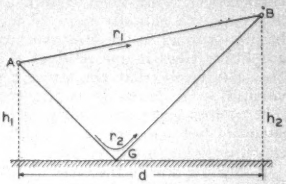
$$E = 240\pi^2HIh_1h_2/\lambda^2d^2 \tag{5}$$

If I is in amperes, d in meters, H the effective height of the antenna, and λ the wave length in the same units, E_0 is given in volts per meter.

Equation 5 shows that the field over level terrain is inversely proportional to the square of the distance from the source. Since distance appears in this equation only as a factor and not as an exponent, the reduction with distance of the field strength of ultra-short waves over level terrain is independent of wave length, polarization, dielectric constant, etc., as all of these quantities cancel in the ratio of the field strength at one point to that at another. The absolute magnitude of the field strength is proportional to the frequency for the same radiated power and antenna heights. If the antenna heights are sufficiently low, the field is also dependent upon the polarization and ground constants as indicated by expressions 3*a* and 3*b*.

Data presented in figure 8 of reference 1 show that at a frequency of 69 megacycles per second the field strength variation with distance follows approximately the inverse-square relationship for a range of from 2 to 90 kilometers. In fact, the best straight line through these data agrees with the numerical values obtained from equation 5 well within the accuracy of the experimental data. While undoubtedly at the greater distances the field suffers additional attenuation above that shown by equation 5 due to the curvature of the earth, such additional attenuation evidently takes place at distances beyond those employed in any of the authors' experiments. Experiments designed to test the validity of this equation now are being conducted at Deal, N. J., and data obtained to date confirm it both as to absolute value and variation with terminal heights and wave length for horizontal polarization within the range $2 < h_1 < 25$, $2 < h_2 < 25$, $2 < \lambda < 17$, $d = 9{,}420$, and 26,300, all measured in meters.

Fig. 3. Diagram illustrating wave propagation over level terrain



The experimental confirmation of this formula for these distances indicates that the earth's curvature is secondary to the negative reflection effect upon which this formula is based. This might be expected in view of the fact that both diffraction and refraction tend to mitigate the additional attenuation that would be caused by reflection from a plane tangent to the earth's surface at the point of geometric reflection.

When the propagation is through built-up areas instead of over level terrain, the condition is more complicated. Even here, however, for terminals well above the tops of buildings, theoretical considerations[1] indicate that the same explanation of direct and reflected waves is valid. Data presented by Jones[4] may be used as a verification for this explanation even for transmission over buildings. Figure 11 of his paper shows that for heights between 170 and 1,500 feet the field is proportional to the height in accordance with equation 5. When the terminals are lowered within the building region, the field should decrease more rapidly than proportionally with the height above the ground. In fact, data presented in figure 4 indicate that, with one

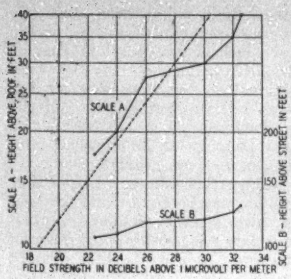


Fig. 4. Variation of field received at Berkeley and Stuart streets with antenna height

Curve A shows the variation with height above the roof, while Curve B shows the variation with height above the ground. The slope of the broken line indicates a linear relationship between field and height

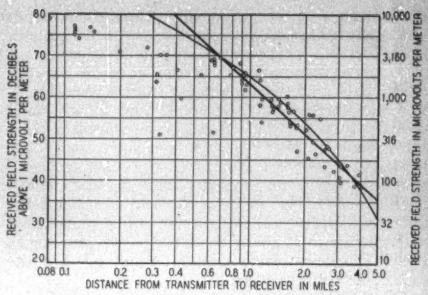


Fig. 5. Attenuation curve for 5 meter transmissions as replotted from paper by Muyskens and Kraus (see reference 7)

The straight heavy line shows an inverse-square-of-distance variation in accordance with the physical picture. The thin curved line is a replot of the curve presented by Muyskens and Kraus as representing these data by a variation according to an inverse-distance times an exponential factor. It is evident that these data may be interpreted equally well on the basis of the physical picture (heavy curve) as on the basis of the empirical equation assumed by Muyskens and Kraus

terminal above a flat roof that was of approximately the same height as other nearby flat roofed buildings, the field is more nearly proportional to the height above the roof than the height above the ground. When the terminals are lowered below the average building height, additional complications are introduced. While this is somewhat difficult to picture because of the irregularity of the surface bounding the transmitting medium (this surface is, of course, that formed by the ground and the walls and tops of buildings), the main outline seems simple enough. Above the building level there is a tendency for the field to follow the simple rules that hold for transmission over level country. In general, the field strength actually received in the street would be proportional to the field overhead, but of smaller amplitude since it is a product of scattering. This does not imply that the street signal comes down vertically; it probably is the result of scattering from points lying in a fairly large zone about the receiver and consists of a multiplicity of signals traveling in inclined directions.

Returning now to the present data on the propagation of ultra-short waves through urban areas, figure 2 shows that the field strength is in general inversely proportional to the square of the distance from the transmitter. (It will be shown later that the empirical formula assumed by Schröter, Sohnemann, Jones, and Muyskens and Kraus cannot be made to fit these data.) The mean curve through the data is 12 decibels below the curve for level terrain free from obstacles, plotted from equation 5, indicating the additional attenuation due to man-made structures. An analysis of the individual points shows that the reduction in field due to the obstacles (i. e., in addition to the level terrain attenuation) is independent of the distance so that there is no *absorption* due to the buildings in the usual meaning of the word; otherwise the additional attenuation would increase with the distance.

This method of interpretation is radically different from that of investigators of the propagation of ultra-short waves through urban areas whose papers have come to the attention of the authors[4, 6, 7]. They have assumed that the transmission occurs as in free space except for an additional attenuation *through the absorbing layer of buildings*. Such an assumption that the propagation of ultra-short waves is unaffected by the presence of the ground except in so far as the waves penetrate the absorbing layer of buildings, appears to be inconsistent with the physical picture[1,3,8,9] of ultra-short wave propagation which has been confirmed by basic experimental data.

The data presented by Muyskens and Kraus as figure 2 of reference 7 has been replotted in figure 5 of the present paper on logarithmic coördinates in order to facilitate reinterpretation on the basis of this physical picture. Figure 5 shows that it is possible to interpret their data as following an inverse-square-of-distance law equally as well as an inverse-distance law times an exponential factor. In this interpretation little weight has been given to the points that are well below the curve, in accordance with the view of the experimenters that these points represent particularly unfavorable receiving locations.

Trevor and Carter[8] have made a similar interpretation of the data presented by Jones[4] which shows that for the larger distances the field strength was inversely proportional to the square of the distance. If this inverse-square-of-distance curve were extended to shorter distances, it would be found that most of the nearby points would lie somewhat below it. This is presumably because of the lack of favorable receiving locations in the high building area. While the empirical formula arrived at by Jones may represent his data satisfactorily, the physical picture assumed of a free space field times an absorption factor is untenable since it requires a radiated power approximately 20 decibels below that measured. Undoubtedly the power radiated is not in error by this amount, since Trevor and Carter obtained a satisfactory numerical check on the basis of the other picture by using the value of power radiated as given by Jones.

It is possible, of course, to represent any data by

an inverse-distance factor times an exponential factor for a limited range of distances. An attempt to do this with the data of figure 2 by making the empirical curve agree with the experimental inverse-square-of-distance curve at 1 and 4 miles results in a curve that agrees well with the data between 0.6 and 5.0 miles but is 11 and 22 decibels low at 0.2 and 12.0 miles, respectively. Even if this discrepancy at the limits of the curve were neglected it would still be impossible to interpret the data in terms of the free space field times an exponential absorption factor, because the empirical curve so determined requires a radiated power 35 decibels below that measured; this is beyond reason since the over-all uncertainty in the absolute value of the measurements is only a few decibels.

It should be pointed out that each point of figure 2 represents the average field over an interval of either $^1/_{10}$ or $^1/_2$ mile depending upon whether the transmission path involved was less or greater than 2 miles. Within each interval the field varied by 5 to 15 decibels because of the local wave interference pattern, as is shown by the samples of the graphs taken with the recorder, which are presented in figures 6 and 7. Figure 6 is an example of the record taken in the business district of Boston at a distance of about $1^1/_2$ miles from the transmitter near the region *A* shown in figure 8. The maxima and minima are spaced very closely and differ by 10 to 15 decibels. This was characteristic of the type of record obtained at the shorter distances. At the greater distances the magnitude of the local variations was less, as illustrated by figure 7, which is a sample of the record taken at a distance of 5 miles (near *B* in figure 8). The change in the magnitude of the variations might have resulted from the fact that all the data for the greater distances were taken in residential districts with correspondingly lower heights and densities of buildings.

An idea of the variations to be expected from the inverse-square-of-distance relationship is shown by the contour map of figure 8. The data already presented will give an idea of the impossibility of showing much detail in such a map. Likewise it would be an almost endless job to make measurements on every street in a city of this size. While data were obtained within reasonable intervals over the area for which solid contours are drawn (continuous field strength records taken over 143 miles of street are represented by this figure), another set of data might result in a somewhat different looking map. The broken contours are not based upon field strength measurements, but are merely a plausible way of joining the solid contours to aid the eye of the reader. The 2 20 decibel contours in the lower part of the figure have not been joined because of insufficient data. The low field strengths along the Neponset River may be a result of local conditions, and possibly the 20 decibel contours should be continued to the right along an arc of more nearly constant radius. In this connection it may be mentioned that the field is nearly constant within the bulge of this contour to the southwest.

A striking fact brought out by the map is the crowding of the contours in the business district. There are particular directions for which the attenuation is greater presumably due to the combined effects of high buildings, for example to the east-northeast. There are other directions where the field strength is higher than the average. Several such places were noted when salt water extended immediately in front of the measurement location in the direction of the transmitter. The closed contours in the Mystic River to the north illustrate the better reception over salt water as predicted by theory.[1] An example of the records taken over bridges upon which these contours are based is shown in figure 9. (The route over which these data were taken is indicated at *C* of figure 8.) The average increase in field when going over bridges was 10 decibels. This may be explained by the better conductivity of the water, which results in a receiving directive characteristic that is more favorable to low angle reception. In some cases, the absence of buildings and increase in the height of the antenna due to the elevation of the bridge undoubtedly contributed to the greater field.

Another fact illustrated by the map is that the effects of obstacles and type of terrain are in general local. For example, the higher field strengths beyond salt water are soon reduced to normal with the intravention of additional land, illustrated at *D* in figure 8.

It was found that the field strengths along Columbus Avenue (indicated by *E* on figure 8) were about 10 decibels higher than those obtained on either side. This increase probably resulted from the fact that a more or less unobstructed optical path existed along Columbus Avenue.

While a detailed analysis of the attenuation of ultra-short waves over paths as complicated as those considered in this paper is impossible, the

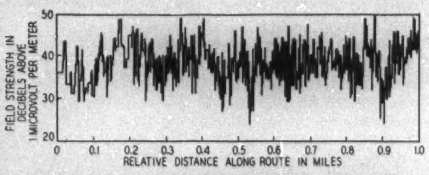


Fig. 6. Portion of record showing the large field strength variations as recorded while driving through the business district of Boston at a distance of about 1.5 miles from the transmitter

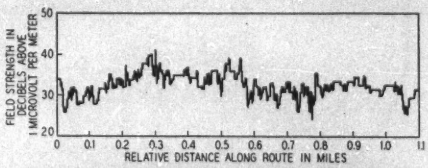
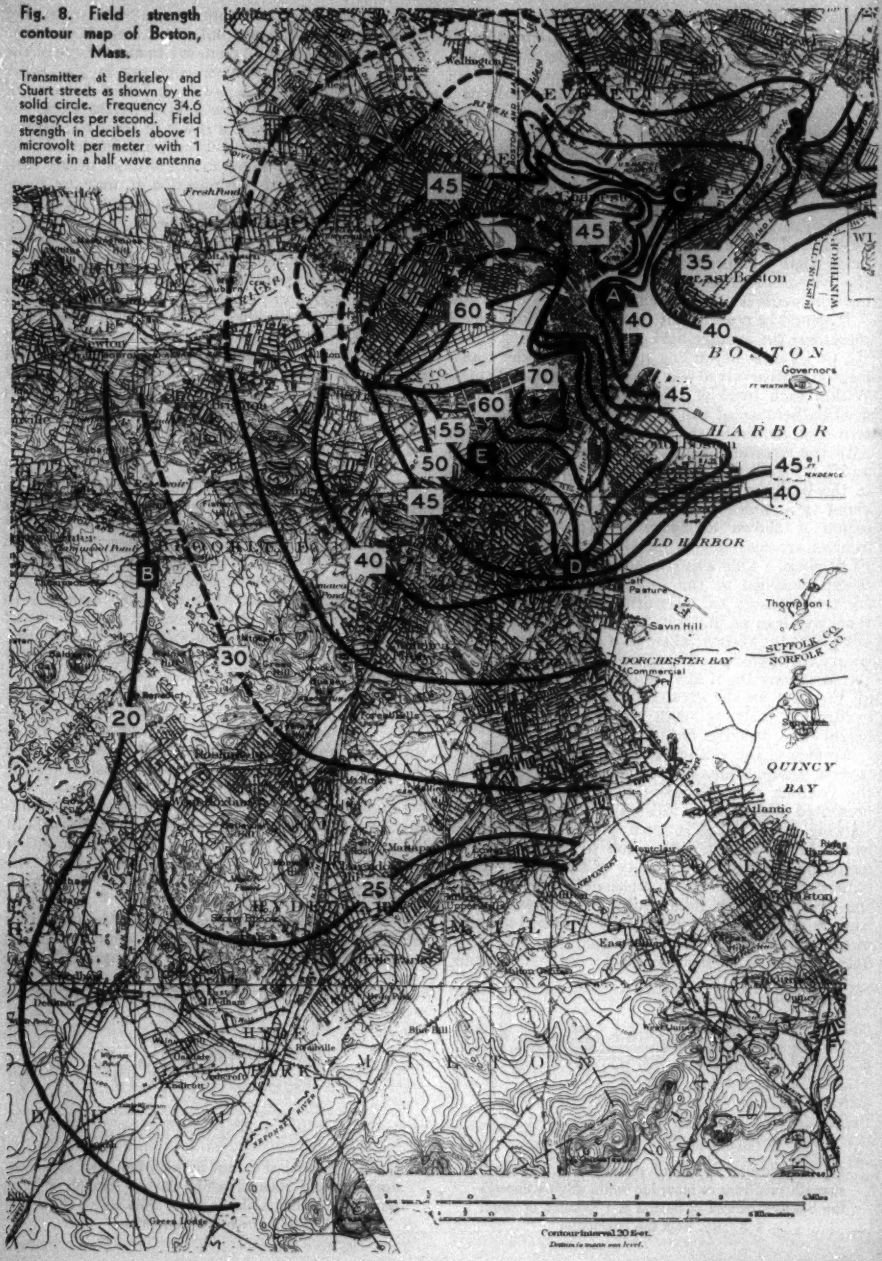


Fig. 7. Portion of record showing the small variations of field strength while driving through the residential section of Boston at a distance of about 5 miles from the transmitter

Fig. 8. Field strength contour map of Boston, Mass.

Transmitter at Berkeley and Stuart streets as shown by the solid circle. Frequency 34.6 megacycles per second. Field strength in decibels above 1 microvolt per meter with 1 ampere in a half wave antenna



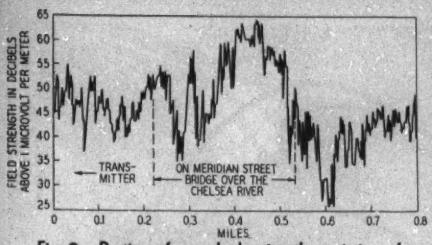


Fig. 9. Portion of records showing the variation of field strength on going over water

known facts indicate several general characteristics that seem worthy of mention for further experimental investigation. The fact that the field was found to be approximately proportional to the height of the antenna above the roof level of the surrounding buildings (figure 4) rather than to the height above the ground, as in the case of transmission over level terrain free from buildings, confirms the expectation that the "ground" conditions in the immediate vicinity of the fixed terminal would play an important part in determining the magnitude of the received field strength.

It is perhaps correct to assume that for the fixed terminal the height to be substituted in equation 5 should be the height above the roof rather than the height above ground. This would reduce the level terrain curve of figure 2 by 10 decibels.

Figures 6, 7, and 9 show marked wave interference patterns which indicate reflections from a multiplicity of points in the immediate vicinity of the mobile terminal. Besides these variations in the magnitudes of the fields observed at points in close proximity to each other, which are undoubtedly caused by reflections from irregularities in the immediate vicinity of the terminal, there are the variations represented by the spread of the points about the mean curve (figure 2). That these variations may be attributable to conditions local to the terminal is indicated by the fact that the increase in field on the far side of salt water and the decrease in the field on the far side of hills, etc., do not persist at further distances. Even if the irregularities of the contours of figure 8 were removed, the contours would not be concentric circles about the transmitter. At this stage in the development it would be unwise to attempt to say how much of the deviation of the contours from circles may be attributable to directional characteristics at the fixed terminal and how much to the intervening terrain. Statistically speaking, however, it is safe to say that the additional attenuation attributable to deviations from level terrain such as is produced by the presence of buildings, is independent of the length of the transmission path, so that there is no *absorption* in the usual meaning of the word. Another experimental result that points to the possibility that the effect of the buildings is local may be deduced from the data presented by Jones[4] and by Trevor and Carter.[8] The latter showed that the more distant points lie on the inverse-square-of-distance curve expected for transmission over level terrain free from buildings. The nearby points, however, lie below this curve, indicating that the major effect of the buildings is a local one.

The greatest difficulty encountered in attempting to apply the results of these experiments to the predetermination of the field to be expected for transmission in other cities would be the interpretation of the method of assigning values to the heights in equation 5. While sufficient data are not available to establish an empirical relation, for a first estimation it seems reasonable that if the height of the fixed antenna were measured from the average roof level of the surrounding buildings and the height of the mobile antenna were measured from the street level, the resulting field strengths would lie within the range of expected values.

Field Strength Measurements: Receiver at a Fixed Location

The field strength data obtained with the receiver at Seaverns Street and the transmitter in the truck are shown in figure 10. These data may be represented also by an inverse-square curve. By comparison with figure 2 no differences that can be attributed to the change in position of the fixed terminal nor the direction of transmission is evident. There is a small difference in the separation between the mean curves and the level terrain curves, but in both instances the mean curve lies very close to the level terrain curve (not shown) that would result from measuring the antenna height of the fixed terminal from the average roof level instead of from the ground.

Most of the nearby points were taken in the park system. They indicate that it is not more difficult

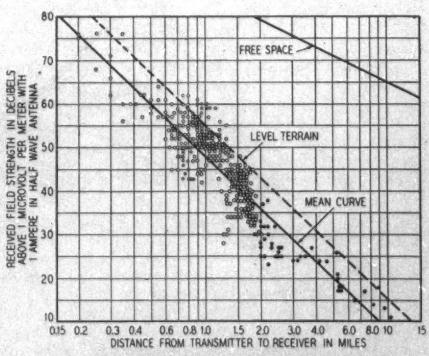


Fig. 10. Mass plot of field intensities measured with the transmitter at various distances about the Seaverns Street location

The open circles represent fields averaged over $^1/_{10}$ mile intervals while the solid circles represent averages over $^1/_2$ mile intervals

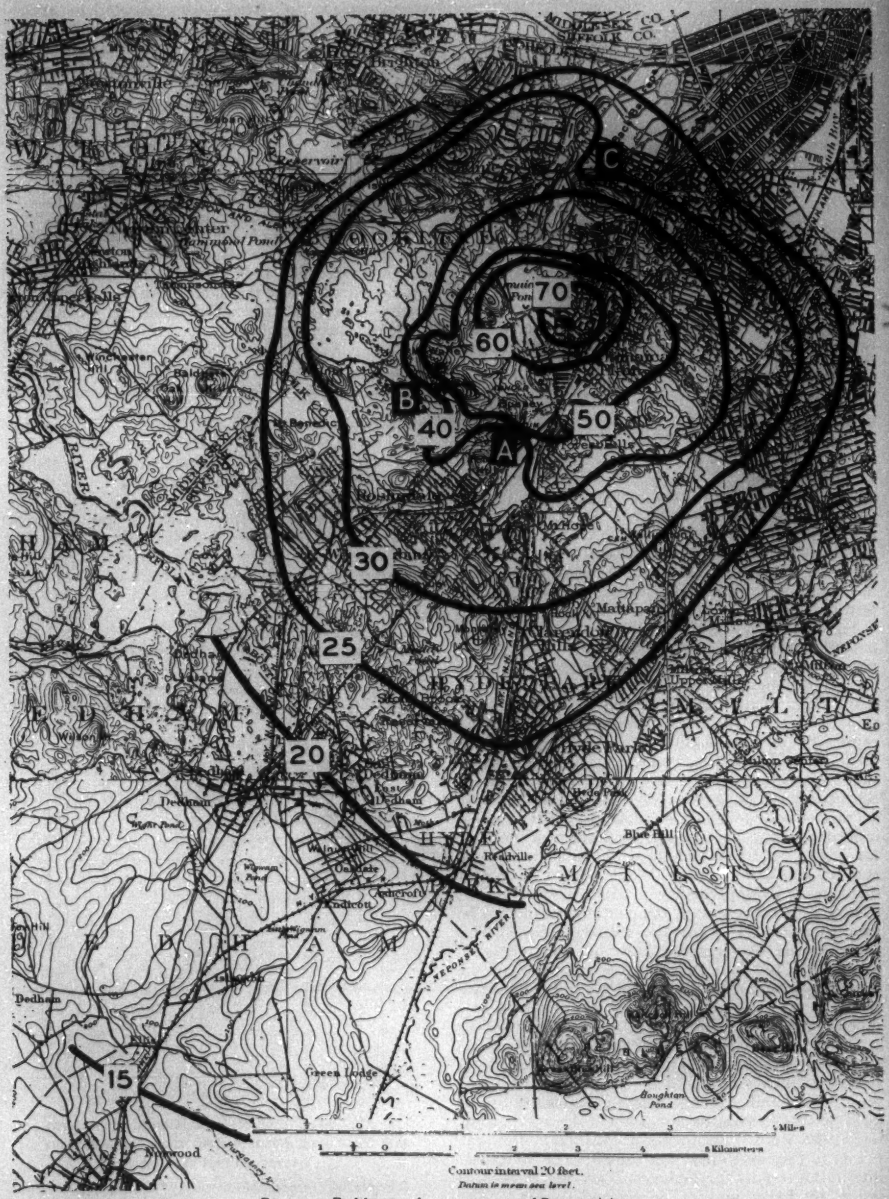


Fig. 11. Field strength contour map of Boston, Mass.

Receiver on Seaverns Street near Center Street as shown by the solid circle. Frequency 34.6 megacycles per second. Field strength in decibels above 1 microvolt per meter

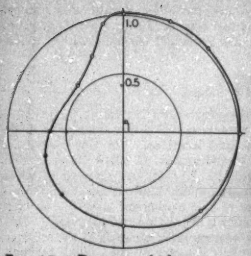


Fig. 12. Directional characteristic in the horizontal plane of the mobile receiver

Fig. 13 (right). Fixed terminal transmitting equipment at Berkeley Street

to transmit through wooded areas than through built-up sections.

A field strength contour map illustrating the results with the receiver fixed at Seaverns Street is shown in figure 11. The disturbing effect of hills is illustrated at several points on the map. There was a reduction of field strength when the transmitter was behind either Bussey Hill at *A* on the map or Green Hill at *B*, while the field was higher when the transmitter was between them. There was a rather deep minimum when the transmitter was immediately behind Parker Hill at *C* to the north, but $^1/_2$ mile further away there was no noticeable effect.

Effect of Obstacles

In the course of the measurements some qualitative observations were made which will be summarized in this section. It was noticed in particular that when the receiver passed underneath an intersection of overhead trolley wires, the field was somewhat reduced. An example of this effect was observed at the intersection of Massachusetts and Huntington avenues where the reduction was 15 decibels. At this point the maze of overhead trolley and support wires apparently constituted a fairly efficient screen for these waves. Observations made during the tests showed that sometimes the field was reduced considerably on the far side of hills as has been brought out by the contour maps. A large reduction in field strength resulted upon going behind a low hill on Saratoga Street in Breeds Island. The most striking example of this effect occurred with the measuring set at Seaverns Street and the mobile transmitter being driven from Huntington Avenue onto South Huntington Avenue (*C* of figure 11). Soon after rounding the corner at the foot of Parker Hill, which is 200 feet high, the average field dropped about 15 decibels.

The field was 20 decibels lower under Funeral Bridge than on either side of it. This is a stone and earth bridge appearing as a short tunnel to the road beneath it. The field usually was reduced upon passing underneath bridges of this general type of construction.

A separation of the field strengths into those obtaining in the high-building area (indicated by open circles in figure 2) from those in the lower-building area (indicated by solid dots) shows that the attenuation is somewhat greater in the former.

No effect of the elevated railway structures on the average field was observed.

Noise Measurements

For reception in the car, by far the greatest interference is that caused by the electrical systems of passing automobiles. Special tests to determine whether or not street cars produced any noise gave a negative result; that is, under conditions where automobile noise was a limitation to reception, trolley noise was inaudible. While no special tests were made of the noise from elevated trains, at no time was it found objectionable.

With the receiver on top of the building at Berkeley and Stuart streets, the predominating interfering noise was caused by an electrical substation next door. When the antenna was lowered approximately to the roof level the noise from the elevator motors and switching equipment in the penthouse nearby was well above any other noise. Upon raising the antenna to its proper position the elevator noise was reduced to a negligible amount compared with the power station noise, because of the combined effect of the directivity of the antenna and increased distance. The resulting noise was of approximately the same magnitude, indicating that the elevator switching noise was reduced by a fairly large factor in raising the antenna. This fact has an important bearing on reception of signals on the roofs of office buildings, since elevator switching noise is in general the limiting factor. Occasionally an automobile, started in the street below, would produce measurable interference. At Seaverns Street, however, the most

objectionable noise was caused by the ignition systems of automobiles that were accelerating in low gear in the street below.

The authors wish to acknowledge the coöperation of the New England Telephone and Telegraph Company and the Graybar Electric Company, and also Commissioner E. A. Hultman and Signal Director T. A. J. Hayes, both of the Boston police department.

Appendix

Methods of Calibrating

In order to obtain an absolute calibration of the measuring equipment, the field strengths at a distant point in space at the same height above the ground as the center of the receiving antenna was obtained by a standard method of field strength measurement. This method consists of comparing the unknown field with a known field produced by a "standard field generator," which is a small compact self-contained oscillator. It is very carefully shielded except for a small balanced loop extending in a vertical plane above the shield. A thermomilliammeter is located in the loop at the point of low potential with respect to the shield. From the reading of the meter and the dimensions of the loop, the field at nearby points may be computed. (See *Proceedings* of the Institute of Radio Engineers, volume 21, March 1933, pages 430–1.) This equipment then was removed and the truck placed in such a way that its antenna was always at the point where the field strength had been determined. By pivoting the truck about the point, the horizontal polar diagram of the mobile receiving equipment was obtained. It is shown in figure 12. As the field was known at this point in the absence of the truck, the attenuator settings gave a calibration of the receiving equipment for all directions. With this calibration as a standard, an auxiliary standard field generator which employed a loop radiator attached to the opposite side of the truck was calibrated also. The auxiliary generator then was used throughout the test to check the calibration of the receiver. Since the polar diagram was fairly constant on the right side of the truck, care always was taken to orient the truck in such a way that the direction of the transmitter was at the right side rather than the left.

When the receiver was at Berkeley and Stuart streets it was possible to employ the usual method of calibration as described in the preceding paragraph, because the roof was flat. With the receiver at the Seaverns Street location, however, the gabled roof made it impractical to support the standard field generator opposite the midpoint of the antenna. In the latter case, accordingly, the constancy of the gain of the receiving equipment was depended upon in reducing the measurements to field strengths in absolute units. This lack of calibration did not introduce a large uncertainty, since the receiving equipment has been used over a period of years during which time its gain has remained constant within a few decibels.

Two-Way Tests

At the conclusion of this survey, actual 2-way tests were made between a cruising car and fixed locations. For this purpose a car was equipped by E. B. Ferrell and R. C. Shaw (both of Bell Telephone Laboratories, Deal, N. J.) with an ultra-short wave transmitter and receiver arranged for simultaneous 2-way communication. A distinctive feature of this equipment was the use of a single antenna for simultaneously transmitting and receiving. This was made possible by the use of a suppressor circuit in the receiver to prevent overloading of the first detector by the outgoing signal. With this suppressor circuit, which consisted of only a half section of a simple band-elimination filter, it was possible to transmit and receive simultaneously on frequencies differing by only 5 per cent. The equipment at the fixed transmitting location is shown in figure 13.

The car was used for communication at distances up to about 5 miles from the fixed transmitter and up to a little more than 3 miles from the fixed receiver. The circuit from the moving car to the fixed receiver was consistently good for distances up to about 2 miles.

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Modern Transportation—An All-Metal Passenger Plane

One of the new all-metal Douglas airliners which are in service on the lines of Transcontinental and Western Air, Inc., flying low over city buildings. Airliners of this same type will be at Newark, N. J., airport during the Institute's forthcoming winter convention at New York, January 22–25, 1935. Inspection trips scheduled include visits to the plant of the Wright Aeronautical Corporation, at which the manufacture of the engines used in the Douglas airliner may be seen, and to Newark airport, where these planes will be available for those who wish to schedule flights over the city in them. Some details of this plane were given in Electrical Engineering for February 1934, page 349.

News

Of Institute and Related Activities

Winter Convention Program Offers Many Attractive Features

A SCHEDULE of events replete with both professional and social activities has been arranged for the A.I.E.E. winter convention to be held in the Engineering Societies Building, 33 West 39th Street, New York, N. Y., January 22–25, 1935. The convention will open on a Tuesday and technical sessions will be held during the mornings and afternoons of the first 3 days. In the evenings a smoker which this year will be a radical departure from the time-honored type, medal presentations and demonstration lecture, and the dinner-dance will be held. In addition special entertainment has been arranged for the visiting ladies. Friday, the last day of the convention, will be devoted entirely to inspection trips to a number of places of interest in New York and vicinity, some of which are entirely new and have not been seen heretofore. The program will be interspersed with important committee meetings and those who attend will have a busy and profitable week with ample opportunity for social enjoyment.

Schedule of Events

A summarized schedule of events follows. Capital letters A, B, etc., denote technical sessions.

Tuesday, January 22

9:00 a.m.	Registration
10:00 a.m.	Opening of convention
10:30 a.m.	A—Electrical machinery B—Communication
2:00 p.m.	C—Transformer symposium D—Education
6:00 p.m.	Smoker at Casino de Paree

Wednesday, January 23

10:00 a.m.	E—General overhead line problems F—Noise symposium
2:00 p.m.	G—Illumination H—Electric welding
8:15 p.m.	John Fritz Medal presentation Edison Medal presentation Demonstration lecture

Thursday, January 24

10:00 a.m.	I—Electronics symposium—I J—Cables
2:00 p.m.	K—Electronics symposium—II L—Induction motor symposium
7:00 p.m.	Dinner-dance at Hotel Pierre

Friday, January 25

All day.	Inspection trips

Technical Session

The technical program was planned to present to the membership the latest advances in the theory and practice of electrical engineering and the allied arts. Among the 53 papers to be presented in 12 technical sessions much subject matter will be found that is of interest to the average engineer as well as the specialist. The program as announced in Electrical Engineering for December 1934, pages 1662–3, is complete with the addition to the session on communication of the paper entitled "Ultra-Short Wave Propagation" by C. R. Burrows, L. E. Hunt, and Alfred Decino, all of the Bell Telephone Laboratories, Inc. All of the papers have been published in advance of the convention, the issue of Electrical Engineering in which each paper appears having been given in the above-mentioned program.

In addition to the 12 technical sessions several informal sessions with round-table discussions on the subjects of transformers, the induction motor test code, and sound will be held. The papers and discussions given at these informal meetings will not be published but engineers are invited to attend these meetings and feel free to take part in the discussions. Notice of the meeting room locations will be posted on the bulletin board during the convention.

Following are special comments on one of the symposiums, that on noise.

Noise Symposium

Important progress has been made during recent months by the committees of the American Standards Association working on the problems of noise measurement and standards, so that the forthcoming noise symposium to be held on Wednesday, January 23, is being looked forward to with great interest. At the meeting of the Acoustical Society in Pittsburgh during the last week in December several papers dealing with the general question of noise measurement were presented and a discussion was participated in by a number of engineers and physicists present. A feature of the meeting was a paper presented by B. G. Churcher, of the Metropolitan-Vickers Research Laboratory, which brought to the meeting at first hand the experiences of one of the leaders in this field in England. Mr. Churcher will also present a paper at the Institute convention, dealing in this case more specifically with the practical problems of noise measurement in the field.

The symposium will be opened by a statement by R. G. McCurdy, chairman of the A.S.A. technical committee on noise meters and noise levels. He will outline the technical points on which agreement is required to secure identical readings when the same noise is measured with different meters, and will explain the conclusions so far reached by the committee. The work of this committee is based upon the fundamental standards of noise measurement agreed upon by Dr. Harvey Fletcher's subcommittee of the A.S.A. on noise measurement, and which are now being given final consideration by letter ballot.

With the completion of these standards the various industries will be in a position to experiment with the new noise meters to ascertain the most satisfactory practical means for measuring noise produced by their own types of equipment so as to arrive at acceptable standard test conditions for each type of apparatus and thus be able to determine if any given piece of equipment meets noise specifications. In order to facilitate coördination among the various industries and technical bodies engaged in this problem, the committee on standardizing the noise meter has been enlarged in its personnel and scope and designated a technical committee on noise meters and noise levels. It is contemplated that it shall act as an advisory group to industry on this subject and as a clearing house for the exchange of information. All of this activity by providing language in which noise specifications may be expressed and adequate technical methods for determining if these requirements are met should place the various industries in a far better position than ever before to serve the public demand for quieter apparatus and to secure recognition for results which may be accomplished.

Following Mr. McCurdy's statement on the status of the standardization work, Mr. Churcher will present a paper on his experiences in England on the measurement of noise under a variety of conditions. Three other papers will be presented by A. P. Fugill, C. G. Veinott, and E. J. Abbott, dealing with field experiences in noise measurement, noises from transformers and fractional horsepower motors, and specific methods for quieting of substations. The entire program should appeal to all those interested in the problem of reduction of noise from electrical machinery and apparatus as well as those engaged in the rapidly developing art of noise measurement.

Medal Presentations and Demonstration Lecture

The Edison Medal will be presented to Dr. Willis R. Whitney in the engineering auditorium on the evening of January 23 at 8:15 p.m. The medal has been awarded to Doctor Whitney "for his contributions to electrical science, his pioneer inventions, and his inspiring leadership in research." A personal sketch of Doctor Whitney's career is given in a "personal" item on page 139 of this issue.

The John Fritz Medal awarded to the late Dr. Frank Julian Sprague for "distinguished service as inventor and engineer through

the application and control of electric power in transportation systems" will be presented to a member of his immediate family. Details regarding this award were published in ELECTRICAL ENGINEERING for December 1934, page 1664.

At the conclusion of the medal presentation ceremonies, a demonstration lecture on "New Developments in Illuminants and Their Application" will be given by A. L. Powell, president of the Illuminating Engineering Society.

In view of the limited seating capacity of the auditorium admission to the medal presentations and the lecture will be by ticket only.

SMOKER

As in the past the smoker again will be held on the first evening of the convention, that is, Tuesday, January 22, 1935. However, in order to eliminate the inconveniences that were unavoidable in holding the affair at the Engineering Societies' Building, the committee has decided on a radical but promising innovation. Arrangements have been made with the management of the Casino de Paree, 254 West 54th St., New York, N. Y. The Casino will be reserved for A.I.E.E. members and their friends from 6:00 p.m. to 10:30 p.m. An unusually fine course dinner will be served followed by the regular show. In your interests the committee has sampled the dinner and the show; both received unanimous approval. There will be lots to eat and you will eat in comfort with ample room to move around and meet your friends. Then without leaving your table you get an unobstructed view of a fine show. Finally the price this year has been reduced to $2.35 per person, including tax. Enter your order for tickets early with H. E. Farrer, A.I.E.E. Headquarters, 33 West 39th St., New York, N. Y., as the committee expects to more than fill the house.

ANNUAL DINNER-DANCE AND BUFFET SUPPER

The outstanding social event of the winter convention will be held Thursday, January 24, 1935, at the Hotel Pierre, Fifth Avenue and 61st St., New York. It is to be a combination dinner-dance and dance-buffet supper.

The program offers for your selection several combinations designed to retain all the pleasurable features of long standing and the innovations of last year's successful affair, in surroundings that are unexcelled.

Music will be furnished by George Ellner's orchester whose fascinating rhythm and emotional harmonies ensure perfect enjoyment. They will play a sufficient number of dances to enable you to inflict yourself upon all of your friends. The entire ballroom floor of the Hotel Pierre, one of New York's newest and smartest hotels, will be available for your enjoyment. The spacious Grand Ballroom for dinner and dancing, the Corinthian Room for supper, and the several lounge rooms for beverage service and for bridge and other games are all beautiful. Most delectable menus have been prepared for the dinner and supper, with a wide choice to be had for the latter. Transportation by subway is convenient and parking facilities in the neighborhood are good or, if desired, will be provided by the Hotel Pierre for a moderate fee.

The program is as follows:

7:00 p.m.	Annual dinner	Grand Ballroom
9:30 p.m. to 2:00 a.m.	Dancing	Grand Ballroom
Midnight to 2:30 a.m.	Buffet supper	Corinthian Room

The cost of tickets per person will be as follows:

Dinner—dance—buffet supper	$6.50
Dinner—dance	5.00
Dance—buffet supper	3.00

Tables will be laid for 8 or 10 places. Send reservation requests promptly to the A.I.E.E. dinner-dance committee, 33 West 39th Street, New York, N. Y., and make checks payable to H. H. Henline, national secretary. Please indicate names of guests and desired seating arrangement. Every effort will be made to comply with the requests. To assist the committee in making arrangements, please purchase tickets early.

Future AIEE Meetings

Winter Convention,
New York, N. Y., Jan. 22–25, 1935

South West District Meeting,
Oklahoma City, Okla., Apr. 24–26, 1935

Summer Convention,
Ithaca, N. Y., June 24–28, 1935

Pacific Coast Convention,
Los Angeles vicinity, Fall 1935

Great Lakes District Meeting,
Indianapolis—Lafayette Section territory (date to be determined)

Radio Room at New York City Police Headquarters

VISITORS to the Institute's 1935 winter convention will have the opportunity of inspecting the police radio equipment installed for New York City. The dispatcher's control map in the radio room at police headquarters is shown here. The numbered brass disks on the map indicate the location of radio patrol cars.

WOMEN'S ENTERTAINMENT

In addition to the social events on the program the women's entertainment committee, Mrs. H. R. Woodrow, chairman, has arranged special entertainment for the visiting women. A luncheon and bridge will be given, a visit will be made to the Good Housekeeping Institute, and the Damrosch broadcast will be attended, together with a tour of the studio.

INSPECTION TRIPS

The inspection trips committee has arranged a program embracing a wide variety of subjects, many of them to be seen for the first time by Institute members. Power, transportation, communication, and illumination will be covered by inspections of significant developments in each of these fields. In addition, several trips to points of general engineering interest are planned. In spite of the times there are many new things to be seen in and about New York.

Last year's plan of reserving all day Friday for inspection trips will be repeated, but opportunity will be offered during the other days of the convention to visit points of interest, some of them chosen because of

Membership—

Mr. Institute Member:

This month the membership committee is inviting into Associate membership those Students who were graduated last June. There are 1,244 of these young men. Personal letters from Institute headquarters and personal contacts from the Section membership committees bring the invitation.

The membership committee asks that where you may know any of these young men you acquaint them further of Institute activities.

Chairman National Membership Committee

their relationship to specific subjects on the technical program.

The following tentative schedule is proposed:

Tuesday, January 22

1. Long lines department—American Telephone and Telegraph Company
2. Radio communication facilities—New York police department. (Also on Friday)

Wednesday, January 23

1. Midtown vehicular tunnel
2. Seatrane Lines, Inc.
3. Warner Bros. moving picture studio
4. Hudson Avenue generating station—Brooklyn Edison Co., Inc.
5. Sodium vapor street lighting installation on Jerome Avenue, Bronx

Thursday, January 24

1. New light weight subway train
2. "Million dollar street car"
3. Electrical Research Products, Inc.
4. Mercury turbine and Kearny generating station—Public Service Electric and Gas Company

Friday, January 25

1. Edgewater plant—Ford Motor Company
2. Okonite-Callender Cable Company
3. Wright Aeronautical Corporation
4. Radio City Music Hall
5. General Electric "House of Magic"
6. Radio communication facilities—New York police department. (Also on Tuesday)
7. Airplane flights from Newark airport
8. S. S. California—Panama Pacific Line
9. R.C.A. Radiotron Company

One of the most interesting items on the program is an all-day trip by motor bus leaving headquarters at 9:30 a.m., Friday, January 25. An inspection of the Edgewater plant of the Ford Motor Company in the morning will be followed by luncheon for the party as guests of that company. In the afternoon the trip will continue to Paterson, N. J., where visits to the plants of the Okonite-Callender Cable Company and the Wright Aeronautical Corporation will be made. The return route will include the George Washington Bridge.

Another Friday trip which should prove popular is a visit to Newark airport where an opportunity to fly in one of the new Douglas air liners will be had.

On Wednesday afternoon, January 23, a bus trip will be made to the Warner Bros. studios where the actual "shooting" of movies may be seen as well as the sound equipment and incandescent lighting. On return a stop will be made at the Hudson Avenue station of the Brooklyn Edison Company, Inc., where competent guides will conduct the party and explain many of the interesting features of this large station.

Because of possible changes in the above schedule brought about by unforeseen developments, inquiry should be made at the inspection trips desk at the opening of the convention. It is requested that members make reservations for the regular trips and arrangements for special trips promptly. In certain cases a nominal charge for transportation will be made.

In addition to the regularly scheduled trips, visits may be arranged through the inspection trips committee to a large number of points of restricted or special interest, a list of which will be available.

Register in Advance

Fill in and post promptly the mail registration card which was included with the mailed announcement of the winter convention sent to members in nearby Districts. This will permit the committee to have badges ready and prevent congestion at the registration desk upon arrival. There will be a registration fee of $2 for nonmembers with the exception of Enrolled Students of the Institute, and the immediate families of members.

Hotel Accommodations

One of the hotels within a 15 minute walk from convention headquarters is offering to A.I.E.E. members attending the convention a special "all expense" rate of $11.20 covering all essential services for the period of the convention exclusive of lunches and also exclusive of dinners on the evenings of which the Institute has dinner functions. For details write at once to National Secretary Henline for descriptive booklet and full information. In all other cases, hotel reservations should be made directly with the hotels.

Reduced Railroad Rates

Fare and one-third for the round trip over the same route will be available to members and guests, provided 100 certificates are validated at the registration desk. Consult your local ticket agent regarding the territory and dates applicable. Obtain your certificate authorized by the railroad passenger associations.

Announcement of Special Dinners

A dinner for Columbia electrical engineers will be held on Wednesday, January 23, 6:30 p.m. at the Columbia University Club, 4 West 43rd Street. The dinner will conclude in time to permit attendance at the Edison Medal presentation. Price for the dinner is $1.50. Apply for reservations to J. W. Balet, 4 Irving Place, New York, N. Y.

The Union College Engineers' Club has an annual dinner each year in New York. The next dinner takes place on January 25 at 6:30 p.m. at the Phi Gamma Delta Club, 106 West 56th Street, New York City.

A.I.E.E. Executive Committee Meets

A meeting of the executive committee of the American Institute of Electrical Engineers was held at Institute headquarters, New York, N. Y., on December 7, 1934.

Present: J. Allen Johnson, chairman; H. P. Charlesworth, F. M. Farmer, Everett S. Lee, W. I. Slichter, R. H. Tapscott, and J. B. Whitehead, members of the committee; L. W. W. Morrow, A. C. Stevens, and A. M. Wilson, other members of the board of directors; and H. H. Henline, national secretary.

A resolution was adopted in memory of Dr. Frank Julian Sprague, a past president of the Institute, who died on October 25, 1934. (The resolution appears on page 128 of this issue.)

A report of a meeting of the board of examiners held on November 27, 1934, was presented and approved. Upon the recommendation of the board of examiners, the following actions were taken: 1 applicant was transferred to the grade of Fellow; 38 applicants were elected and 47 were transferred to the grade of Member; 93 applicants were elected to the grade of Associate; 751 Students were enrolled.

The finance committee reported monthly disbursements amounting to $18,702.93.

Upon the recommendation of the committee on student Branches, the organization of a student Branch at Union College, Schenectady, N. Y., was authorized.

The national nominating committee reported its selection of an official ticket of nominees for election, in the spring of 1935, to Institute offices becoming vacant August 1, 1935. Information concerning the nominees appears on pages 128–9 and pages 137–9 of this issue.

Approval was given to a revision of the

by-laws of the United Engineering Trustees, Inc.

A communication from the American Society of Safety Engineers, Engineering Section, National Safety Council, regarding a plan for coöperation between agencies concerned with the technical aspects of accident prevention work, was referred to the committee on safety codes.

Other matters were discussed, reference to which will be found in this or future issues of ELECTRICAL ENGINEERING.

"A Summer Convention for the Entire Institute"

Plans being made for the Institute's 51st annual summer convention, to be held at Ithaca, N. Y., June 24–28, 1935, indicate that particular emphasis is being placed on securing arrangements which will make the convention available to the largest possible number of members. It is planned to make it a convention that all members can afford to go to, enjoy, and profit by. All of the features included in previous summer conventions are expected to be included, as well as several innovations.

One feature is that there will be no registration fee. Another, the college dormitories will be open to members of the Institute at a very low rate during the convention week. Also, the food at the Cornell Cafeteria is reported to be exceptionally good and unusually low in price. On the other hand, plans are being made for the hotels to furnish the customary first-rate accommodations. The usual sports of golf and tennis will be featured, as well as other simpler forms of amusement.

In addition to the usual technical and other sessions, several informal group meetings are being planned at which topics of interest to special groups may be presented and discussed. It is hoped that all those interested in any such conferences on special topics will get in touch immediately with Prof. W. H. Timbie, Massachusetts Institute of Technology, Cambridge, Mass., so that arrangements for such conferences may be made.

In Memoriam

THE death, on October 25, 1934, of Dr. Frank Julian Sprague removed from the American Institute of Electrical Engineers its eighth President, a member who had been active in its affairs for 47 years.

While a student at the U.S. Naval Academy, he became deeply interested in electrical and mechanical developments and the studies and experiments conducted during his free time for several years after his graduation, in 1878, led to many inventions. The inventive urge was so strong that he soon resigned from the Navy, and, after assisting Thomas A. Edison for one year, he organized, in 1884, the Sprague Electric Railway and Motor Company.

FRANK J. SPRAGUE

His technical and inventive ability, his success in managing the financial affairs of the companies which he organized, and his keen perception of future needs for electrical methods in the industries made his career one of outstanding success, and brought him fame for many particular achievements, especially those in the development of high speed elevators, electric traction, and remote control systems.

His work brought him many high honors, including medals and honorary degrees, and he was informed only a few days before his death that the John Fritz Medal for 1935 had been awarded to him.

Doctor Sprague joined the Institute in 1887, and was transferred to the grade of Member in 1897, and to the grade of Fellow in 1912. He was elected an Honorary Member in 1932. He served on various Institute committees, as vice president 1890–92, and as president 1892–93. The Institute awarded the Edison Medal to him in 1910.

RESOLVED: That the executive committee of the American Institute of Electrical Engineers hereby expresses, upon behalf of the membership, its deepest regret at the death of Doctor Sprague, and its sincere appreciation of his many important contributions to its activities and to the development of the entire engineering profession, and be it further

RESOLVED: That these resolutions be entered in the minutes and copies be transmitted to members of his family.

—A.I.E.E. Executive Committee, Dec. 7, 1934

Nominating Committee Announces Candidates

A complete official ticket of candidates for the Institute offices that will become vacant August 1, 1935, was selected by the national nominating committee at its meeting held at Institute headquarters, New York, December 7, 1934. This committee, in accordance with the constitution and by-laws, consists of 15 members, one selected by the executive committee of each of the 10 geographical Districts, and the remaining 5 selected by the board of directors from its own membership.

The following members of the committee were present: Walter Brenton, Portland, Ore.; H. P. Charlesworth, New York, N. Y.; A. B. Cooper, Toronto, Ont.; R. F. Danner, Oklahoma City, Okla.; L. F. Fuller, Berkeley, Calif.; W. B. Hall, New Haven, Conn.; F. H. Lane, Chicago, Ill.; Everett S. Lee, Schenectady, N. Y.; W. S. Rodman, Charlottesville, Va.; G. H. Sechrist, Laramie, Wyo., C. E. Stephens, New York, N. Y.; A. C. Stevens, Schenectady, N. Y.; J. B. Whitehead, Baltimore, Md.; and A. M. Wilson, Cincinnati, Ohio.

The following is a list of the official candidates selected by the committee:

FOR PRESIDENT

E. B. Meyer, vice president, United Engineers and Constructors, Inc., Newark, N. J.

FOR VICE PRESIDENTS

W. H. Harrison (Middle Eastern District, number 2), vice president, Bell Telephone Company of Pennsylvania, Philadelphia, Pa.

Mark Eldredge (Southern District, number 4), chief engineer, Memphis Power and Light Company, Memphis, Tenn.

R. H. Fair (North Central District, number 6), plant operations supervisor, Northwestern Bell Telephone Company, Omaha, Neb.

N. B. Hinson (Pacific District, number 8), chief engineer, Southern California Edison Company, Los Angeles, Calif.

C. V. Christie (Canada District, number 10), professor of electrical engineering and chairman, department of electrical engineering, McGill University, Montreal, Quebec.

FOR DIRECTORS

C. R. Jones, eastern transportation manager, Westinghouse Electric and Manufacturing Company, New York, N. Y.

W. B. Kouwenhoven, professor of electrical engineering and assistant dean, Johns Hopkins University, Baltimore, Md.

G. C. Shaad, dean, school of engineering and architecture, University of Kansas, Lawrence, Kans.

FOR NATIONAL TREASURER

W. I. Slichter, professor of electrical engineering, Columbia University, New York, N. Y.

The constitution and by-laws of the Institute provide that the nominations made by the national nominating committee shall be published in the January issue of ELECTRICAL ENGINEERING. Provision is made for independent nominations as indicated in the following excerpts from the constitution and by-laws:

CONSTITUTION

Sec. 31. Independent nominations may be made by a petition of twenty-five (25) or more members sent to the national secretary when and as provided in the by-laws; such petitions for the nomination of vice presidents shall be signed only by members within the District concerned.

BY-LAWS

Sec. 23. Petitions proposing the names of candidates as independent nominations for the various

offices to be filled at the ensuing election, in accordance with Article VI, Section 31 (Constitution), must be received by the secretary of the national nominating committee not later than February 15th of each year, to be placed before that committee for the inclusion in the ballot of such candidates as are eligible.

On the ballot prepared by the national nominating committee in accordance with Article VI of the Constitution and sent by the national secretary to all qualified voters during the first week in March of each year, the names of the candidates shall be grouped alphabetically under the name of the office for which each is a candidate.

(*Signed*) National Nominating Committee
by H. H. Henline,
Secretary

Biographies of Nominees

That those not personally acquainted with the nominees may know something of them and their qualifications for the Institute offices for which they have been recommended, brief biographical sketches are given on pages 137–9 of this issue.

Great Lakes District Executive Committee Meets

A meeting of the executive committee of the A.I.E.E. Great Lakes District (number 5) was held in the rooms of the Electric Club, Civic Opera Building, Chicago, Ill., September 28, 1934.

Those that attended were G. G. Post, vice president, and chairman of the District executive committee; Burke Smith, secretary, Chicago Section; J. A. Rogers, vice chairman, Chicago Section; J. R. North, chairman, Detroit-Ann Arbor Section; O. Kiltie, chairman, Fort Wayne Section; D. H. Hanson, secretary, Fort Wayne Section; F. R. Finehout, secretary, Indianapolis-Lafayette Section; B. S. Willis, chairman, Iowa Section; R. E. Johnson, chairman, Madison Section; C. D. Brown, chairman, Milwaukee Section; J. H. Kuhlmann, secretary, Minnesota Section; L. L. Smith, chairman, Urbana Section; K. A. Auty, District treasurer; and A. G. Dewars, District secretary.

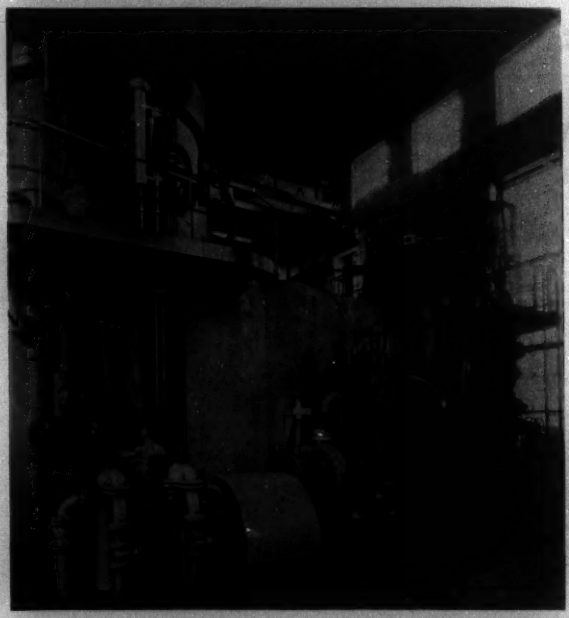
After approving the minutes of the 1933 meeting, the District treasurer's report was read. A cash balance of $306.63 in addition to a holding of stock having a market value of $774 was shown.

K. A. Auty was unanimously reëlected to succeed himself as District treasurer. F. H. Lane was unanimously elected to serve as the District representative on the national nominating committee. The following were unanimously elected to serve on the District coördinating committee which, with 2 members of the sponsoring section, will be in charge of the coming District meeting: T. F. Irvine, chairman, Indianapolis-Lafayette Section; O. Kiltie, chairman, Fort Wayne Section; F. R. Finehout, secretary, Indianapolis-Lafayette Section; and D. H. Hanson, secretary, Fort Wayne Section. The vice chairman, District secretary, and chairman of the District committee on Student activities are ex-officio members of the coördinating committee.

Reports were presented by Section officers in which the activities of their respective Sections during the past year were described and plans for the coming year were outlined.

The desirability of increasing the territory of certain Sections, due to the larger distances which can be traveled easily with modern means of transportation, was discussed. A number of questions regarding the value of Institute membership and the nature of the activities of the Institute and organizations with which it is related were brought up. In particular, questions were raised regarding American Engineering Council, and the schedule of Institute dues. It was decided that additional information on these subjects should be obtained from Institute headquarters and the board of directors.

Mercury Vapor Turbines at Kearny Station



The mercury vapor boiler and turbine-generator installation at Kearny (N. J.) generating station of the Public Service Electric and Gas Company may be inspected by those attending the Institute's forthcoming winter convention in New York, N. Y., January 22–25, 1935. This installation is reported to represent the most efficient cycle which has been developed to generate electricity. The turbine end of Number 1 mercury unit is shown here. The electric generator which it drives is not visible in this picture, as it is on the other side of the unit. 20,000 kw capacity is available from the generator, and, through the production of superheated steam which is utilized in steam turbine units, an additional 33,000 kw capacity is produced by the mercury boiler.

Honorary Members Elected by Japanese Institute

Honorary membership in the Institute of Electrical Engineers of Japan (the "Denk-Gakkwai") was bestowed upon Dr. Frank B. Jewett (A'03, M'10, F'12, and past president) vice president of the American Telephone and Telegraph Company, and president of the Bell Telephone Laboratories, Inc., and to Dr. Irving Langmuir, associate director of the research laboratory of the General Electric Company, Schenectady, N. Y. The election of Doctor Jewett and Doctor Langmuir to honorary membership was made at the officers' conference of the Institute of Electrical Engineers of Japan at its meeting held October 18, 1934. The ceremony for the awarding of the diploma and badge of honorary membership was held on November 7.

On this date, Doctor Langmuir gave his first lecture under the Iwadare Foundation. The Iwadare Foundation, under the trusteeship of the Institute of Electrical Engineers of Japan, provides means for promising Japanese students to study in the United States, and also provides means for bringing to Japan noted American electrical engineers as lecturers. Doctor Langmuir is the

third Iwadare lecturer from the United States. The A.I.E.E. committee on the Iwadare Foundation, which selects the lecturers and assists the Japanese students in this country has, since its inception in 1931, been under the chairmanship of Doctor Jewett. At the presentation ceremony, Doctor Langmuir received the diploma and badge on behalf of Doctor Jewett.

Doctor Langmuir was born in Brooklyn, N. Y., January 31, 1881. He graduated from Columbia University in 1903 with the degree of metallurgical engineer, and 3 years later received the degree of doctor of philosophy from the University of Göttingen. Returning to the United States in 1906, he became instructor in chemistry at the Stevens Institute of Technology, and 3 years later entered the research laboratory of the General Electric Company where he is now associate director. Doctor Langmuir's researches have been conducted in the fields of chemistry, physics, and engineering, and through his pioneer investigations he has been successful in opening up these fields in many new directions. His chemical researches have been directed largely toward deriving from the phenomena of physical and organic chemistry the underlying principles of the atomic and molecular mechanisms which give rise to these phenomena. In the field of physics he has done much pioneer work in electronics. He also has been actively engaged in a number of auxiliary lines of research which have contributed to the success of vacuum tube production. Among the best known of his inventions are the gas-filled incandescent lamp, and the atomic hydrogen arc welding process. He has been the recipient of many prizes and medals, and also of a number of honorary degrees; in 1932 he was given the Nobel prize in chemistry.

A brief biographical sketch of Doctor Jewett's career is given in the "Personal Items" on p. 140 of this issue.

The honorary members from countries other than Japan, and the dates of their election, are as follows:

1929 Thomas A. Edison (A'84, M'84, HM'28, and member for life). (*Deceased*, 1931.)

1929 Elmer A. Sperry (A'84, M'93, and member for life). (*Deceased*, 1930.)

1929 Carl Köttgen.

1931 Arthur E. Kennelly (A'88, M'99, F'13, HM'33, Life Member, and past president).

1933 Guglielmo Marconi (HM'17).

1934 Frank B. Jewett (A'03, M'10, F'12, and past president).

1934 Irving Langmuir.

The Engineering Societies Library

In the last issue of Electrical Engineering (December 1934, pages 1666–7) an article appeared describing one of the agencies in which the Institute and its members are interested, namely, American Engineering Council. References to 3 other articles giving information on the Institute and the agencies related to it were contained in the "Membership" item on page 1664 of the December 1934 issue. Supplementing these articles, the following article on the Engineering Societies Library has been prepared by Prof. W. I. Slichter (A'00, M'03, F'12, and national treasurer) chairman of the library board:

The Engineering Societies Library

The members of the American Institute of Electrical Engineers may justifiably be proud of their library and for their own benefit should become better acquainted with the service it can render them.

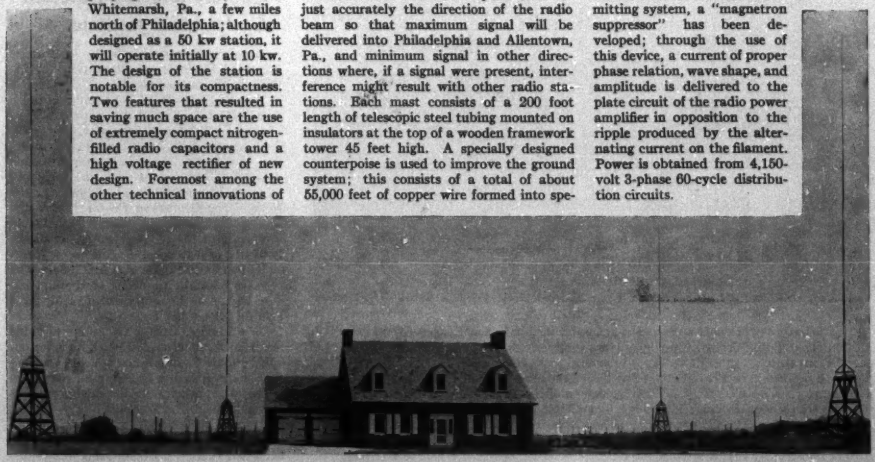
The Engineering Societies Library is the property of the 4 national societies of civil, mining and metallurgical, mechanical, and

Radio Broadcast Station KYW Moves Into New Quarters at Philadelphia

On December 3, 1934, Westinghouse radio station KYW began broadcasting from its new facilities in Philadelphia, Pa., on a frequency of 1,020 kilocycles per second. Prior to that time, the station was located at Chicago, Ill., the first program having been broadcast from there in 1921. The new transmitter, which is shown in the accompanying illustration, is at Whitemarsh, Pa., a few miles north of Philadelphia; although designed as a 50 kw station, it will operate initially at 10 kw. The design of the station is notable for its compactness. Two features that resulted in saving much space are the use of extremely compact nitrogen-filled radio capacitors and a high voltage rectifier of new design. Foremost among the other technical innovations of the station are its directional antenna system, the use of alternating current for all transmitting tube filaments, and the use of a cathode ray oscilloscope for monitoring.

The antenna system consists of 4 245-foot vertical masts each connected separately to the transmitter; by controlling the phase relationship of the current delivered to these 4 masts it is possible to adjust accurately the direction of the radio beam so that maximum signal will be delivered into Philadelphia and Allentown, Pa., and minimum signal in other directions where, if a signal were present, interference might result with other radio stations. Each mast consists of a 200 foot length of telescopic steel tubing mounted on insulators at the top of a wooden framework tower 45 feet high. A specially designed counterpoise is used to improve the ground system; this consists of a total of about 55,000 feet of copper wire formed into special cages which are suspended horizontally between insulators on poles at a height of 10 feet above the ground around the bases of the 4 antenna masts.

This new station is said to be the first high power broadcasting station to use alternating current for the filaments of all transmitting tubes. To neutralize the noise thus introduced into the transmitting system, a "magnetron suppressor" has been developed; through the use of this device, a current of proper phase relation, wave shape, and amplitude is delivered to the plate circuit of the radio power amplifier in opposition to the ripple produced by the alternating current on the filament. Power is obtained from 4,150-volt 3-phase 60-cycle distribution circuits.



electrical engineers, and is maintained by funds contributed by these societies, a contribution which amounts to 58 cents per year per member of the A.I.E.E. This library contains a vast fund of very valuable engineering material and may be considered the depository of the valuables handed down to us by preceding generations of engineers. But it is not only a depository of information, it is also a working laboratory of information because expert specialists are working continuously to make this information available to all. The library has been so indexed that there are available some 476,000 cards bearing almost every item of engineering topic that can be suggested, and directions to where that knowledge may be found on the shelves of the library. This information may be obtained by visitors by a reference to the card catalogue which is arranged so as to be very easily understood, but in many cases the information is given by the staff by letter or telephone as the result of hurried requests. These requests cover a wide range of questions, from simple questions that may be answered by a note, such as "What is a tester coil?"—"What does mho mean?"—"Where can I find the consumers voltage in Berlin?"—"Where was Steinmetz born?"—"Where is there a description of the Dnieprestroy plant?"—to questions which involve an elaborate study and many pages of report either in the form of bibliographies, translations, or photostatic copies of the original articles.

It is interesting to note that during the past years of depression the work of the library has very much increased, as many persons having time on their hands have devoted this time to develop ideas to which they did not have time to give much study in the busy days, and others who are out of employment considered the best use they could make of their time was to improve their education by study. Last year 32,000 individuals visited the library in person and there were 10,000 requests for information by mail or telephone.

In spite of this increase in use of the library the budget has been decreased 33 per cent since 1930 and is now at the lowest figure it has been since 1919. The library is under the control of a board having representatives from each of the 4 above mentioned founder societies and this board takes its responsibilities very seriously and is endeavoring to manage our library so that each of the 50,000 members of the 4 societies will receive service when he turns to the library, and so that the collection of books will continue to grow and therefore include the latest books on every subject. In addition it is necessary to keep up the work of binding because new periodicals are always being added to the collection and must be bound to be useful, and many of the books are used so much that they have to be rebound every few years.

We possess about 145,000 volumes and this is probably the best collection of engineering literature in the country, and one to which not only all engineers should look for published information on any technical subject but to which some of the other libraries in the city also look for information which is not available on their shelves.

In the December 1934 number of ELECTRICAL ENGINEERING, pages 1668–9, there appeared an article describing the searches and bibliographies, and listing some of those which would be most interesting to electrical engineers. This gives some idea of the requests which we have had in the past, of the character of work which is being done, and the suggestion that many engineers could use this service with profit to themselves. It is the sincere desire of the library board to keep the library in condition to be of greatest service to the members of the societies which own it.

Finding Work*

The second and concluding section of an authoritative dissertation dealing in a practical way with the important problem of finding work, and keeping it after it is found, is presented herewith. This article, the first section of which was published in Electrical Engineering for December 1934, pages 1670–4, was written by Samuel S. Board, placement specialist of New York, N. Y., for The American Society of Mechanical Engineers.

Planning a Job Campaign

PERHAPS engineers will be inclined to say—if they get this far—"Now at last we are getting down to something important." But if the preceding discussion has not been read carefully, what follows will probably be of much less use. You cannot plan a job campaign unless you know something about yourself and about the field of work you are approaching.

The first step in planning a sales campaign for yourself is the preparation of a statement of your record. A man came in the other day bearing a large folio-size volume, leather-covered, and 2 inches thick. It was filled with data about himself, his picture, letters of recommendation, even articles he had written, and yet to me it was almost a complete waste of effort since it was not assembled in an intelligent order. It had no index and there was no brief summary of the man's career or of what he could do. In any but the most exceptional cases, a one-page summary would have been far more effective.

Many plans have been outlined for preparing such statements and great things have been claimed for some of them, but rather than give an exact form, I am going to suggest certain principles. If you have made the personal analysis previously outlined, this is all that will be necessary. Be sure, however, to eliminate most of the details you have accumulated and make the result a summary.

In the first place, any such statement should contain a statement as to what you want to do, even if this has to be changed a dozen times in applying for a dozen different jobs. If you do not want to include this with the rest of the summary, it should be on an attached sheet or in an accompanying letter. How to determine this has been discussed previously. In the second place, it should contain a consecutive chronological experience record. There is no substitute for this. Recently, many men have tried to emphasize their abilities by describing functions they have performed without indicating how long ago they were performed and for how long a period. Such an analysis is of value and frequently helps the man, but it does not satisfy the employer unless, at the same time, he is given an idea as to when and how it was done. Also, I think it is helpful with most employers to have a picture of the flow of a man's experience. Engineers who are hiring men seem to like this experience record presented in chronological order, but other employers prefer to know what the man's recent experience has been and give it more satisfactory attention when it is described in the reverse order It is really better selling to present it this way also, since, otherwise, the reader is likely to give too much attention to the time the applicant was an apprentice or an office boy.

Finally, such a record should be rounded out by giving details which will complete the picture of the applicant as a man—his birth, education, family status, interests, and habits.

Of course, the physical make-up of the summary must be varied to suit conditions, depending on whether it is to be used in a letter or presented in person, but it is desirable in any case to have it written out. It is easier to present verbally, it reinforces the applicant's case afterward, and it seems to act as a reminder.

If it is to be used for such a purpose it should be typed or printed with a pen, well laid out on good paper, and as concise as possible. Many times such a record can be condensed to one sheet of paper. At the most it should not be more than 2 pages long.

There was a time when booklets or brochures were uncommon enough so that employers would read them through, but, un-

*Reprinted by permission from the November 1934 issue of *Mechanical Engineering*. Copies of this article, reprinted in small pamphlet form, may be obtained from the publication sales department of The American Society of Mechanical Engineers, 29 West 39th Street, New York, N. Y., at the following prices: Single copies, 10c.; 100 copies, $9; 200 copies, $15; 300 copies, $21; 400 copies, $24; 500 copies, $25.

less they are brief and extraordinarily well done, employers now are likely to look at the first page rather carefully, glance at the second, and thumb the rest. It does no good to write a nice story if it is not read.

Perhaps a word should be said about references. The general reference is so much abused in this country that it is of little use except to verify dates and duties. Employers wish rather to have the privilege of consulting the people themselves for whom the applicant has worked. Occasionally, a letter written by a former employer to some other person may be used, but even this is not given as much credence as a fresh inquiry. On this account such opportunities to refer to busy men should be used sparingly and only when a real job is in prospect. In many European countries, including Germany, the Scandinavian countries, and, I think, France, a man carries with him what amounts to a dossier—a complete record of his former employment with formal letters of reference—and such papers can usually be accepted at their face value, but the English follow a system much like our own.

Where to Look for a Job

After you have armed yourself with a summary of your experience and a decision as to what you wish to do, the next question is where you are to find a job. To do this (unless you quite literally create it) the surest way is to study the areas of opportunity. Given the abilities and interests you have, where can you find the opportunities to use them? You should have settled the question as to the functional part you want to pursue and know whether it is production, sales, or control, and then, within what type of business.

Suppose you are an operating man and wish to go into factory work. Shall it be steel or glass or textiles or shoes or machinery or automobiles? You must pick a field or fields—1, 2, 3, or more. The field should be located within the geographical area accessible to you and in which you want to work. It ought to have at least the possibility of being busy shortly. The business ought to be such an essential one that it cannot be discontinued and be in fair shape financially. Preferably it should not be popular or have glamour, like airplane manufacturing, else you will be elbowed by a horde seeking the same thing.

The next question is, do they use engineers? If they do not, could they? Perhaps you can sell them the idea.

There are more questions one could ask about the field, such as the limits of its rates of pay, the overcrowding of its ranks with technical men, and so on, but those already mentioned are fundamental. Where can you get this information? Any good newspaper, for one source; also from technical and financial magazines, from discussions with business men, and from the list of dividends paid or omitted.

Having selected 3 or 4 fields, the next step is to find in these fields specific companies whose policies are sound, whose product is well made, whose finances are not too involved, and whose affairs are not marked with an excess of internal friction. How can you find out these things? From the financial directories, from leaders in the field, from your bank, and from men who have formerly worked for the companies. All this information should be recorded, tabulated, and sorted, so that you can make a list of companies in order of the desirability of work with them, and then proceed to cover that list. Doing it in person is best—by letter, if there is no other way.

You must go after something *definite*, however. Don't just ask for a job. Tell your prospective employer that you wish to work for him and what you can do.

Finding and Holding a Position

A Check List for a Standard Technique

In Looking for a Job:

- Write out an experience record ☐
- Analyze it according to functions ☐
- List your personal qualifications ☐
- Combine these into an effective record for presentation ☐
- Decide on functions you have performed best and liked best ☐
- Decide on geographical location ☐
- Select fields or areas of work, such as industries ☐
- List desirable employers in these fields of work ☐
- Plan your approach: (1) In person ☐ (2) By mail ☐ (3) Otherwise ☐
- Follow up your contacts ☐
- Restudy your technique (in light of last 2 items) ☐

After You Get a Job:

- Analyze your job ☐
- Study the jobs that lie ahead of you ☐
- Study your coworkers ☐
- Make outside acquaintances ☐
- Develop your social life ☐
- Plan your reading ☐
- Join professional organizations ☐
- Study allied fields ☐
- Plan and develop hobbies ☐

I'm talking, I know, to men, many of whom have been looking for weeks and months and even years—tired, discouraged, and disheartened—but, men, we must "sell them a bill of goods!" Many of you have just been asking for jobs. Others haven't been doing even that. They have been calling on acquaintances and wistfully asking them if they know of anything. What they forget is that they *have* something to sell—brains, experience, drive, enthusiasm, determination, even brawn, if necessary. We must not be apologetic or ashamed but *sure* that we have something to offer.

Several years ago I had a boss whom I still consider a typical example of the better type of business man and I learned quite a bit about selling ideas from him. I found that if I went down to see him in the afternoon and put an idea before him with pros and cons but without urging a favorable decision the answer was likely to be "no," but if I waited till the morning, took care to be well-groomed, entered alertly, explained the proposition, and said, "I think we ought to do thus and so," the answer was, "Go ahead." He wanted me to believe in it first. Lots of college men out of work have come to my office this summer. Some I have helped to get work, many are still looking, but there was one boy who stood out. He was a little under medium height, good looking in a way, but with no special attractiveness of that sort. However, when he came in he *knew* what he wanted to do. He presented his desires briefly but enthusiastically. He acted on suggestions promptly. The field he entered has been overcrowded and was dull at the time, but in 2 weeks he had 3 jobs lined up, and, naturally, he took 1. It isn't so easy with older men, since there are fewer jobs and the requirements are likely to be more definite, but the approach makes a world of difference.

There are other ways of finding work. No one should be ashamed of using the help of friends, if it is offered, but you should help them by making clear what they can do to help. There are also employment agencies, public and private, good and bad. Despite the opinion of many, good opportunities are to be found that way. You should, of course, be listed with your professional society. There are the advertisements in the newspapers. These bring a lot of heartaches, however, unless you learn to discriminate between them and are willing to write repeatedly without having extended to you the courtesy of a reply. In reply to inquiries your letter should be as brief as possible. It should give the information asked. It should be carefully typed or printed (if you do hand-lettering easily and well) and set up so as to stand out for its neatness and clarity.

There are some good blind advertisements; but the chances are better of its being a genuine and desirable job if the firm's name and address are given. Blind advertisements are like blind dates—occasionally a "honey" but usually "sour."

Many men ask me about writing letters—letter campaigns—and about following up personal or letter applications. My experience has been that in good times letter campaigns are very useful. Frequently, we can get results from them (if the applicant is employed and wants a better job, for instance) through a third party, but in these times the only campaigns worth mentioning are those carried on in the name of the man himself to individuals instead of firms, and by means of individually typed letters *very* well done. Even these will sometimes bring a lot of nice replies without anything favorable. The writing of letters, however, by agencies and organizations has almost approached the stage of a racket, and in many places has spoiled this medium of getting jobs. As to follow up, you must strike a happy medium. It certainly doesn't do to let a favorable lead go too long unacted upon, but you must be careful not to arouse resentment by writing unnecessarily. Two-week intervals are about the right length in most cases, unless you are asked to do otherwise.

The Salary Question

One of the most important matters to be decided in applying in person or by mail is the amount of the salary. If you can, and unless you know the rate the employer desires to pay, it is better to get him to make an offer which you can accept or try to raise as you think fit. If you *must* name a price, make it fit the job. It is no use asking too much for a minor job and it is foolish to ask too little for a good one. Even in these times I have known employers to turn men down because they were too eager for the job and have asked too little.

The first thing in determining a fair price is the value of the work to be done. If you can, find out what others are getting. Ask about standard prices in employment agencies; but find out if you can the *going* price for such work. Next, you should consider the policy of the company in question. Is it tight or liberal, prosperous or broke? It is foolish to ask as high wages of a company that is having rough going instead of having a nest egg in the bank. The third factor is the impression you make. If the price is not fixed, you can count on a difference of at least 30 per cent between the wage paid a man who is diffident or seedy or somewhat beaten and the man who is "on his toes" and confident of himself. Sometimes a man will have a big "front" with nothing behind it, but I don't know why a man who can do the work should not act as if he himself believed he could.

College men, as a whole, have been accused quite generally of thinking too well of themselves. After having worked with them for several years I should say the reverse is true, but engineers never could be accused of it. They may know the value of steel and brass and tools, but when it comes to themselves, the rule doesn't hold. Some day we may have a code of fair salaries for technical men, but in the meantime you must be your own appraiser.

Closing the Deal

Finally, it is necessary to learn how to "close the deal." It has been mentioned already that "signing on the dotted line" is the equivalent of this for most salesmen, and it is the critical point of any salesman's effort. The only satisfactory way to do this is to create a desire and then leave it unsatisfied until the agreement is reached.

A very able salesman, who was one of my mentors years ago, told me repeatedly, "Sam, more men oversell than undersell. If they only knew when to stop talking, they would have a better chance to close the deal."

Back in 1929 an engineer who was working at something he didn't like came to me and asked me to get him a technical job. I put him in touch with half a dozen over a 2-year period and he "muffed" them all. Finally, in 1930, after the depression had hit us, a position became open near his home. It involved a good salary and it was something I thought he could do. It seemed as if this were *the* chance, so I called him in and made him apply to me for a job. Then we analyzed his technique together. There seemed to be 2 troubles: First, he was not well enough prepared, and, second, he didn't know how to close the deal. In order to remedy the first difficulty I sent him down to a friend of his who was doing similar work and he (the friend) generously told the man all he could about the job. Then he went home, at my suggestion, and boiled down all his experience and his ideas about the job to a 20 minute presentation. I told him, "When a pause comes in the interview, tell your story, not like a canned speech but genuinely, as it applies to that situation. When you finish you may find another pause. If you do, get up and *leave*." He followed instructions. A committee of 4 men interviewed him and they asked a few questions. There came a pause and he said to himself (as he told me later), "Well here's where I shoot the works." He did so and again there was a pause, so he arose and said, "Well, gentlemen, if you want me you can get me on the 'phone." They called him up at 9 that night to make sure they would not lose him.

Personnel men sometimes have to be treated differently. They have certain questions to ask and will not be denied, but if you know your story you'll probably know the answers. In any event, *you* terminate the interview. Numbers of men visit my office every day. Only a very few know enough to terminate the interview, and if I try to tell them and intimate that

A Reading List for Junior Engineers

A LIST of books recommended for reading by junior engineers has been prepared by a number of eminent men, many of them distinguished in the engineering profession. One section of this list, that on "natural science," was published in the December 1934 issue of Electrical Engineering, page 1667. Two other sections are published herewith, and others are scheduled to follow in subsequent issues. The complete list includes more than 100 titles.

Systematic reading of worth while books adds breadth and vision to the background of an engineer and should be considered a part of the intellectual development designed to fit the young engineer for full professional recognition. It is suggested that over a period of about 4 years a minimum of about 25 of these books might be selected and read, with the limiting recommendation that the selection made will include at least one book in each classification, preferably in accord with the individual engineer's most vital interests.

Philosophy and Religion

This Believing World, Lewis Browne. Macmillan, 1930. A fascinating account of the development of the chief modern religions.

Meaning of Right and Wrong, R. C. Cabot. Macmillan, 1933. Discussion of the characteristics of right and wrong conduct as related to ordinary human experience, for people unfamiliar with philosophy.

Philosophy and Civilization, John Dewey. Minton, 1931. Might be described as "essays in experimental psychology." Form is more readable than that of his earlier books.

Dance of Life, Havelock Ellis. Houghton, Mifflin, 1925. Author's philosophy of life as an art. From a study of dancing as an essential and primary art, the theme is expanded through a consideration of the arts of thinking, writing, religion, and morals.

Types of Philosophy, W. E. Hocking. Scribner, 1929. History of the leading types of philosophy, with thorough comparative analysis. Intended for beginners in philosophical study.

Effective Thinking, Joseph Jastrow. Simon and Schuster, 1931. An informal account of thinking. Part 1 deals with the technique of thinking; part 2 with impediments to clear thinking; part 3 with constructive phases by which right thinking is guided and encouraged.

Humanism and Science. C. J. Keyser. Columbia University Press, 1931. Evaluation of science and mathematics as agencies for realizing the ideals of humanism.

Education and the Good Life, Bertrand Russell. Boni and Liveright, 1926. Stimulating book, full of common sense and practical advice. Deals with postulates and aims of education, education of character, and intellectual education through university years.

The Coming Religion, Nathaniel Schmidt. Macmillan, 1930. Survey of origin and development of religion to our time, and search for the direction in which religion is moving today. Author is professor of semitic languages at Cornell University.

Misuse of Mind, Karin Stephen. Harcourt, Brace, 1922. This book is likely to open one's mind to unexpected possibilities; an excellent introduction to the philosophy of Bergson.

Imitation of Christ, Thomas a Kempis. Macmillan, 1924. For 5 centuries the Christian manual. Expresses with simplicity yearning of the devoted worshipper for communion with God and Christ. Offers ethical counsel and personal guidance and is an unfailing source of comfort and inspiration.

Psychology

Psychology at Work, P. S. Achilles, et al. McGraw-Hill, 1932. Material derived from a series of lectures arranged by the Psychological Corporation in 1931; gives a good idea of a few things being done today in the broad field of applied psychology.

Everman's Psychology, Sir John Adams. Doubleday, 1929. Book of applied psychology written in terms the layman can readily understand. Recent psychological tendencies and schools are presented, question of individual adjustment taken up, and studies of emotion and instinct as applied to individual development discussed.

Human Traits and Their Social Significance, Irwin Edman. Houghton, Mifflin, 1920. Introduction to contemporary civilization. Processes of human nature from man's simple inborn impulses and needs to their most complete fulfillment in relation to art, science, and morals.

Man as Psychology Sees Him, E. S. Robinson. Macmillan, 1932. Man, and comments on his nature; psychology, its aims; a lucid exposition of what psychology is accomplishing in helping man to self-understanding.

Psychology for Executives, Elliott Dunlap Smith. Harper, 1928. Deals with themes such as habits and how to handle them, personality, self control, and the effect of group psychology in industry.

Industrial Psychology, Morris Viteles. W. W. Norton, 1932. An attempt to present a comprehensive picture of modern industrial psychology in its applications, principally in Germany, France, England, Italy, etc., from its inception about 20 years ago, its problems, settings, findings, and accomplishments.

they are taking too much time, they either get scared or feel hurt. I often wonder why.

Looking Ahead While Working

There remain 2 related topics which are pertinent. The first is concerned with the time when you have a job. Many men seem to follow the reasoning of the old farmer who was taxed with the leaks in his roof. "Why don't you fix them, John?" he was asked, "It wouldn't be much work." "Wall," he said, "When it's raining tain't possible, when tain't, tain't necessary." No one can be so sure of his position that he does not need to do 2 things: First, to study the possibilities in his present position, and, second, keep in touch with outside activities.

Many men go on the theory that if they do a good job that is all that is necessary, but nothing could be more mistaken. Other people may not be doing a good job, the company may be losing its market, policies may change, top management may change, and with it changes the whole picture which looked so rosy when you started. You may also lose opportunities for 2 reasons, first, because you have no one to take your place, and, second, because you do not know what is required in the job above you. Some time ago a man was brought in from the outside to fill an executive position when there was an old employee in the place just below, apparently fitted for the job. It seemed so unfair on the part of the company that ordinarily was decent that I took pains to find out the reason and was told that the only reason was that the old employee had not learned to speak in public, whereas the job required, incidentally perhaps, attendance at conferences and meetings where the company needed a spokesman. This is not an advertisement for public-speaking courses, but the incident is told because comparatively little things so often handicap a man unnecessarily.

There is insurance from many angles also in keeping in touch with the outside. It is not necessary always to be yearning for some other kind of a job, but neither does it hurt to keep your abilities before others. This is especially true for engineers who work on specific jobs, be it a bridge, or a factory survey, or the installation of new machinery. How can this be done? Well, it is considered bad form in some circles of society to talk about your job but among men it's always permissible if your description isn't extended unduly. Men like to know what others are doing, but if you talk about your work you must also give others a chance to talk about theirs. You needn't talk much about yourself in doing this and you shouldn't, but your job is another matter.

Beyond this, every one should keep in touch through reading, through conversation, and through professional meetings, with new developments. It is necessary for growth.

Keeping in touch with other businesses and new developments does not necessarily imply leaving your old concern. A highly successful employee of one of our largest corporations confessed that he did not really start to go up until he had had a good offer from another firm and turned it down. Many men have had that experience, but this man let his firm know and it was not long before he was advanced.

Professional Advancement

The foregoing applies to most men who work for others, but engineers have both an excuse and means offered them for doing it in that they belong to what is generally called a profession. I will not attempt to define a profession here, but it does imply, as is the fact, that there are others of similar training and experience and that these have joined together to study common problems, to develop standards of training and performance, and to safeguard the ethical bases of the occupation.

I have known men who derided or ignored their professional societies, although, I am glad to say, not frequently; but these organizations are really of tremendous benefit in stimulating new thinking, in providing a common meeting ground for men of like interests, and in the establishment, even though sometimes in an elementary fashion, of standards of performance and training.

Moreover, they are a big help in making possible the professional and intellectual growth without which a man of professional status will retrogress. There is no such thing as standing still. Either we keep our minds active and flexible and keep abreast of new developments, or we fall behind. It is not easy to keep reading new professional literature, especially after a hard day's work. Neither is it always a pleasure to attend meetings, when they are not concerned with our particular tasks, but new ideas come that way—encouragement from the experience of others, facts which are useful when we least expect them.

It may seem a little ironic to go from this to social pleasures but social activities are also important, especially if they take the form of relaxation. Here again it is a case of keeping your mind flexible and adaptable as well as learning to deal with people.

I am not going to duplicate the endless success stories it is possible to read, but a well-rounded man is more able to meet new emergencies, and, regardless of what we would like to believe, social activities have been the means of advancement of a host of men. Professional integrity and eminence need not be sacrificed to social eminence, but social contact, sports, hobbies, amateur public service, all offer the means to meet and know others and are enjoyable in themselves.

A good deal of nonsense has been said and written about the development of personality, as if you could have your personality "lifted" like your face; but, as we are affected by our environment, we learn to talk with others easily and more fluently, and we should, but sometimes do not, learn the lesson of tolerance.

Some men will come into a room or an office and will immediately make an impression. They seem to have a little something that sets them apart, that makes others remember their names. It isn't height or weight or ugliness or beauty, despite all the advertisements. It's a man's sureness of himself or his individuality that distinguishes him from the rest of the herd. Such a man finds opportunity because he is remembered. Do people say about you, "What was the name of that man we saw last Friday?" or do they say, "Remember that man Jones we saw last Friday?" It's very much up to you; and your career, if not your happiness, may depend on it.

Engineering Foundation

Officers Elected by Engineering Foundation

At a meeting of the board of the Engineering Foundation the following were elected to fill the unexpired portion of terms of members of the board ending on February 21, 1935:

Chairman: H. P. Charlesworth (M'22, F'28, and junior past president), American Institute of Electrical Engineers; assistant chief engineer, American Telephone and Telegraph Company, New York, N. Y.

First Vice Chairman: D. Robert Yarnall, The American Society of Mechanical Engineers; member of firm, Yarnall-Waring Company, Philadelphia, Pa.

Second Vice Chairman: Edwards R. Fish, member-at-large; The American Society of Mechanical Engineers; Hartford Steam Boiler Inspection and Insurance Company, chief engineer, Boiler Division, Hartford, Conn.

Representative on National Research Council: H. P. Charlesworth.

Additional member of executive committee: Otis E. Hovey, American Society of Civil Engineers; also member, A.S.M.E., consulting engineer, American Bridge Company, New York, N. Y.

Standards

A.S.A. Reëlects Officers for 1935

Howard Coonley, president of the Walworth Company, was reëlected president of the American Standards Association for 1935, at the annual meeting of the organization held in New York, N. Y., December 12, 1934. Frederick E. Moskovics, representing the Society of Automotive Engineers, was reëlected vice president. Mr. Coonley, who represents The American Society of Mechanical Engineers, has served 2 terms as president.

J. C. Irwin, Boston and Albany Railroad, and F. M. Farmer (A'02, F'13) vice president and chief engineer of the Electrical Testing Laboratories, New York, N. Y., were reëlected chairman and vice chairman, respectively, of Standards council.

During 1934, 22 new American Standards of interest to the lumber, jewelry, pipe, gas and gas appliance, electrical, paper, textile, petroleum, and construction industries were approved by the Association. During 1934 the Association reached an all-time peak in membership, with 47 member-bodies and associate members, representing 52 national organizations and 1244 company members.

New members of the Standards council representing member-bodies of the Association, who were introduced at the December 12 meeting, were R. P. Anderson, American Petroleum Institute; D. A. Zimmer, division of safety, U.S. Labor Department; Col. John Mather, War Department; and

O. B. Blackwell (A'08, F'17) of the American Telephone and Telegraph Company, New York, N. Y., who represents the telephone group.

American Engineering Council

A.E.C. to Hold Annual Meeting

The Annual Meeting of American Engineering Council in Washington, D. C., January 10–12, 1935, comes at a period likely to approach an all-time high for Washington activity. The present lull will break into a long-pent rush of action as Congress and the top Federal officials line up the program for 1935. If organized engineers are to have any say in the shaping of these events, mid-January is the time to make themselves heard.

The annual meeting, therefore, finds itself in the midst of a situation wherein the scope and direction of the recovery program are of first interest. What part are engineers to play as executives, planners, technical workers, and builders under the government? What can they offer in the way of constructive criticism? What are the new public responsibilities of organized engineers? This meeting proposes to make a careful review of the facts so that all may get a sense of direction and be guided thereby.

Committee meetings of Council, and conferences of engineering society secretaries, are to be held on Thursday, January 10. On Friday, January 11, there will be a symposium by officials of the major Federal units who are invited to appear before the Assembly of Council for frank discussion of their objectives, on the relations of government to engineering development. A dinner will be held in the evening.

On Saturday there will be development by the Assembly of continuing programs as influenced by the proceedings of the previous day.

All sessions will be held in the Pan American Room of the Mayflower Hotel, Washington, D. C., starting 10:00 a.m., January 10. Acceptances are being received in gratifying number from the secretaries of engineering societies throughout the country, all of whom are invited to attend.

Resources Board Report Shows Federal Trends

The outlook for further extension of the recovery program in ways of most interest to engineers begins to shape itself in the report of the National Resources Board to the President December 1. A permanent Public Works Administration with broad powers for the planning and execution of Federal projects is among the principal recommendations. It is proposed also to set up permanent groups for national planning under the National Resources Board, with sections specializing in land, water, and other phases of the program.

Planning is the keynote of the report which includes a "plan for planning"—for coördinating the coördinators. Systematic development of water resources is discussed in terms of power, sanitation, flood control, reclamation, and other uses. Suggested land policies include eliminating production on marginal areas, control of soil erosion, and conservation of minerals. Under these headings, the recommendations call mainly for further studies rather than dealing at once with the scope and cost of the final work.

Little can be done to advance the sections of the report of concern to engineers until it is known how far the Administration will go toward pushing such plans. Meanwhile the unqualified and specific recommendations with regard to survey items give some measure of assurance that the Federal responsibilities of engineers will be augmented during the present session of Congress.

Census of Engineers

The U.S. labor department survey of the engineering profession is rapidly taking form. Questionnaires, up for final approval before the (Federal) Central Statistical Board, will go out as soon as the mailing list is completed. (See Electrical Engineering, December 1934, page 1677, for details.)

Dr. Isador Lubin, director of the Bureau of Labor Statistics, making the survey in coöperation with Council and member societies, has this to say: "Checking up on the status of engineers is one of the steps toward a better understanding of the problems surrounding the professional and white collar workers in general. . . .If anyone can make immediate and practical use of statistics, it ought to be the engineers. So we are seeking to provide some of the basic figures to this group. . .in order that they may analyze their problem without any guesswork as to the actual trends and conditions. . . .In dealing with professional people, it is believed that we can secure an unusually high return as to accuracy and completeness."

Directory of Engineering Societies

A directory of 236 engineering societies—national, state, and local—has been compiled through questionnaires under the auspices of American Engineering Council, the Engineering Foundation, and the Engineering Council for Professional Development. To be issued early in the year, the booklet includes names of officers, type and number of members, publications, dates of annual meetings, etc. Copies may be ordered at 50 cents each from American Engineering Council, 744 Jackson Place, Washington, D. C. Please send orders promptly so that the printing schedule may be arranged accordingly. Payment in advance will help cut billing costs.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. Electrical Engineering will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or to reject them entirely.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Overcompounded D-C Generators in Parallel Without an Equalizer

To the Editor:

In the November 1934, issue of Electrical Engineering, pages 1553–4 appears a "Letter to the Editor" in which Prof. O. W. Walter takes issue with Dr. Harold Pender and me. The problem under discussion is one concerned with the operation of overcompounded d-c generators in parallel without an equalizer. Mr. Walter believes he has shown "the unsoundness of (the) reasoning" used by Dr. Pender in his book "Direct Current Machinery" and states that others have obtained experimental results contradicting those given by me (Electrical Engineering, October 1932, p. 745).

It is the purpose of this reply to point out that Mr. Walter and the persons to whom he refers have not disproved or contradicted either the theoretical or experimental results he attacks, for the simple reason that he is not discussing the problem we were. In order to make this clear, the following is quoted from the October 1932 note referred to above, in which were given oscillograms showing, for a given generator, *speed increasing* and current simultaneously decreasing:

"The problem is not of importance practically but has considerable theoretical interest, as has been evidenced by the discussion aroused by the statement in 'Direct Current Machinery,' . . . . that for a given total line current, if the *speed* of one generator *increases* after the equalizer has been opened, the current output of that generator decreases, and, ...

"These oscillograms show conclusively

that the majority argument (contra Pender). . . . cannot be of universal application. It cannot be claimed, however, that the oscillograms prove completely the other (Pender) point of view. The problem is one which depends on many factors—the system would be unstable without an equalizer if the speeds remained constant—but the oscillogram of Fig. 3 does indicate that for the particular case the changes took place so slowly, comparatively, that the analysis using the steady state regulation curves would be expected to indicate at least qualitatively the action."

The following paragraphs are excerpted from Mr. Walter's note:

"The actual transient solution of the current . . . . . is not difficult. . . . . By making certain simplifying approximations, solutions may be obtained which are helpful in visualizing the manner in which the current changes.

"As the simplest case, in Fig. 2 assume zero load current (each armature supplying only its shunt field current), constant shunt field currents, *and constant speeds.*"

The situation is then this: Doctor Pender has given a theoretical argument based on the change *of speed* of a generator. I have presented experimental results consisting of oscillograms *of speed* and current, confirming Dr. Pender's argument.

Mr. Walter has discussed the case in which *the speed is held constant.*

Hence there is no comparison between the 2 cases.

For the benefit of anyone who cares to analyze the case considered by Dr. Pender and me, it may be suggested that the prime mover must be considered. In our work we have implicitly assumed a drooping speed-torque characteristic.

Yours very truly,

J. G. Brainerd (A'32)
(Assistant Professor, Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia)

New Uses for Overproduced Products

To the Editor:

I have read with great interest the speeches of Doctor Jordan and Colonel Chevalier delivered before the Institute in New York on October 10 (see Electrical Engineering for November 1934, page 1546–51), and I quite agree with practically all of the statements made by these gentlemen on that occasion. They have presented a masterly analysis of the situation, but I am also mindful that the national administration has on several occasions rather bitterly complained that while there is no dearth of criticism and analysis there have been no helpful suggestions pointing the way toward improved industrial conditions and the President has said that in case any of his pet schemes did not work out successfully they would be dropped forthwith in favor of something perhaps less drastic but more promising.

In view of the fact that the N.R.A. and A.A.A. for instance, have distinctly fizzled it may not be inopportune for the engineering fraternity to at least discuss and perhaps offer to the administration alternate schemes to be considered by those who happen to be directing recovery measures at the moment. As a starter may I offer the following idea in the rough:

One of the principal problems has been: "What shall we do about overproduction and dead stock?" We all know what the self-sufficient management tried to do in so far as agricultural products are concerned. As an alternative to the actions taken, may I suggest that the administration might better have considered: "What action would a large producer of any commodity take if he found he had on hand large surpluses of stock, especially raw material?" The answer, I think, is perfectly obvious. He would not only set up or employ an experimental station or laboratory and engage *practical* scientists to discover and develop new uses for his raw material just as the steel people, the aluminum people, and the plastic moulding people have done, but he would also concern himself very seriously with marketing and publicity measures.

Take the staple "cotton" for instance: It may not be generally known but cotton has many characteristics that have not been exploited to any considerable extent commercially. Pressed cotton is one of the best thermal and sound insulators known. Processed with the proper binding material it might be fabricated as slabs or boards for efficient heat and sound insulating purposes in buildings, cooling rooms, car insulation, etc. The uses of rubberized cotton fabrics may, no doubt, be multiplied in coverings, tenting, umbrellas, etc. "Washed cotton" has recently been proved to have very high electrical insulating qualities.

No one has yet found a satisfactory way to fire-proof cotton fabric but when this is done the field of application will be unlimited—curtains, drapes, sheetings, etc. When we take cognizance of what is going on in the field of metallurgy it seems but reasonable to suppose that any so called overproduction of the staple cotton might quickly be absorbed by worth-while products of a new type; quite certainly more economically than plain destruction and suppression.

As to wheat, the greatest of foodstuffs, almost any practical person can think of a number of ways of better disposal of this commodity than destruction and suppression. There are possibilities in beverages, confections, concentrated foods, etc., and the possibilities inherent in quality rather than quantity production.

As to the marketing phase: Where would you or I go today to purchase a few pounds of the grain in case we knew just how to prepare a delicious table food or beverage from it? The point of all of which is: Why is it not practical to discover the full value of our surplus stocks and consume them?

Whether or not some such plan as outlined above might have far reaching results, its adoption would at least have some effect in convincing the people that government measures are to be constructive rather than destructive, and this perhaps would be helpful.

Yours very truly,

B. D. Willis (M'32)
(Automatic Electric Co., 1033 W. Van Buren St., Chicago, Ill.)

A.I.E.E. Service to the Electrical Industry

To the Editor:

A man's knowledge and experience should be a source of great satisfaction to him but its value to others depends upon the use he makes of it. We are remembered by the thoughts we give to others and by our good deeds. Knowledge may be obtained from mathematical analysis and laboratory experiments by men who do not know how to put it to practical use. The analytical mind points out the reason why things happen but lacks the kind of imagination required to use this information to develop new and practical devices. The contributions to scientific knowledge sift down to commercial practice through several layers or stages of thought and practice.

The engineer who knows how to use new facts in design may not have the ability to select, without help from the application engineer and the enterpriser, articles that the public will buy. Sometimes we call the enterpriser a salesman, but the marketing of new products needs more than just salesmanship. The idea must first be presented to the public and the desire created before sales can be made.

Long after we knew how to design gas engines it took a Henry Ford to give the world an inexpensive automobile. Westinghouse visualized the use of alternating current when it was still unpopular and hard to use. Recently Daniel Willard gave us the air conditioned train and stimulated the demand for air conditioned rooms. Motor generator control was advocated by H. Ward-Leonard 25 years before the variable voltage elevator became a reality and made the modern installation in "Radio City" a possibility. The Diesel engine is old; its rapidly increasing use is due to the vision of men who invested time and money and patience in its commercial development. The electron tube emerged from the laboratory largely as a plaything; it was an interesting stunt to make the tube do something unusual. Gradually, practical use is being found for tubes as more people understand their use.

Sometimes we find persons who have the vision and ability to understand what the public would like to have, who know how to design and build it and then to market it, but usually better results are obtained through the coöperation of several persons. Greatness in individuals is as much due to their ability to recognize and use the talents of others as to their own ability to originate. Men of this kind become great leaders and enable others to find practical use for the knowledge which might otherwise remain locked within their own minds and useless to society.

One element of success is to give freely and wisely of our time to help others. Out of this effort will come contacts and ideas that will help us.

In this evolution of thought to practice the A.I.E.E. has a definite place. Those who complain that the Institute's publications are made up largely of papers that are of interest to the few and can't be understood by the membership at large forget that it and these authors are rendering a service to the profession that should be utilized more widely. It is not the func-

tion of the Institute to tell individuals and organizations how to make money. It tells them of the progress of knowledge in electrical engineering and it is for them to translate this knowledge into commercial uses through their engineers and enterprises. The Institute can best perform this service and it is one of the reasons for its existence. The business executive can't rest in quiet and content with things as they now are. Public demand is continually changing, commercial surveys are predicated on the past, not the future demand; alert business men are pressing for new things to sell; a successful business today may be outdistanced by competition and become bankrupt.

During the depression large business units have been forced on the defensive and had to retrench. Pioneering work has been dropped and, worst of all, many of their trained men with vision have left them but are still active. These men will increase competition in many novel ways and now constitute a threat to the profits of the older companies. The men who remain in these organizations should take an increasing interest in the Institute; it may be of great help to them.

Very truly yours,

H. D. James (A'98, F'12)
(Consulting Engineer, Gulf Building, Pittsburgh, Pa.)

Personal Items

E. B. Meyer Nominated for Presidency

Edward Barnard Meyer (A'05, M'13, F'27, and past vice president) vice president, United Engineers and Constructors, Inc., Newark, N. J., has been nominated for the presidency of the A.I.E.E. for the 1935–36 term. He was born October 22, 1882, at Newark. He received his technical education at the Newark Technical School, from which he graduated in 1901, and at Pratt Institute, Brooklyn, N. Y., where he graduated from the electrical engineering course in 1903. That same year, Mr. Meyer entered the employ of the Public Service Corporation of New Jersey as an engineering assistant, and remained continuously with that organization and its subsidiary companies until 1922. During this period he became, in 1906, field engineer in charge of the underground conduit and cable system; in 1909, assistant engineer on special engineering reports, estimates, and construction work; in 1912, assistant to the chief engineer; and in 1919, assistant chief engineer. With the formation in 1922 of the Public Service Production Company he was appointed its chief engineer. In 1929, Mr. Meyer was made a vice president of the Public Service Production Company, and in 1930, on the occasion of the merger of that company with United Engineers and Constructors, Inc., he was appointed a vice president of the latter corporation in the capacity of executive and engineering head of the Newark office. In addition to having been a director of the Institute, 1928–31, and later a vice president, 1932–34, Mr. Meyer has served on many of the Institute's committees. These committees are: executive, 1928–30, 1932–34; constitution and by-laws, 1929–35 (chairman 1934–35); coördination of Institute activities, 1925–35 (chairman 1932–34); Edison medal, 1927–29, 1930–36; finance, 1927–31, 1932–34 (chairman 1928–30, 1933–34); headquarters, 1928–30, 1933–34; Lamme medal, 1928–30; membership, 1924–25; award of Institute prizes, 1925–28, 1931–34 (chairman 1925–27); publication, 1923–35 (chairman 1927–28, 1931–34); Sections, 1926–27; technical program, 1918–29, 1932–34 (chairman 1925–27); transfers, 1932–35 (chairman 1932–33); power generation, 1928–32; and power transmission and distribution, 1918–24 (chairman 1918–23). He also has served on the special committees of Institute policies, 1931–33; Associate dues and related matters, 1932–35; and biographies and talking motion pictures, 1930–33. He has served as an Institute representative on the U.S. National Committee of the International Electrotechnical Commission, 1927–30; and on the Engineering Societies Monographs Committee, 1930–35; and the Engineer's National Relief Fund. He has also served on several of the Institute's subcommittees and on local Section committees, having been chairman of the New York Section, 1926–27. He was chairman of the Institute's 1932 winter convention committee. Mr. Meyer's other technical activities have included active participation in the affairs of the American Standards Association, the former National Electric Light Association, the New York Electrical Society, Inc., of which he is now first vice president, membership in the Essex (County, N. J.) Electrical League, State of New Jersey Emergency Relief Administration, U.S. Chamber of Commerce, The American Society of Mechanical Engineers, and the American Transit Association. During the World War he served on important committees of the U.S. Army and Navy. His numerous contributions to the technical press have dealt chiefly with electric transmission and distribution problems and include his book, "Underground Transmission and Distribution."

Vice Presidential Nominees Are Christie, Eldredge, Fair, Harrison, Hinson

Clarence Victor Christie (A'08, M'13, F'32) professor of electrical engineering and chairman of the department of electrical engineering, McGill University, Montreal, Canada, has been nominated to serve the Institute as vice president representing the Canadian District (number 10). He was born at Couva, Trinidad, British West Indies, February 2, 1882. He received the degree of bachelor of arts in 1902, and that of master of arts in 1903 from Dalhousie University, Halifax, Nova Scotia, and that of bachelor of science in electrical engineering from McGill University in 1906. After graduation he spent one year 1906–07 on the apprenticeship course of Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa., returning to McGill University as lecturer in electrical engineering in 1907. He was appointed assistant professor in 1908, associate professor in 1915, and since 1926 has been professor of electrical engineering and chairman of the department. In 1918 he became associated with the Shawinigan Water and Power Company as consulting engineer and has thus been able to keep in close touch with the practical side of the profession of electrical engineering. In addition to his duties with this company, he has made studies and reports on important transmission projects as well as appraisals of large electrical utility properties. He has served the Institute for several years as a member of the transmission and distribution committee, 1928–29, 1930–35; and as a member of the committee on education, 1927–28. He was recently appointed a member of the transmission and distribution committee of the Edison Electric Institute. Since 1926 he has been chairman of the electrical sectional committee of the Canadian Engineering Standards Association, and as their representative was appointed a member of the sectional committee on electrical definitions, and is acting as chairman of subcommittee 2A engaged in preparing definitions on rotating machinery. Since 1928 he has been chairman of the engineering section of the Canadian Electrical Association; he also is a member of the Engineering Institute of Canada, for which he has served as a member of its council, 1931–32. His textbook "Electrical Engineering," first published in 1913, is now in its fourth edition and has been widely used both in Canada and the United States.

Mark Eldredge (A'14, M'20, F'33) chief engineer, Memphis Power and Light Company, Memphis, Tenn., has been nominated to serve the Institute as vice president representing the Southern District (number 4). He was born at Woodbury, N. J., May 17, 1882. After attending public schools he learned the trades of electrician and lineman, and in 1906 graduated from Worcester Polytechnic Institute, with the degree of bachelor of science in electrical engineering. During the year 1906–07 he was on the graduate student engineer course of the General Electric Company of Schenectady, N. Y.; and the next 2 years, 1907–09, he was engaged on North Dakota pumping projects of the U.S. Reclamation Service. During 1909–11 he was superintendent of power for the Gilson Asphaltum Company, Dragon, Utah, and superintendent for the Rocky Mountain Manufacturing Company, Colorado Springs. He then became professor of electrical engineering at Ewing College, Allahabad, India; and in 1913 became electrical assistant to the textile engineer of the Tata

Hydro-Electric Power Supply Company, Bombay. During 1915–18 he was distribution engineer of the same company. He was a captain, construction division, quartermaster corps, U.S. Army, on the staff of the constructing quartermaster, Erie Proving Grounds, Ohio, 1918–19. From 1919 to 1922 he was superintendent of power for the Ludlow Jute Company, Calcutta, India, building a jute textile mill with complete electric drive, and employees' town with all utility services, and a modern high efficiency generating station. From 1922 to 1924 he was assistant engineer of the Electric Bond and Share Company, New York, N. Y., and since 1924 has been chief engineer of the Memphis Power and Light Company. Mr. Eldredge organized and was first chairman of the Memphis Section of the A.I.E.E., and is serving the Institute as a member of the committee on power transmission and distribution, 1933–35, and Sections committee, 1934–35. He also has been active on the committees of the former National Electric Light Association, and was vice chairman of its engineering national section, 1930–33. He is now chairman of the transmission and distribution committee of the Edison Electric Institute. Mr. Eldredge is president of the Engineers' Club of Memphis.

Richard Harvey Fair (A'09, M'20) plant operations supervisor of the Northwestern Bell Telephone Company, Omaha, Neb., has been nominated to serve the Institute as vice president representing the North Central District (number 6). He was born on a farm in Dakota County, Neb., December 16, 1872. After graduating from Midland Academy, he completed his sophomore year in the classical course at Midland College, and afterward studied electrical engineering for 2 years at the University of Nebraska. He entered the employ of the Nebraska Telephone Company (Bell) in 1896, and has been continuously in the employ of that company and its successors since that time. Since 1909 he has been in the employ of the Northwestern Bell Telephone Company, covering the states of Minnesota, Iowa, Nebraska, South Dakota, and North Dakota. During these periods, he was in construction and engineering work for 12 years, including 2 years as superintendent of construction; then outside plant engineer for 12 years; general superintendent of plant for 8 years; and, since 1928, plant operations supervisor of the Northwestern Bell Telephone Company. His responsibilities when outside plant engineer also included transmission engineering, valuation and rate case work, and relations with power and electric light companies on all phases of outside plant standards. During this service as outside plant engineer, he collaborated with other engineers in the Bell system in developing outside plant standards. As general superintendent of plant he had responsibility for the field engineering and construction of all outside plant and station equipment, and for the maintenance of the entire plant. As plant operations supervisor, he acts in a consulting capacity to the 4 area operating organizations and acts in a coördinating capacity between these organizations. Since 1923 he has taken a leading part in the management group dealing with employee relations.

William Henry Harrison (A'20, M'30, F'31) operating vice president of the Bell Telephone Company of Pennsylvania and the Diamond State Telephone Company of Delaware, with headquarters in Philadelphia, Pa., has been nominated to serve the Institute as vice president, representing the Middle Eastern District (number 2). He was born in Brooklyn, N. Y., June 11, 1892. He graduated from the electrical engineering course of Pratt Institute, Brooklyn, and in 1909 joined the New York Telephone Company in New York City, as repairman. His work until 1915 included apparatus inspection, assembling, and wiring. Between 1915 and 1919 he was engaged in telephone circuit design with the Western Electric Company, in its engineering department. Between 1919 and 1924 he was engaged in general plant maintenance engineering as a member of the engineering staff of the American Telephone and Telegraph Company. In 1924 he was made equipment and building engineer of the American Telephone and Telegraph Company, with general supervision of the engineering and design, including layout, of subscribers' station and central office plant of the Bell system. In 1929 he became plant engineer, this appointment giving him general supervision of the engineering, design, and layout of all parts of the Bell system plant including system relations with other wire-using utilities. In 1933, he was appointed to his present position of operating vice president of the Bell Telephone Company of Pennsylvania, and the Diamond State Telephone Company of Delaware. Mr. Harrison has been active for several years on the committees of the Institute, having been a member of the following committees: technical program, 1929–35 (chairman, 1931–33); coordination of Institute activities, 1931–33; publication, 1931–33; award of Institute prizes, 1931–34 (chairman, 1931–33); Popular Science Award, 1931–34; legislation affecting the engineering profession, 1932–35; and special committee on Associate dues and related matters, 1932–35. He also has served as a representative of the Institute on the Alfred Nobel prize committee of the American Society of Civil Engineers, 1932–34; and on the American committee on marking of obstructions to air navigation, 1932–33.

Noel Bertram Hinson (A'19, M'26) chief engineer and chairman of the engineering committee for the Southern California Edison Company, Ltd., Los Angeles, has been nominated to serve the Institute as vice president representing the Pacific District (number 8). He was born December 25, 1885, at Evansville, Ind. In 1906 he joined the organization of the former Edison Electric Company, a predecessor of the Southern California Edison Company; here he remained in the test department until 1912 when he was transferred to the distribution department in the general offices. In 1913 he was appointed to the position of distribution engineer in charge of the general layout of distribution lines over the entire system. He was made assistant superintendent of distribution of the Southern California Edison Company, in 1920, the name having been changed in 1915. In 1923 he was appointed system planning engineer and chairman of the planning committee, and as such had general supervision over the location and general design of the major portion of the transmission system, substation, and main distribution feeders of the Edison company system as it exists today. In 1928, he was given the position of assistant manager of operation, still remaining chairman of the planning committee. The operating department operates and maintains the generating plants, substations, and transmission and distribution lines, and constructs all distribution lines and most of the transmission lines. In 1934 he was made chief engineer of the company and chairman of the engineering committee. Mr. Hinson is a past chairman of the Institute's Los Angeles Section, and is the author of a large number of technical papers on the operation and construction of various features of power systems.

Jones, Kouwenhoven, Shaad Nominated for Institute Directorships

Charles Ramey Jones (A'16, M'30) eastern transportation manager, Westinghouse Electric and Manufacturing Company, New York, N. Y., has been nominated to serve the Institute as a member of its board of directors. He was born at Norristown, Pa., May 11, 1886. In 1907, he graduated from the University of Pennsylvania, with the degree of bachelor of science in electrical engineering. Since 1907 he has been continuously with the Westinghouse Electric and Manufacturing Company. For the first 2 years, until 1909, he was on the engineering apprentice course of the company at East Pittsburgh, specializing in railway work. For the next 2 years, until 1911, he was in the engineering and railway department of the company, also at East Pittsburgh, being transferred in the latter year to the New York office where he was assistant to the manager of the railway division until 1916. From 1916 to 1925 he was sales engineer in the New York office of the Westinghouse company, representing the company on large contracts involving both engineering and commercial phases. This included work in connection with the electrification of steam railroads and power supply and car equipment for the local rapid transit company. From 1925 to 1930, he was section manager of the transportation division of the New York office, continuing the same work, but in a supervisory capacity. In the latter year he became assistant northeastern transportation manager, and in 1931 transportation manager of what is now the eastern district. Mr. Jones has served the Institute as a member of the national membership committee, 1928–31, and has engaged for a number of years in the activities of the New York City District (number 3), having been District secretary

1930–35. He also has served the Institute's New York Section as secretary, 1930–31; chairman, 1933–34; and as chairman of the transportation group and as a member of program committees. He has been active for several years in connection with the Institute's winter convention, having served as a member of convention executive committees, and being at present chairman of the general committee for the 1935 winter convention. He is a member of the New York Electrical Society, Propeller Club (national marine organization), New York Railroad Club, New York Engineers' Club, Hackensack (N. J.) Golf Club, and Sigma Alpha Epsilon fraternity.

William Bennett Kouwenhoven (A'06, M'22, F'34 and past vice president) professor of electrical engineering and assistant dean, The Johns Hopkins University, Baltimore, Md., has been nominated to serve the Institute as a member of its board of directors. He was born January 13, 1886, at Brooklyn, N. Y. From Brooklyn Polytechnic Institute, he received the degree of electrical engineer *cum laude* in 1906, and that of mechanical engineer *summa cum laude* in 1907 From the Karlsruhe Technische Hochschule, Baden, Germany, he received the diploma in engineering *summa cum laude* in 1913, and the degree of doctor of engineering *magna cum laude* in 1914. During 1906–07 he served as assistant in physics at Brooklyn Polytechnic Institute, and during 1907–10 was instructor in physics and electrical engineering at the same institution. During 1913–14 he was instructor in electrical engineering at Washington University, St. Louis, Mo. In 1914 he joined the staff at The Johns Hopkins University. Here he was instructor in electrical engineering, 1914–17, and associate in electrical engineering, 1917–19. After a leave of absence, 1919–20, he was engineering superintendent at the Winchester Repeating Arms Company, New Haven, Conn., and in 1919 returned to The Johns Hopkins University as associate professor in electrical engineering. He held this position until 1930 when he received his present appointment as professor of electrical engineering and assistant dean. Professor Kouwenhoven acted as instructor in the Reserve Officers Training Corps unit and held the rank of captain during the war. He has served part-time acting as a consulting electrical engineer at the U.S. Bureau of Standards. Professor Kouwenhoven served the Institute as a vice president 1930–33, and has been a member of the following Institute committees: coordination of Institute activities, 1927–30; Sections, 1925–34 (chairman, 1927–30); technical program, 1931–35; safety codes, 1933–35; electrophysics, 1924–33; instruments and measurements, 1925–35 (chairman, 1933–35); research, 1933–35; and telegraphy and telephony (now communication) 1919–20. He now represents the Institute on the sectional committee on electrical insulating materials of the American Standards Association. He also has been active in the Institute's Baltimore Section, having served as chairman and in other capacities. Professor Kouwenhoven has published a very large number of papers and articles on his research work, including, most recently, the subjects of instruments and measurements, and the effects of electric shock. Professor Kouwenhoven has been active in the American Society for Testing Materials, and is a member of The Johns Hopkins Club and the Baltimore Engineers' Club. In 1932 he was awarded special honor by those in charge of the International Electrical Congress held in Paris, July 4–12, 1932.

George Carl Shaad (A'03, M'08, F'13, and past vice president) dean, school of engineering and architecture, University of Kansas, Lawrence, has been nominated to serve the Institute as a member of its board of directors. He was born in Stratford, N. Y., May 5, 1878. He graduated from Pennsylvania State College in 1900 with the degree of bachelor of science in electrical engineering, and in 1905 received the degree of electrical engineer from the same institution. On graduation he entered the testing department of the General Electric Company at Schenectady, N. Y., and in 1902 transferred to the switchboard engineering department. In the latter year he was appointed instructor in electrical engineering at the University of Wisconsin. In 1904 he became assistant professor of electrical engineering at that institution. In 1906 he transferred to the Massachusetts Institute of Technology, where he was assistant professor of electrical engineering. In 1907 he was made an associate professor at M.I.T. When the electrical work at the University of Kansas was separated from the department of physics in 1909, he accepted the appointment as professor of electrical engineering in charge of the department of that institution, and has retained his connection with the University of Kansas since that date. He acted as dean of the school of engineering and architecture and was in charge of the work of the student army training corps in 1917–18. Since 1927 he has held the position of dean of the school of engineering and architecture at the University. He has been employed in engineering work along with his teaching duties and acts in a consulting capacity in connection with various engineering problems. He has been interested in the work of the student Branches of the Institute, and served several years as student Branch counselor delegate for the District. He has also served as chairman of the Kansas City Section. Professor Shaad, in addition to being a member of local engineering organizations, is a member of The American Society of Mechanical Engineers and the Society for the Promotion of Engineering Education, of which he is now a vice president.

W. I. Slichter Renominated as Institute Treasurer

Walter Irvine Slichter (A'00, M'03, F'12, past vice president, and national treasurer) professor of electrical engineering at Columbia University, New York, N. Y., has been nominated to succeed himself as treasurer of the Institute. He was born in St. Paul, Minn., May 7, 1873, and graduated from Columbia University in 1896 with the degree of electrical engineer. Since 1914 Professor Slichter has been an active member of 18 Institute committees and has represented the Institute on 6 joint bodies; he is now a member of 7 committees and a representative on 4 bodies. A full biographical sketch of Professor Slichter's career was published on page 56 of Electrical Engineering for January 1931.

Willis R. Whitney to Receive Edison Medal

Willis Rodney Whitney (A'01) vice president in charge of research for the General Electric Company, Schenectady, N. Y., has been awarded the A.I.E.E. Edison Medal for 1934 "for his contributions to electrical science, his pioneer inventions, and his inspiring leadership in research." Actual presentation of the

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medal will take place during the forthcoming A.I.E.E. winter convention to be held in New York, N. Y., January 22–25, 1935. The Edison Medal was founded by friends and associates of the late Thomas A. Edison (A'84, M'84, HM'28, and member for life) and is awarded annually for "meritorious achievement in electrical science, electrical engineering, or the electrical arts," by a committee consisting of 24 members of the Institute. Doctor Whitney, the 24th recipient of this medal, was born at Jamestown, N. Y., August 22, 1868. He graduated from the Massachusetts Institute of Technology, Cambridge, with the degree of bachelor of science in 1890, and in 1896 received the degree of doctor of philosophy from Leipsig University. Honorary degrees have since been conferred upon him by 6 universities. Since his graduation from Massachusetts Institute of Technology, he has held the following positions at that institution: assistant instructor in general chemistry 1890–92, analytical chemistry 1892–94, sanitary chemistry 1896–98, instructor in theoretical chemistry and proximate analysis 1898–01, assistant professor of theoretical chemistry 1901–04, nonresident associate professor of theoretical chemistry 1904–08, and nonresident professor of chemical research since 1908. Doctor Whitney assumed the directorship of the

research laboratory of the General Electric Company at Schenectady upon its establishment in 1900. The expansion of the laboratory followed the development by Doctor Whitney of a new type of incandescent electric lamp, and since 1903 the laboratory has grown rapidly. In 1928, Doctor Whitney became vice president of the company, and director of research. In 1932 he retired from active direction of the laboratory due to ill health, and was made vice president in general charge of research, which position he has since held. Although Doctor Whitney's greatest personal activity has been in the field of chemistry, he has, through the laboratory, been active in many researches which have made outstanding contributions to the electrical industry. He also has contributed frequently to technical literature, having published more than 80 papers. Among the many honors which Doctor Whitney has received are the Willard Gibbs Medal, 1916; Chandler Medal, 1920; Perkin Medal, 1921; the gold medal of the National Institute of Social Sciences, 1928; and the Franklin Medal, 1931. Doctor Whitney is a member of the American Chemical Society (president 1909), American Society of Chemical Engineers, American Electrochemical Society (president 1912), American Institute of Mining and Metallurgical Engineers, American Physical Society, American Association for the Advancement of Science, American Philosophical Society, American Academy of Arts and Sciences, National Academy of Sciences, National Research Council, and the British Institute of Metals. He is also a member of the U. S. Naval Consulting Board, and is an honorary member of the American Society of Steel Treaters. Doctor Whitney is a member of the board of governors of Union University, a trustee of Union College and of the Albany Medical College, and was a term member of the corporation of the Massachusetts Institute of Technology, 1917–21, 1923–28.

F. B. Jewett (A'03, M'10, F'12, and past president) vice president of the American Telephone and Telegraph Company, and president of the Bell Telephone Laboratories, Inc., has been elected to honorary membership in the Institute of Electrical Engineers of Japan (the "Denki-Gakkwai"). Doctor Jewett was born in Pasadena, Calif., Sept. 5, 1879, and in 1898 graduated from Throop Polytechnic Institute (now the California Institute of Technology) at Pasadena, with the degree of bachelor of arts. He then took up graduate work at the University of Chicago under Prof. A. A. Michelson, receiving the degree of doctor of philosophy in 1902. After serving one year as an assistant to Professor Michelson, he became instructor in physics and electrical engineering at Massachusetts Institute of Technology, and in 1904 joined the staff of the American Telephone and Telegraph Company. In 1912 he became assistant chief engineer of the Western Electric Company, in 1916 chief engineer, and in 1921 vice president of the company. At the beginning of 1925 he became vice president of the American Telephone and Telegraph Company, and at the same time was made president of the Bell Telephone Laboratories, Inc., which positions he has since held. Doctor Jewett has served the Institute as manager, 1915–18; vice president, 1918–19; and president 1922–23. He also has served on some 16 of the Institute's committees and as its representative on 8

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other bodies. He has presented many papers and articles before the Institute and other organizations, and has been active in The Engineering Foundation and National Research Council. Since the formation of the Institute's committee for the Iwadare Foundation in 1931, Doctor Jewett has been its chairman. This committee selects lecturers sent to Japan under the Iwadare Foundation of the Institute of Electrical Engineers of Japan, and assists students sent to this country from Japan. The Fourth Order of the Rising Sun and the Third Order of the Sacred Treasure have been bestowed upon him by the Japanese government. In 1928, Doctor Jewett was awarded the Edison Medal of the A.I.E.E. He is active on many other bodies, being a term member of the Massachusetts Institute of Technology, a member of the committee on Carnegie Institute of Technology, and a member of the board of trustees of the Carnegie Institution of Washington, D. C.

H. P. Charlesworth (M'22, F'28, and junior past-president) assistant chief engineer, American Telephone and Telegraph Company, New York, N. Y., was recently elected chairman of the board of the Engineering Foundation and representative on the National Research Council to fill unexpired terms ending on February 21, 1935. Mr. Charlesworth has been active in Institute committee work, and is now chairman of the committee on Institute policy and a member of the Edison medal and code of principles of professional conduct committees, and a representative of the Institute on the John Fritz medal board of award. He was a manager 1923–27, vice president 1930–32, and president 1932–33.

C. V. Woolsey (M'22) for several years system engineer, Brooklyn Edison Company, Brooklyn, N. Y., has been appointed director of the inventory, heading the newly created department of the inventory. The function of the department is to provide a continuing record of all future additions and withdrawals of property. Since joining the company in 1909 Mr. Woolsey has been draftsman, assistant to the electrical engineer, electrical system engineer, and system engineer. He was a member of the Institute's membership committee 1926–7.

F. A. Gaby (A'06, F'18) formerly chief engineer, Hydro-Electric Power Commission of Ontario, Toronto, Can., has been appointed assistant to the president of the Canadian Pacific Railway, with headquarters at Montreal. He had joined the commission in 1907, and had been chief engineer since 1912. In his new position he will have charge of the investigation of the forms of competition, and company policies in regard to them. Mr. Gaby has been a member of the Institute's Edison medal committee since 1930.

J. S. Mahan (A'12, F'27) fire prevention and electrical engineer, Oak Park, Ill., has been employed by the Edison Electric Institute to present the views of the electric utilities on national electrical code questions. He was formerly an electrical inspector connected with the Western Actuarial Bureau and for many years was a member of the electrical committee of the National Fire Protection Association. More recently he has been connected with various manufacturers of electrical wiring materials.

H. S. Broadbent (A'22) formerly manager, commercial engineering department, Westinghouse Lamp Company, Bloomfield, N. J., has been appointed assistant to the vice president of the company. Mr. Broadbent graduated from Cornell University in 1917 and joined the Westinghouse organization in 1921 as a lamp development engineer, later transferring to the commercial engineering department. He has served on the Institute's committee on the production and application of light since 1929.

D. W. Atwater (A'34) has been appointed manager of the commercial engineering department of the Westinghouse Lamp Company, Bloomfield, N. J. He is a graduate of Stevens Institute of Technology, and has been with the Westinghouse organization about 15 years. Among the lighting installations on which he coöperated were the Holland Tunnel, New York, N. Y., and the Century of Progress, Chicago, Ill.

R. A. Hopkins (M'19) formerly a member of the consulting engineering firm of Hopkins and Gove, Waltham, Mass., has been appointed engineer in charge of hydroelectric station design for the Tennessee Valley Authority, Knoxville, Tenn. Mr. Hopkins was with Stone and Webster Engineering Corporation, Boston, Mass., for 22 years and has been in charge of a number of electrical project developments.

Wilfred Sykes (A'09, F'14) assistant to president, Inland Steel Company, Chicago, Ill., has been nominated as a director of the American Institute of Mining and Metallurgical Engineers. Mr. Sykes has served on a number of A.I.E.E. committees, most recently as a member of the committee on

applications to iron and steel production, and was a manager of the Institute 1917–21.

J. B. Cox (A'09) recently retired electrical engineer of the transportation department, General Electric Company, Erie, Pa., now resides at Knoxville, Tenn. He had charge of the company's interests in many railroad electrification projects in this country and abroad, including the Chicago, Milwaukee, St. Paul and Pacific; Great Northern Railway; and the Mexican Railway.

G. E. Castellan (A'30) formerly engineering estimator with the General Electric Company, Ltd., Birmingham, England, is now with Clements and Son, London, where he will assist in technical matters. He recently received a diploma in electrical engineering from University College, London, and is a member of the Institution of Electrical Engineers.

G. N. Brown (A'13, M'21) manager of the electric refrigeration bureau, Edison Electric Institute, New York, N. Y., for the past 3 years, has been appointed a special utilities sales representative for Kelvinator Corporation, with headquarters in New York. Mr. Brown has previously been connected with the Ohio Insulator Company and the Pittsburgh Transformer Company.

E. E. Johnson (A'25), since 1931 assistant executive engineer, research laboratory, General Electric Company, Schenectady, N. Y., has been appointed engineer of the generator voltage regulator department. Mr. Johnson is a graduate of Washington State College and has been with the company since 1922.

H. J. Reeves (A'30) since 1929 junior engineer, New York and Queens Electric Light and Power Company, Flushing, N. Y., has formed the partnership of Paul and Reeves, manufacturing agents, Spokane, Wash. He has served on several New York Section committees.

T. H. Hogg (M'31) chief hydraulic engineer, Ontario Hydro-Electric Power Commission, Toronto, Can., has been appointed a member of the main committee of the Canadian Engineering Standards Association. Dr. Hogg has been a member of the Institute's standards committee since 1932.

S. A. Stange (A'10, F'19) formerly a consulting engineer with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., is now a consultant for Black-Clawson Company, Hamilton, Ohio, and Shartle Brothers Machine Company division at Middletown, Ohio.

H. J. Gille (A'01, M'13) manager, agricultural and industrial development, Puget Sound Light and Power Company, Seattle, Wash., has been named as one of a committee of 12 to study the creation of a new state bureau for promoting new settlers in the state of Washington.

Paul Ransom (A'21, M'31) formerly electrical engineer, Utah Apex Mining Company, Bingham Canyon, Utah, has accepted a position as electrical engineer for the Mountain Copper Company, Ltd., Shingle Springs, Calif.

R. R. Law (A'31) of Cicero, Ill., formerly a research assistant in geophysics at Harvard University, Cambridge, Mass., is now an electrical engineer in the research and development laboratory of the R.C.A. Radiotron Company, Harrison, N. J.

I. F. McIlhenny (A'25) assistant professor of electrical engineering, Fenn College, Cleveland, Ohio, is on leave of absence and is engaged on the construction of the Madden dam and power station for the Panama Canal.

E. W. Fisher (A'33) until recently power plant cadet engineer, Kansas City Power and Light Company, Tecumseh, Kan., is now engineering and technical advisor, public service commission of Kansas, Topeka.

H. W. Graybrook (A'26) New Albany, Ind., has become chief engineer for the Clements Manufacturing Company, Chicago, Ill. He was previously chief engineer for the Marathon Electric Manufacturing Corporation, Wausau, Wis.

H. R. Stewart (A'26) formerly general engineer, Westinghouse Electric and Manufacturing Company, Boston, Mass., has joined the New England Power Engineering and Service Corporation as protection engineer.

D. L. Bement (A'25) formerly technical assistant, Northern Indiana Public Service Company, Hammond, has been named general superintendent in charge of production transmission, and distribution for the entire system.

Russell Ranson (A'33) who was employed in the radio consulting department, General Electric Company, Schenectady, N. Y., has become an instructor in electrical engineering at Duke University, Durham, N. C.

H. K. Ansingh (M'22) former manager, Canadian Crocker Wheeler Co., Ltd., St. Catherines, Ont., Can., has become vice president and managing director of the Commonwealth Electric Corporation, Welland, Ont.

J. B. MacLean (A'27, M'30) formerly assistant engineer, Central Railroad Company of New Jersey, Jersey City, is now with the Riegel Paper Corporation, New York, N. Y.

W. S. McCrea, Jr. (A'26) formerly with the department of public works, state of Washington, Olympia, is now rate engineer, department of public utilities, city of Tacoma.

J. F. Imle (A'32) geophysical engineer formerly with the Standard Oil Company of Venezuela, Marcaibo, is now employed by the Humble Oil and Refining Company, Houston, Tex.

A. C. Alizo (A'32) has resigned as manager and engineer, Cia. Annma. Planta Electrica de Valera, Venezuela, and has engaged in private work as a consulting engineer at Escuque, Trujillo, Venezuela.

G. A. Anderson (A'31) formerly assistant to regional construction manager, Montgomery Ward and Company, Oakland, Calif., has become assistant construction superintendent.

J. R. C. Armstrong (A'02, F'13) who recently became engineer examiner for the Federal Emergency Administration of Public Works, has been transferred from Washington, D. C., to Fort Worth, Texas.

W. C. Cram, Jr. (A'14) formerly Georgia district manager, Allied Engineers, Inc., Atlanta, is now technical assistant to the assistant secretary of the treasury, Washington, D. C.

F. R. Phillips (M'27) president, Philadelphia Company, Pittsburgh, Pa., was elected president of the American Transit Association at the recent annual convention held in Cleveland, Ohio.

G. H. Bucher (M'24) president, Westinghouse Electric International Company, New York, N. Y., has been elected a director of the American Manufacturers Export Association.

A. J. Althouse (A'11, M'29) assistant general manager, Metropolitan Edison Company, Reading, Pa., was recently elected a vice president of the Pennsylvania Electric Association.

L. A. Ferguson, Jr. (A'28) formerly construction engineer, Commonwealth Edison Company, Chicago, Ill., has been appointed to the newly created position of assistant general service manager.

D. E. Batchelder (A'28) research assistant, Pasadena Water Department, has been transferred from Azusa, Calif., to Pasadena. He is working on measurements on the Morris Dam.

M. N. Larson (A'28) assistant system operator, Public Service Company of Northern Illinois, has been transferred from Wheaton to Evanston.

J. A. Smith (A'31) electrical engineer, Associated General Electric Industries, Ltd., has been transferred from Perth, Australia, to Tasmania.

J. E. Vipond (A'23) has recently become electrical designer and draftsman for W. G. Chace, consulting engineer, Toronto, Ont., Canada.

C. E. O'Donnell (A'32) of Champaign, Ill., has recently entered the distribution department of the Central Illinois Public Service Company, Maltoon.

F. E. Chester (M'28) ship designer formerly with the Electric Boat Company, Groton, Conn., is now with the United Dry Docks Company, New York, N. Y.

I. L. Craig (A'09) rate engineer, Philadelphia Electric Company, Philadelphia, Pa., was recently elected a vice president of the Pennsylvania Electric Association.

C. K. Beyette (A'34) is a student engineer employed by the Texas Electric Service Company, Eastland.

D. H. Smith (A'32) of St. Elmo, Ill., is now employed by the Illinois Testing Laboratories, Inc., Chicago.

E. T. Lentz (A'33) until recently a repairman, Ohio Bell Telephone Company, Toledo, is now a draftsman for the company.

L. W. Henry (A'16) electrical engineer, Aluminium, Ltd., has been transferred from New York, N. Y., to Montreal, Que., Can.

Obituary

George Fitch Brown (M'18) manager generator and converter division, central station department, General Electric Company, Schenectady, N. Y., died November 26, 1934. He was born at Geneva, Neb., May 2, 1880. In 1904 he graduated from the University of Nebraska with the degree of bachelor of science in electrical engineering and, until he entered the General Electric Company in 1905, worked as an estimator for an electrical contractor. He became a designing engineer in the a-c department in 1907, and remained in this work until 1915, when he became an engineer with the Southwark Foundry and Machine Company, Philadelphia, Pa. Two years later he returned to the General Electric Company as an engineer in the central station engineering department, and was placed in charge of the apparatus section in 1928. He became manager of the generator and converter division when it was formed in 1933.

Christopher Marsh Goddard (A'96, M'02) chairman committee on public relations, New England Insurance Exchange, Boston, Mass., died Nov. 12, 1934, at his home in Summit, N. J. He was born at Claremont, N. H., April 16, 1856. In 1877 he received the degree of bachelor of science from the Chandler school of science, Dartmouth College, and for the following 3 years was instructor in higher mathematics at Cheshire (Conn.) Academy. During the next 10 years he was employed successively in a banking firm, a telegraph company, and in electric lighting construction, accepting an appointment as electrical inspector for the New England Insurance Exchange in 1890. The following year he became secretary and consulting electrician. At this time he formulated the requirements for construction and equipment of electric light and power stations, and in 1892 suggested and organized the Underwriter's National Electric Association, which had charge of formulating the national electrical code. He became a member of the National Fire Protection Association at the time of its formation, and is credited with originating in 1892 a publicity campaign for a national fire prevention week. At one time he served as president of the association. Mr. Goddard was the author of a number of articles on the fire hazard of electricity, and was the chairman of a special committee appointed at the request of the A.I.E.E. to consider the subject of the grounding of low potential circuits. He resigned as secretary of the insurance exchange in 1925.

Herschel Hugh Edwards (A'31) assistant to transmission engineer, New York Telephone Company, Mt. Vernon, N. Y., died in June 1034, according to word just received at Institute headquarters. He was born at Indianapolis, Inc., May 4, 1906. After graduating from Balboa high school, Canal Zone, in 1923, he was employed by the Bell Telephone Company there for 2 years, after which he was employed for short periods by the Christophers Ice Cream Company, Los Angeles, Calif., and the Luxortone Talking Picture Corporation. In 1928 he became transmission engineer's assistant with the New York Telephone Company.

James F. Sinclair (A'27) general manager, Jeffery-Dewitt Insulator Company, Kenova, W. Va., died October 23, 1934. He was born at Sarnia, Ont., Can., April 17, 1877. In 1922 he assumed the office of general manager of the insulator company, and the following year became also general manager and treasurer of the Champion Switch Company, Buffalo, N. Y. During the past 2 years he had been in poor health and had delegated most of his duties to others.

Frank O'Ryan (A'16) Denver, Colo., district manager Allis-Chalmers Manufacturing Company, died November 23, 1934. He was born in 1881, and received his early electrical experience as a testing and installation engineer with the General Electric Company at Fort Wayne, Ind. He went to Denver in 1910 to enter the sales office of the Allis-Chalmers Company, and became manager in 1919. Mr. O'Ryan was also a member of the Rocky Mountain Coal Mining Institute.

T. J. Drury (A'25) teacher, board of education, New York, N. Y., died August 3, 1934. He was born at Roscommon, Ireland, November 20, 1885, and was a graduate of Cooper Union, New York, N. Y. For a short time in 1918 he was employed by the Western Electric Company as an inspector, and had similar duties for the war department in 1918. More recently he had been employed by the Star Publishing Company, New York, N. Y.

Charles Ellison Hendricks (A'27) General Electric Company, Chicago, Ill., was killed in a motor accident on June 29, 1934. He was born at Douglas, Ga., July 4, 1904, and received the degree of bachelor of science from Georgia Institute of Technology. For a short time in 1925 he was employed by the Georgia Railway and Power Company, entering the General Electric Company later in that year.

Membership

Recommended for Transfer

The board of examiners, at its meeting of December 19, 1934, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Culver, L. R., assoc. prof. of elec. engg., Univ. of Cincinnati, Cincinnati, Ohio.

1 to Grade of Fellow

To Grade of Member

Bartholomew, Francis J., president and general manager, Electric Power Equipment Ltd., Vancouver, B. C.
Bell, Edgar, test engr., Penn. Pwr. & Lt. Co., Hazleton, Pa.
Cole, Clarence S., engr., Peter F. Loftus, consulting engineers, Pittsburgh, Pa.
Eaton, James R., transmission line engg., Consumers Pwr. Co., Jackson, Mich.
Kvamme, Ingolf, division engr., Duquesne Lt. Co., Beaver Falls, Pa.
Maxwell, Howard, mgr., design and manufacture, induction motors, Gen. Elec. Co., Schenectady, N. Y.
Ransdall, Ralph A., asst. engr. of line constr., Pacific Gas & Elec. Co., San Francisco, Calif.
Webb, Roy L., asst. engr., Brooklyn Edison Co. Inc., Brooklyn, N. Y.

8 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before Jan. 31, 1935, or March 31, 1935, if the applicant resides outside of the United States or Canada.

Baker, R. V., Union Elec. Lt. & Pwr. Co., St. Louis, Mo.
Bangs, G. L., Rochester Gas & Elec. Corp., Rochester, N. Y.
Bartley, J. L., Cleveland Securities Corp., Cleveland, Ohio.
Besson, J. P., 1186 Washington Ave., Bronx, N. Y.
Blair, W. H., Potomac Elec. Pwr. Co., Washington, D. C.
Bloomberg, J. B., Southwestern Bell Tel. Co., St. Louis, Mo.
Bryan, P. D., N. Y. Tel. Co., Albany.
Campbell, J. H., Gen. Elec. Co., Cleveland, O.
Cary, A. R., Buffalo Steel Co., Tonawanda, N. Y.
Chase, C. W., Indianapolis Ry., Indianapolis, Ind.
Dalton, W. J., Brooklyn Edison Co., Inc., Bklyn., N. Y.
Davis, W. C., Penn College, Cleveland, Ohio.

Diestler, E. A., 125 Salisbury St., Worcester, Mass.
Fisher, D., American Tel. & Tel. Co., N. Y. City.
Fountain, J. B., Mississippi Pwr. & Lt. Co., Greenville.
Fryer, J. C., Schweitzer & Conrad Inc., Chicago, Ill.
Gilliland, C. W., General Cable Corp., Emeryville, Calif.
Graham, A. L., Eastern Pwr. Devices, Ltd., Toronto, Ont., Can.
Helldoerfer, C. J., Dayton Pwr. & Lt. Co., Dayton, Ohio.
Honig, A. R., Jr., Gen. Elec. Co., Jackson, Mich.
Horsley, C. B. (Member), Waite & Bartlett X-Ray Mfg. Co., Cleveland, O.
Kaleda, G. M., Philadelphia & Reading Coal & Iron Co., Mahanoy City, Pa.
King, R., 2601 Kingsland Ave., Oakland, Calif.
Kopas, J. S., Fenn College, Cleveland, Ohio.
Krusska, J. F. (Member), Jensen, Bowen & Farrell, Newark, N. J.
Lawrence, G. R., 14 Ivy St., Boston, Mass.
Logan, F. G., Ward Leonard Elec. Co., Mt. Vernon, N. Y.
Lorenz, R. D., El Paso Elec. Co., El Paso, Tex.
Nimmo, J. M., Jr., Virginia Elec. & Pwr. Co., Norfolk.
Nisula, C. W., U. S. Navy, Rm. 629, Federal Bldg., Detroit, Mich.
Oliver, G. W., Pwr. & Lt. Co., Pine Bluff, Ark.
Otani, M., Internatl. Gen. Elec. Co., Schenectady, N. Y.
Perine, W., N. Y. Edison Co., N. Y. City.
Phillips, C. A., Virginia Elec. & Pwr. Co., Richmond.
Plusch, J. O., U. S. Coast Guard "Aurora," San Pedro, Calif.
Porter, J. S., Westinghouse Elec. & Mfg. Co., Oklahoma City, Okla.
Reid, C. A., U. S. Geological Survey, Rolla, Mo.
Reisman, L., 4065 Carpenter Ave., N. Y. City.
Robert, P. A., 312 West 109th St., N. Y. City.
Roper, B. W. A., Penn. P. & L. Co., Hazleton, Pa.
Salembier, A. H., Desarmont Worsted Co., Woonsocket, R. I.
Schumacher, H. A., Bishop Wire & Cable Corp., N. Y. City.
Smith, R., Oklahoma Gas & Elec. Co., Oklahoma City.
Steinhauer, W. H., Toledo Edison Co., Toledo, O.
Strehlow, H. E., Buffalo Steel Co., Tonawanda, N. Y.
Swartz, T. W., Northwestern Elec. Co., Portland, Ore.
Trefton, J. P., Indianapolis Ry., Indianapolis, Ind.
Walters, N. F., Locke Insulator Corp., Baltimore, Md.
Whistler, J. P., Bell Tel. Lab., N. Y. City.
Williams, H. I., Univ. of Vermont, Burlington.

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Chandra, K., United Provinces Hydro Elec. Scheme, Sambhal, Dist. Moradabad, India.
Maine, B. C. (Member), Cerro de Pasco Copper Corp., Cerro de Pasco, Peru, S. A.
Reiner, R. M., Braden Copper Co., Rancagua-Coya, Chile, S. A.

3 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the address as it now appears on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Adams, William C., 801 S. Lynn St., Champaign, Ill.
Babloozian, Levon M., 776 N. Cass St., Milwaukee, Wis.
Demeros, Andrew G., P. O. Box 787, East Pittsburgh, Pa.
Eberhard, Jacob J., 525 Grant St., Santa Clara, Calif.
Fenn, Fred H., 204 Church St., Baton Rouge, La.
Fennis, A. M., 4266 Old Orchard Ave., Montreal, Que., Can.
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20 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

A.T.M.—Archiv für Technisches Messen. Lieferungen 31–38, January 1934–August 1934. Munich and Berlin, R. Oldenbourg. Illus., 12x8 in., paper, 1.50 rm. each. An application of the loose leaf method to encyclopedia production. The text consists of brief articles upon measuring instruments and methods for all industrial and scientific purposes, hydraulic, acoustical, chemical, and electrical, together with summaries of accepted practice and reports upon research work, new instruments, etc. No. 38 contains an index to the first 36 issues.

CODES, CARTELS, NATIONAL PLANNING, the Road to Economic Stability. By B. Burn in collaboration with S. Pink. N. Y. and Lond., McGraw-Hill Book Co., 1934. 413 p., illus., 9x6 in., cloth, $4.00. The author, who has had long experience in the management of cartels and trade associations in Germany, here discusses the influence of our present codes upon economic stability, the possible ways in which cut-throat competition and overexpansion can be checked, the organization of American business for self-administration, and the compatibility of national planning with American institutions.

DESIGN of ELECTRICAL MACHINERY. By H. Cotton. Lond. and N. Y., Oxford Univ. Press, 1934. 479 p., illus., 10x6 in., cloth, $9.00. This textbook, intended to meet the requirements for the examinations of the Institution of Electrical Engineers, presents the fundamental principles of the design of all classes of electrical machinery, both d-c and a-c. These principles are discussed, and the necessary formulas derived from them where possible.

ELECTRON TUBES in INDUSTRY. By K. Henney. N. Y. and Lond., McGraw-Hill Book Co., 1934. 404 p., illus., 9x6 in., cloth, $5.00. This book aims to describe industrial applications of thermionic and light-sensitive electron tubes, to explain the fundamental principles involved, and to describe rather fully the newer tubes which are not generally known. The work is a useful survey of a new field, which will obviate the necessity of consulting much scattered periodical material.

Die ELEKTRISCHEN MASCHINEN, Bd. 3. Berechnung und Bemessung. By M. Liwschitz. Leipzig u. Berlin, B. G. Teubner, 1934. 409 p., illus., 9x6 in., cloth, 22.50 rm. Preceding volumes have discussed the general principles of electrical machines and their construction and insulation. This final volume is devoted to design, discussing the magnetic circuit, leakage, losses, heating, current diagram of induction machines, transformers, and all types of machines.

ENGINEERING RADIOGRAPHY. By V. E. Pullin. Lond., G. Bell & Sons, Ltd., 1934. 136 p., illus., 11x8 in., cloth, 45 s. This is intended to be a practical guide to the radiologist in interpreting radiographs of forgings, castings, and other engineering structures. A comprehensive collection of radiographs is presented, showing all the chief and most common flaws in castings, accompanied by photographs of sections of the castings which show the actual conditions. The causes of the flaws are explained in terms of common engineering experience.

Die TECHNIK der FERNWIRKANLAGEN. By W. Stäblein. Munich and Berlin, R. Oldenbourg, 1934. 294 p., illus., 10x7 in., cloth, 15 rm. This volume discusses apparatus and methods for the remote operation, supervision, and control of electric stations, gasworks, waterworks, and other plants. The principles involved in the various operations are described, and the problems met are discussed.

TECHNIQUE of MODERN WELDING. By Prof. P. Bardtke; translated from the 2d German edition by H. Kenney. Lond. and Glasgow, Blackie & Son, Ltd., 1933. 299 p., illus., 9x6 in., cloth, 15 s. A survey of welding technique which will be of use to engineers and a manual for the training of welders, discussing welding processes, applications of welding, testing of welds, and gas cutting.

TEXTBOOK on HYDRAULICS. By G. E. Russell. 4 ed. N. Y., Henry Holt & Co., 1934. 447 p., illus., 9x6 in., cloth, $3.90. A presentation of the fundamental principles of hydraulics, intended for students and as a reference book for engineers. The results of recent research work are included, and references to sources are given. This edition has 4 new chapters on hydraulic turbines and pumps and an appendix giving a general treatment of fluid flow in pipes, covering the problems presented by fluids other than water.

WATER POWER ENGINEERING. By H. K. Barrows. 2 ed. N. Y. and Lond., McGraw-Hill Book Co., 1934. 762 p., illus., 9x6 in., cloth, $6.00. The principles and practice that underly the design of hydroelectric plants are described in a comprehensive way in this textbook, which has been carefully revised to bring it up to date; especially, the section on the cost and value of water power has been largely rewritten.

WORLD POWER CONFERENCE, SECTIONAL MEETING, SCANDINAVIA, TRANSACTIONS 1933, 7 Vols. Stockholm, Svenska Nationalkommitten för Världskraftkonferenser, 1934. (American Committee, World Power Conference, 1419–21 Chrysler Bldg., N. Y.). illus., 10x6 in., 7 vols., 175 Swedish Kroner. v. 1. 763 p., $14. v. 2. 702 p., $14. v. 3. 336 p., $7.25. v. 4. 515 p., $12.75. v. 5. 602 p., $14. v. 6. 781 p., $16. v. 7. 394 p., $5.50 (approximate prices, vary according to exchange). These volumes contain a full report of the papers and discussions before the technical sessions of the conference, of its organization, personnel, official, and social functions, etc. The theme of the conference was the energy problems of large-scale industry. The individual volumes are: 1, general matters, general summaries of all reports, and the index to the transactions; 2, electrical energy; 3, gas, and solid and liquid fuels; 4, power and heat combinations, and steam-heat consuming industries; 5, iron and steel industry, electrical heating, and the transmission and adaptation of motive power for industrial machinery; 6, railways, and urban and suburban traffic; 7, marine transport.

ELECTRICAL MEASUREMENTS in THEORY and APPLICATION. By A. W. Smith, 3 ed. N. Y. and Lond., McGraw-Hill Book Co., 1934. 413 p., illus., 10x6 in., cloth, $3.00. A progressive text for college students which can be used as a laboratory manual, but which also explains fully the principles involved. The electron theory of electrical phenomena is adopted throughout the book and electrical currents are considered as the flow of electrons along the circuit.

Engineering Societies Library

29 West 39th Street, New York, N. Y.

MAINTAINED as a public reference library of engineering and the allied sciences, this library is a cooperative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

Industrial Notes

The Electrical Outlook for 1935.—According to a recent statement by Gerard Swope, President, General Electric Co., the volume of electrical manufacturing during 1934 has been more than 30 per cent greater than in 1933. Consumption of electricity throughout the United States has been approximately 7 per cent greater than in 1933 and is almost up to the maximum consumption in the years 1929 and 1930. This increase has been due largely to the increased use of electrical appliances in the home. The electrical manufacturing industry, and industry in general, has felt most seriously the failure of the revival of orders for capital goods, but with the increased use of electricity and consumers' goods in general, capital goods must also increase. For the year 1935, Mr. Swope looks forward to a continued improvement in business.

General Cable Discontinues Coil Winding Service.—According to a recent announcement by the General Cable Corporation, New York City, its coil winding department has been discontinued as of December 31. This change in policy pertains to finished coils alone. The production of magnet wires of all types will be continued.

Aerovox Reduces Interference-Filter Prices.—In keeping with the far-reaching purposes of the interference-prevention campaign launched by the Radio Manufacturers Association during the recent I.R.E. convention at Rochester, N. Y., a marked reduction in list prices of interference filters is announced by the Aerovox Corporation, Brooklyn, N. Y. The reductions on four items are intended to stimulate the greater sale and use of interference-prevention devices so that various localities may enjoy present-day broadcast and short-wave reception to wider advantage.

Multiple-Point Recording in Colors.—Reading of multiple-point instrument records is greatly simplified by a new system of "numerals in colors" introduced by Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia. This marking system can be specified on Micromax strip-chart recorders for 2, 3, 4, or 6 points. With each of the thermocouples, resistance thermometer bulbs or other primary elements identified on the chart by a numeral, and each numeral distinguished from the others by being printed in a contrasting color, reading of records is made easy, errors are avoided, and time is saved. Colors used are black, green, red, violet, yellow, and blue. Full details and a reproduction of an actual chart in all six colors are contained in Circular 314-I.

Large Trolley Equipment Order to Westinghouse.—Amounting to approximately $60,000, the Westinghouse Electric & Mfg. Co. has received a contract from the J. G. Brill Co., for electrical equipment to be installed on 10 street cars ordered by the Capital Transit Co., at Washington, D. C. Quadruple type 50 horsepower motors and variable automatic control features will give these cars schedule performance possibilities excelling any street cars now operating in regular revenue service, according to railway engineers. The cars will have smooth accelerating and braking rates of 4.75 miles per hour per second and a balancing speed of 40 miles per hour. The cars, of the center exit type, will weigh 33,000 pounds and are each 44 feet in length.

U. S. Navy Buys Diesel Submarine Engines.—The U. S. Navy has recently placed orders for 30 large Diesel engines to be installed in 5 new submarines. The total cost of these engines and the electrical equipment they will drive is nearly $4,000,000. Twenty of the engines are large units for propulsion service and 10 smaller units are for auxiliary service, generating electricity for operating all equipment aboard the vessels. Eight of the large engines and 4 auxiliary units are of a type not previously built in this country, according to Fairbanks, Morse & Co., and these opposed-piston Diesel engines are being furnished by this company. This type of engine has two pistons, an upper and lower in each cylinder, each connected to its own crank-shaft, one above and one below. Advantages of this type of engine are improved combustion efficiency and extreme compactness and light weight for the power developed.

Trade Literature

Network Protector.—Bulletin GEA-2017, 8 pp. Describes a new heavy-duty, automatic, a-c network protector for subway and vault service. General Electric Co., Schenectady, N. Y.

Connectors.—Condensed folder catalog, 6 pp. Illustrates a wide variety of connectors covering every cable, wire, tube, or bar size. Burndy Engineering Co., Inc., 305 E. 45th St., New York.

Motor Price Wheel.—An unusual device, consisting of two 8-inch, revolving fiber disks, for quickly determining the frame sizes and list prices of 448 popular sizes and types of electric motors. The Louis Allis Co., Milwaukee, Wis.

Arc Welders.—Bulletin GEA-1440C, 8 pp. Describes the improved Type WD self-stabilized, single-operator arc welder.—Welding Electrodes and Accessories.—Bulletin GEA-1546B, 16 pp. Describes various types of welding electrodes and welding supplies and accessories. General Electric Co., Schenectady, N. Y.

Pole Top Switches.—Bulletin, 16 pp. Describes improved types MB-139, VMB-139, and FMB-139 pole top, group operated, vertical break switches for disconnecting or load break service and for manual or motor operation. Delta-Star Electric Co., 2400 Block-Fulton St., Chicago, Ill.

Capacitors.—Catalog 6-S, 20 pp. Describes ultra-compact dry electrolytics in various voltage ratings, special self-healing type wet electrolytic condensers, auto vibrator and suppressor condensers; and paper, mica, trimmer, etc. condensers. Solar Manufacturing Corp., 599 Broadway, New York.

Mechanical Rubber Goods.—Catalog, 96 pp. Describes hose, belting, packing, and miscellaneous mechanical rubber products. Diagrams illustrate various applications; tables are included with belt speeds, steam pressures and temperatures, carrying capacities and dimensions. New York Belting and Packing Co., Passaic, N. J.

Industrial Cable.—Catalog GEA-1838, 128 pp. Describes all standard types of insulated wires and cables used for industrial application in transmission, distribution, and control, as well as for use on or with electric equipment such as mining machinery, locomotives, arc welders, and Neon signs. Another publication, Bulletin GEA-1837, on "How to Select Insulated Cable," should prove valuable to all users of cable for general reference purposes. General Electric Co., Schenectady, N. Y.

Diesel Engines.—Catalog, 20 pp. Describes stationary-type Diesel engines of the 4-cycle, single-acting, solid-injection type, with box-type housing, cylinder liners, and overhead chain-driven camshafts, fully enclosed and provided with automatic lubrication throughout. The I-R Diesel engine is built in sizes ranging from 175 to 1,500 bph and is applicable for direct-connected a-c generator drive, gearing to pumps, direct connection to compressors, for belting to line shafting, and for similar work. Ingersoll-Rand Co., 11 Broadway, New York.

Motor Maintenance.—Booklet, 64 pp. "The Brush Phase of Motor Maintenance"; a non-mathematical explanation of the causes and cure of brush, commutator and slip-ring troubles on rotating machinery. Diagrams and data on commutation, current collection, armature and field reaction due to load are included. Brush, slip-ring, and commutator maintenance methods; the characteristics and manufacture of carbon brushes; and a brief discussion on contact drop, vacuum effect, and other brush properties are dealt with. Ohio Carbon Co., 12508 Berea Road, Lakewood, O.

Phase-Checker.—Bulletin 165, 4 pp. A balanced statiscope for use between two lines to determine the phase relationship between them. It is employed to check phases on lines at the disconnect switches in the substation; consists of a Neon tube and condensers enclosed in a hard rubber case provided with a rubber handle; light in weight, easy to operate, and positive in its indication. The instrument is extremely simple to operate, and no preliminary set-up is necessary. There are no metal parts exposed, insuring safety in operation. Made in 2 sizes—2,000 to 7,500 volts and 7,500 to 15,000 volts. Minerallac Electric Co., 25 N. Peoria St., Chicago, Ill.

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H. H. Henline, National Secretary

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A communication line "after the storm"
Photo courtesy W. R. Pollard, Georgia Power Co.

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The A.I.E.E. as an E

By J. Allen John

THE OBJECTS of the Institute, as defined by i Constitution, are (1) "the advancement of th theory and practice of electrical engineering and the allied arts and sciences," and (2) "the maintenanc of a high professional standing among its members." Now I think no one can misunderstand what meant by the first of these 2 objects because a vancement of the art by which we electrical engineers make our living has been so rapid and spectacular during the last half century that every one knows all about it; but that statement about maintaining "a high professional standing," just what does it mean? What is "professional standing" anyhow and what is involved in maintaining it high among our members?

The stumbling block to a clear understanding of all that this expression means is found in the word "professional"; and the reason, I think, lies in the fact that this word connotes so many different ideas, the combination of all of which is necessary to define it completely, that our inability simultaneously to remember and visualize them all leaves us in a state of mental confusion. In other words, we have only a foggy notion of what this second object of the Institute is.

One of the objects of in its Constitution is "professional standing maintain a high indivi an engineer must keep nical advances in his f expects to advance in tion cannot stop after tional institution, but his career. In this, h Institute's 1935 wint Johnson brings clear attention of Institute m tional activities of th them maintain high p urges that members of dependence of their standing upon their c make full use of the the Institute." This ec nally for presentation burgh Section of the In fore that body by E. C. by request, President J ded it for presentation

Now what the term "profession" implies in all its connotations has been beautifully and completely stated by Doctor Wickenden in that inspiring address he delivered at the Institute's summer convention last year, which was published in the August 1934 issue of ELECTRICAL ENGINEERING, page 1146. I cannot add anything to that statement. It is perfect as it stands; but I can and do urge every member to read it if he has not done so already. However, perhaps I can paraphrase the 2 objects of the Institute into such simple language that any one can understand them. It seems to me that these 2 clauses mean simply this, that the 2 objects of this Institute are:

The A.I.E.E. as an Educational Institution

By J. Allen Johnson, President A.I.E.E.

One of the objects of the A.I.E.E. as stipulated in its Constitution is "the maintenance of a high professional standing among its members." To maintain a high individual professional standing, an engineer must keep himself informed of technical advances in his field; in other words, if he expects to advance in his profession his education cannot stop after graduation from an educational institution, but must continue throughout his career. In this, his opening address at the Institute's 1935 winter convention, President Johnson brings clearly and forcefully to the attention of Institute members the many educational activities of the Institute that will help them maintain high professional standing. He urges that members of the Institute "realize the dependence of their individual professional standing upon their continuing education, and make full use of the opportunities offered by the Institute." This address was prepared originally for presentation at a meeting of the Pittsburgh Section of the Institute, and was read before that body by E. C. Stone on January 8, 1935; by request, President Johnson revised and extended it for presentation at the winter convention.

THE OBJECTS of the Institute, as defined by its Constitution, are (1) "the advancement of the theory and practice of electrical engineering and of the allied arts and sciences," and (2) "the maintenance of a high professional standing among its members." Now I think no one can misunderstand what is meant by the first of these 2 objects because advancement of the art by which we electrical engineers make our living has been so rapid and spectacular during the last half century that every one knows all about it; but that statement about maintaining "a high professional standing," just what does it mean? What is "professional standing" anyhow and what is involved in maintaining it high among our members?

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1. To promote better electrical engineering.
2. To make better electrical engineers.

It is true that the language used in the constitution does not say anything about "betterment" of the professional standing of our members—it says "maintenance"; but whatever "professional standing" may mean in its entirety, in its technological and educational connotations its "maintenance" certainly implies at least a constant relationship between the individual engineer's knowledge of the art and the art itself. Since the Institute, by virtue of its first objective, is committed to the promotion of the advancement of the art, likewise, by virtue of its second objective, it must address itself to the task of helping its members to keep pace with the advancing art. Thus the Institute, in carrying out the second of its constitutional objectives becomes *per se* an educational institution, which brings me finally around to my subject.

MAINTAINING A HIGH PROFESSIONAL STANDING

As pointed out so clearly by Doctor Wickenden in his address already referred to, a profession has group aspects as well as individual aspects. The standing of the profession as a whole is doubtless a group consideration, but the professional standing of an individual engineer is his own personal and individual affair. Once he has graduated from college and entered professional life his professional standing and its maintenance are up to him. The idea that graduation completes his education, and that all he thereafter has to do is to settle down and take it easy, is far from fact. That might conceivably be so if the science and the art were static, but in a field in which development occurs as rapidly as it has in that of electrical engineering, the college graduate quickly learns that he must continue his education even to *keep up* his professional standing; and if he expects to *advance* in his profession, which means broadening as well as deepening his knowledge, he must devote

a very considerable part of his time to study.

The fact that an engineer's professional standing is an individual matter seems to me to indicate conclusively that an engineer's relationship to his clients or employer also must be on an individual basis. To me this clearly implies that no man who deserves to be called an engineer could possibly even think of these relationships in terms of "collective bargaining." The whole idea of group or mass action in the relationships between engineers and their employers is, to my mind, repulsive to the whole concept of engineering as a profession. The kind of services that an engineer performs seem to me to be peculiarly individual services, the value of which depends upon the personality, characteristics, and abilities of the individual, one factor in which is his professional standing. One aspect of his professional standing is the degree in which he has kept up with the advance of his technology.

Here, it seems to me, is where the professional societies like the A.I.E.E. enter the picture. While it is true that every man's continuing education is his own responsibility, engineers discovered long ago that they could help each other educate themselves very effectively by forming societies through the medium of which discoveries and experiences might be interchanged and thus the progress of both engineering and engineers promoted. This motive was the principal one that prompted the organization of this Institute and that has dominated its development. It still is dominating its development, as will, I think, become clear if we now consider briefly the principal activities of the Institute in their educational aspects.

President Johnson

Educational Activities of the Institute

Papers and Discussions. Of course the main educational activity of the Institute is the publication, presentation, and discussion of papers. We are all more or less familiar with this activity, but I suspect that many of us do not think of it as an educational activity. Its success involves an immense amount of work for the "teachers" who write the papers, the committees that receive and review them, the technical program committee and the publication committee which together keep them moving through the mill, and the editorial staff which edits them and oversees the actual mechanics of their publication. Papers may be initiated either by individual members or by the technical committees. Formerly most papers were volunteered; but more recently it has become customary for the committees to sponsor coordinated groups of papers, often soliciting them from those who they feel to be best qualified to furnish the very latest information on a given subject. By this practice the educational value of the papers has been enhanced, as a result of the more orderly, coördinated, and comprehensive treatment of subjects.

I would like to say a word of appreciation of the work performed by the members of all these committees. To some extent, of course, this committee work furnishes its own compensation in the form of earliest contact with new developments in the art and in the inspiration of close personal contacts with other engineers engaged in similar work; but this fact does not detract in the least from the value of this work to the average Institute member. It is the faithful and devoted work of these men that makes the Institute possible and creates its value. I would like to say just a special word in appreciation of the work of the technical program committee under the chairmanship of Mr. R. N. Conwell, during the transition period between the old and the new publication policies. The problems involved in getting the new plan working smoothly, involving as it does the long time planning of convention programs and the supply of a steady stream of papers to the publication committee and the editorial staff in advance of and coördinated with their scheduled dates of presentation, have required no small degree of ingenuity, executive ability, forcefulness, and tact. I hope that sometime Mr. Conwell will tell us about it in Electrical Engineering, especially the mechanical device he has worked out for controlling the progress of papers through the mill.

Section, Branch, and District Activities. Besides providing a wider field for the discussion of Institute papers, these field activities also furnish opportunities for the presentation of lectures and demonstrations on electrical and allied subjects to the various local groups. These serve to broaden the educational work of the Institute thereby reaching many members who otherwise would not receive this benefit. The Branch activities give the young men in the colleges the benefit of the Institute's educational program to supplement that of the colleges, thus helping them to become better electrical engineers, to the benefit of both themselves and the profession as a whole. This contact with the embryo engineers also helps to bring home to them the necessity for continued educational effort after graduation, and thus reacts also to the benefit of the Institute.

Publication of Electrical Engineering. Under the new unified publication policy the Institute now places in the hands of every member and enrolled student all technical papers complete, related discussions, and also many special articles on subjects of current interest and importance written by recog-

nized authorities in their respective fields. Everything of a technical nature that is contributed by Institute members and adjudged by competent reviewers as worthy of publication, and much more besides, is there in ELECTRICAL ENGINEERING. Of course, no member is obliged to read this material, but if he does not he has no right to complain of its value or lack of value. I regret to have to say that I am afraid too many of our members fail to read ELECTRICAL ENGINEERING.

Committee on Education. Since a substantial part of our membership is made up of teachers of electrical engineering, the Institute would not be doing its full educational job if it did not provide these men opportunities to discuss with each other the general subject of engineering education and to listen to the views of other engineers on the same subject. The Institute thus becomes not only a teacher of electrical engineering, but also a teacher of electrical engineering teaching. The work of this committee thus becomes a doubly important part of the Institute's educational activities.

ENGINEERS' COUNCIL FOR PROFESSIONAL DEVELOPMENT

Since the Institute's principal activity is education, it is continually seeking ways to improve its methods and extend the services by which it tries to enable its members to keep themselves abreast of the advancing art and thus maintain their "professional standing." In this connection there are certain services that probably can be performed better and more efficiently by joint action of the national engineering societies and others than by each one separately.

Considerations such as these—which of course are equally true of all the engineering societies—coupled with the movement for the licensing of engineers in the various states, led to the formation of Engineers' Council for Professional Development (E.C.P.D.). This organization is composed of representatives of 5 national engineering societies (civil, mechanical, mining, chemical, and electrical) the Society for the Promotion of Engineering Education (representing the engineering schools), and the National Council of State Boards of Engineering Examiners. Thus there are brought together into a single body the 3 groups primarily interested in the "professional standing" of engineers, namely: the schools which lay its foundations, the societies which build it up and try to maintain it, and the public which apparently believes it necessary to "check up" on it before allowing any one to call himself a "professional engineer."

E.C.P.D. is devoting itself to all phases of the professional advancement of engineers, both as individuals and as a group, inclusive of the educational and legal aspects of professional standing. Its program is broad and comprehensive and I cannot take time now to mention all its activities and plans, but will mention only those having to do with the educational aspects of professional development.

In the first place, E.C.P.D. has been set up by its sponsors as an agency for the accrediting of engineering schools. This means that through E.C.P.D. the process of determining whether or not a certain curriculum offered by a certain school is a satisfactory preparation for the conferring of the bachelor degree in science or engineering may be carried out once for all and not have to be done 28 (or ultimately perhaps 48) times. The Institute's board of directors have been giving intensive study for more than 2 months to E.C.P.D.'s proposed plan for accrediting engineering schools, and voted to sanction the plan at its meeting on January 21, 1935; the plan will go into immediate effect. This activity is under the direction of E.C.P.D.'s committee on engineering schools. E.C.P.D. has also a committee on student selection and guidance, which is working on plans for more rational selection of engineering students. It has still another, a committee on professional training, which is working on plans for the guidance of the self education of junior engineers after graduation from college. If you will look in your December 1934 and January 1935 issues of ELECTRICAL ENGINEERING (pages 1667 and 133, respectively) you will find lists of books recommended for reading by such junior engineers. This list has been compiled by this committee of E.C.P.D., and I have no doubt that many older members can profit by it too, if they are not too proud to read books recommended for juniors. Other lists are to follow from time to time. Perhaps here is the germ of an idea for our technical committees in their respective fields.

E.C.P.D. also is planning a program of accrediting for individual engineers, and in due course all these educational plans are intended to dovetail in with the accrediting plans; these developments are still in the formative stage and are not ready for announcement.

NEW EDUCATIONAL OPPORTUNITIES

My purpose in thus outlining these educational plans and accomplishments of E.C.P.D., which is a joint agency of this Institute and others, is to indicate that this Institute still is developing new methods of providing educational opportunities for its members in order to facilitate in every way it can the "maintenance of a high professional standing among its members." In my opinion the success of the Institute in the past has been the result of its close adherence to the constitutional objectives which I quoted in the beginning, and I believe its future success also will lie in following these objectives and ideals with singleness of purpose. The present urge for the interpretation of professional standing in the sense of "group prestige" is only a phase of the present fever for getting something for nothing. It will pass in due time and we shall rediscover that worth while things are acquired only by effort. In closing, I can only urge, therefore, that our members realize the dependence of their individual professional standing upon their continuing education, and make full use of the opportunities offered by the Institute. If they will do this I feel sure that all petty financial considerations will fade into insignificance in comparison with the value of Institute membership as a means of "maintaining a high professional standing" through continuing education and consequent advancement in competence as an engineer.

High Speed Motion Pictures

High speed motion pictures have been found to be extremely useful in studying the motions of various types of mechanisms, especially transient high speed motions. Modern electronic devices have contributed new methods of producing accurately controlled light flashes of extremely high intensity so that now pictures may be taken by reflected light at rates up to several thousands per second.

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MANY USES for high speed motion pictures have been found in engineering as well as in other fields. Studies of mechanisms by means of high speed motion pictures often reveal unsuspected variations in velocity, acceleration, and deformation, which become paramount in importance as the mechanism is operated at high speed. Motion pictures of this type are taken with the camera driven at a rate greater than normal, and then are projected at the usual rate. The projected picture shows the motion of the subject slowed down by that ratio by which the camera was speeded up.

For periodic motions stroboscopic light provides a very satisfactory means of observing the manner of operation, and for this reason the stroboscope[1] as a measuring instrument has proved itself to be a valuable laboratory instrument. The stroboscope is of very limited use for studying transient or nonperiodic motions, because of the shortness of the entire sequence of events and the difficulty of synchronizing the flashes of light to correspond to the motion. Stroboscopic light of sufficient intensity and of a relatively high frequency of flash, however, makes possible a method of ultra-high speed photography which has tremendous utility for the analysis of complicated and difficult mechanical problems. Modern electronic devices have contributed new methods of increasing the intensity of the light and of accurately controlling the instant of flash to such an extent that motion pictures by means of reflected stroboscopic light are now a practical possibility up to speeds of several thousand pictures per second.

All high-speed motion-picture cameras operating at rates of speed in excess of 200 or 300 frames per second must be constructed so that they use continuously moving film, since the mechanical difficulties of starting and stopping the film for individual pictures so far have been insuperable. In general there are 2 main types of high-speed motion-picture cameras with continuously moving film, namely:

1. Those utilizing a moving optical system to keep the image in a stationary position with respect to the film during the time of exposure.
2. Those utilizing a source of stroboscopic light the flashes of which are sufficiently brief to give a sharp image on the moving film.

The first type of camera is especially useful in studying problems involving the evolution of bright light, such as occurs in the photo-flash lamp and in the burning of explosive mixtures; also it is useful in direct sunlight and other places where the light intensity is high. The high speed cameras of Jenkins,[2,3] Heape and Grylls,[4] Suhara,[5,6,7] Tuttle,[8] Thun,[9,10,11] Legg,[12] and others are examples of the first type, since each of them depends upon a moving optical system to stop effectively the relative motion of the image and the film.

The second type of high speed camera is considerably simpler from a mechanical standpoint, but it requires somewhat involved electrical circuits for producing the flashing light. Bull,[13,14] Seguin,[15] Cranz,[16] N.A.C.A.,[17,18] and possibly others have constructed high speed cameras that depend upon instantaneous flashes of light for exposing photographs upon continuously moving film. This paper describes a camera of this second type that has been constructed at the Massachusetts Institute of Technology. The main advantage of this type of camera over the first type is the extremely short exposure time, which usually is less than 1/1,000, and may be as small as 1/100,000 of the time interval between successive pictures. The exposure time for the moving-optical-system type of camera purposely is made as long as possible in order to get satisfactory exposures, and sometimes actually is made longer than the time interval between successive pictures by simultaneous overlapping of exposures, as described by Jenkins. The second type of camera is of no use in the study of subjects that emit light, or in places brilliantly illuminated by sunlight.

The particular improvements of the camera described in this paper over previous cameras of the same type are:

1. Circuits making it possible to control the instant of flash accurately so that the pictures are framed properly on the film for projection, or so that the interval of time between flashes is known or determined accurately.
2. Circuits making it possible to obtain sufficient light so that reflected-light photographs (in contrast to the usual silhouette type of pictures) may be taken.
3. Mechanical design of camera giving rapid acceleration and constant speed, for a long strip of film.

Sources of Stroboscopic Light and Control Circuits

Capacitor discharges into mercury arc lamps have proved[19,20] to furnish a very useful method of ob-

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1. For all numbered references see bibliography at end of paper.

taining stroboscopic light for photographic work. The light is actinic, the discharge time is short, the timing is susceptible to accurate control by means of pulse amplifiers, the construction of the tubes is relatively simple, and as many tubes may be connected in parallel as desired, since they all flash at the same instant. Figure 1 shows 2 banks of mercury arc stroboscope tubes with 4 lamps in each, the power supply equipment that furnishes the necessary direct-current for charging the capacitors and the high speed camera.

A wiring diagram of the apparatus in Fig. 1 is shown in Fig. 2. A 6-phase 10-kw rectifier unit supplies direct current at 1,000 volts to charge the capacitors. Resistors in series with each capacitor limit the flow of current to the lamps in case of "holdover," but still allow the capacitors to become charged effectively during the interval between flashes. The time constant of a circuit consisting of resistance and capacitance is equal to RC seconds, where R is expressed in ohms and C in farads. This factor is important, since it gives the time required to charge a capacitor from an uncharged condition to 63 per cent of the ultimate charge. The time constant of the discharge capacitor C_1 and the charging resistor R_1 in the diagram, Fig. 2, should not be more than $^1/_2$ of the interval of time between successive flashes in order to have the capacitors effectively charged. A choke coil in series with the resistors is used to increase the time allowed for deionization. Usually this choke is designed to have a large value of inductance on the first part of the charging surge, and a smaller value thereafter.

Power required by a bank of stroboscope lamps depends upon many factors, but mainly upon the number of lamps, the frequency of flash, the size of flashing capacitor, and the voltage to which the capacitor is charged. A method of calculating the power requirement for any particular equipment is as follows: The energy stored in a capacitance of C farads charged to E volts is $E^2C/2$ joules. It is well known that as much energy is lost in the charging resistor as is stored in the capacitor when it is allowed to become fully charged. Therefore the energy required for each flash is E^2C joules. The total

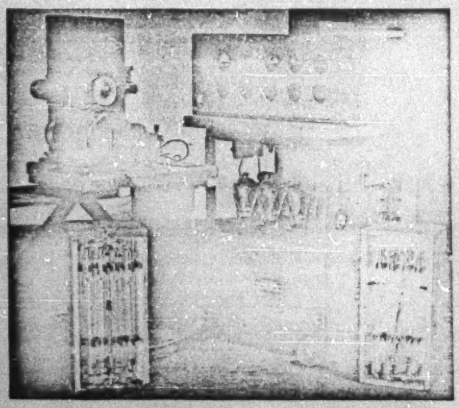


Fig. 1. High-speed motion-picture camera recently developed at Massachusetts Institute of Technology and the electrical apparatus for producing the stroboscopic light

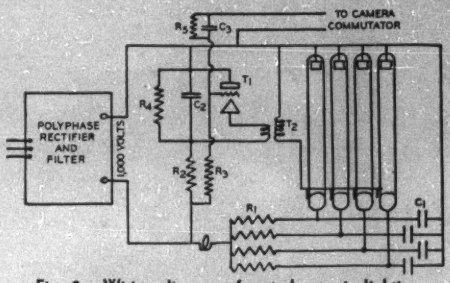


Fig. 2. Wiring diagram of a stroboscopic lighting source for taking high speed motion pictures

R_1	400 ohms, 180 watts	C_1	2μf, 1,000 volts
R_2	1,400 ohms, 80 watts	C_2	1/8μf, 1,000 volts
R_3	5,000 ohms, 10 watts	C_3	0.0001μf, 5,000 volts
R_4	100,000 ohms, 20 watts	T_1	Grid-controlled mercury-vapor-filled tube
R_5	1 megohm, 2 watts	T_2	40:1 ratio transformer

energy per second (power) is equal to the product of E^2C, the number of flashes per second, and the number of lamps in parallel; hence

$$\text{Power in kilowatts required} = \frac{E^2C}{1{,}000}\left(\begin{matrix}\text{number of flashes}\\ \text{per second}\end{matrix}\right)\left(\begin{matrix}\text{number of tubes}\\ \text{in parallel}\end{matrix}\right)$$

As an example, 4 tubes with 2 μf across each, charged to 1,000 volts, and flashed at 600 pictures per second, require 4.8 kw. The filament heating losses and power required for the tripping circuit are not included and hence must be added. Each charging resistor would need to be 400 ohms or less for this case, in order for the time constant to be equal to or less than $^1/_2$ the time between flashes.

Experiments show that the required power is slightly larger than indicated by the equation when the stroboscope lamps are cold, and slightly smaller when the lamps are hot, although the light from the hot tubes may be a great many times brighter than from the cold ones. Studies by means of a cathode ray oscillograph show that the capacitor discharge through a cold lamp is oscillatory; and since the tube is a rectifier it leaves the capacitor with a reversed charge after the flash, thus requiring more energy to charge it for the next flash. As the temperature of the tube is raised, the tube absorbs a larger part of the energy, and therefore the oscillation is damped to a greater extent so that the capacitor does not accumulate as much charge of the reverse polarity. A hot tube actually will overdamp the oscillation and even prevent the capacitor from completely discharging.

A mercury arc lamp $^5/_8$ in. in diameter and 12 in. long is operated conveniently for short bursts at the

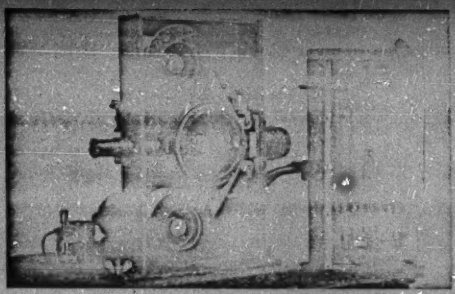


Fig. 3. High speed camera with cover off

value given in the preceding paragraph, that is, about 1 kw of power input. A period of 3 or 4 seconds of operation will warm up the tube, which increases the pressure of the mercury vapor, and as a result more light is obtained. Should the tube become too hot, an objectional trailer appears on the photograph, since the light lasts too long. The duration of the light in this case is greater because the apparent resistance of the mercury tube has been increased, which slows up the electrical time constant of the capacitor discharge.

The operation of the circuit is described briefly in the following paragraphs. The mercury arc stroboscope lamp needs to be well baked and operated at high temperature during exhaust, so that the vacuum is sufficiently good for the tube to withstand several thousand volts without breaking down. This is necessary so that capacitor C_1 in Fig. 2 may be charged to about 1,000 volts without a discharge occurring through the mercury arc lamp except at the desired instant. Control of the starting is obtained by the use of a pulse amplifier which is triggered by the commutator on the camera; the tube used in this amplifier is of the hot-cathode 3-element mercury-vapor-filled type (T_1 in Fig. 2). The firing must be controlled accurately and positively; otherwise the pictures will not be spaced uniformly on the film and will not be suitable for projection.

A high potential (10,000 to 30,000 volts), suddenly applied to a mercury-arc stroboscope tube on the outside of the glass just opposite the junction of the mercury and the glass, has the property of starting the tube and allowing the energy in capacitor C_1 to be discharged through it. Bright cathode spots are formed at the junction of the mercury and glass by the aid of the externally applied high potential, and these spots furnish emission to carry the large peak currents required for the quick capacitor discharges. The peak currents are in excess of 1,000 amp in the circuits used.

The particular method used in the circuit of Fig. 2 for obtaining an accurately controlled high voltage pulse to initiate the discharge in the tube is the use of a capacitor discharge through a step-up transformer. The capacitor C_2 (Fig. 2) is charged to about 900 volts through resistor R_2. During the charging cycle tube T_1 passes no current because the grid is connected so that it is negative with respect to the cathode (the drop through resistance R_2). A bleeder resistance R_4 passes enough current through R_2, after the condenser has been fully charged, to maintain sufficient bias to prevent the tube from firing.

The momentary charging surge of current into capacitor C_2 at the instant when the circuit to the commutator is closed puts a high positive potential on the grid of tube T_1 and causes it to conduct. In this circuit the tube acts as a switch that connects capacitor C_2 directly across the terminals of transformer T_2. A unidirectional surge of current flows through the primary and produces a surge of high voltage in the secondary which is connected to the external starting band of the tube. The secondary surge is oscillatory at a frequency determined by the inductance and distributed capacitance (also external capacitance). The polarity is adjusted so that the first wave is positive on the starting grid. Because of the oscillatory nature of the circuit consisting of capacitor C_2 and transformer T_2, tube T_1 is able to regain control, although connected to a source of direct current. After the surge of current through the primary, the voltage across the capacitor is opposite in sign because of the rectifying action of tube T_1, and by this time the grid again is negative and keeps the tube from starting as the capacitor again charges through R_2 in preparation for the next flash.

The upper limit of speed is determined by the deionization time of tube T_1, the characteristics of the particular transformer used, and the electrical time constants of the circuit. A speed of 6,000 pictures per second has been realized, using 2 tubes operating alternately into the same coil.

Internal structure of the camera is shown in Fig. 3. This camera purposely was designed to eliminate any sliding motion of the film against a gate or other part, since scratches, heat generation, and electrostatic sparks are caused by such friction. The disadvantage of the type shown is that the pictures are taken on the film while it is on a curved surface.

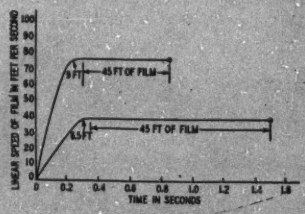


Fig. 4. Speed-time curves showing acceleration period and duration of a 60-ft length of film

Whether or not there is any appreciable distortion depends upon the diameter of the sprocket and the size of the frame, or individual picture. A compromise is made between a very large clumsy sprocket (and, incidentally, a large camera) with its difficulties of acceleration, and a small sprocket with its distortion. Consideration of these factors led to a main sprocket having a diameter of approximately

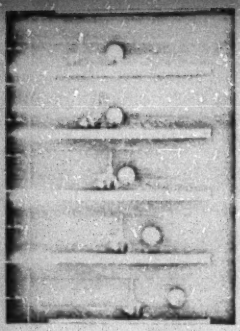


Fig. 5. High speed motion pictures showing impact of a golf club and ball taken at 980 pictures per second

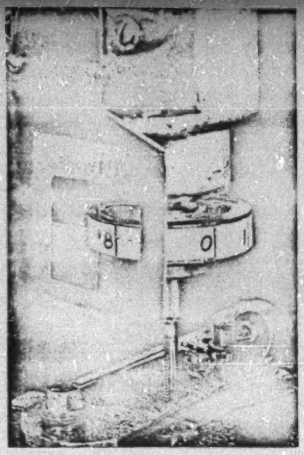
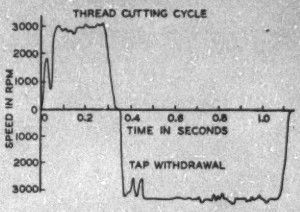


Fig. 6. View showing dial attached to automatic tapping chuck and cross wires for reference

Fig. 7. Velocity-time relationships of automatic tapping machine shown in Fig. 6



5 in. with 20 standard 35-mm frames of film around its periphery. For this sprocket the center of the picture is 0.0295 in. closer to the lens plane than the extreme upper and lower edges of the frame. This distance is naturally smaller for pictures shorter than the full 35-mm frame height. Two square holes exactly the size of a 35-mm frame are placed diametrically in the sprocket for the purpose of alignment of the camera and for critical focusing of the lens, which is accomplished by the aid of a telescope in the back of the camera. This method has been found to be very effective, since the focus and alignment may be checked easily and accurately just before the camera is started. Many subjects are very close to the camera, and for this reason the depth of focus is small.

The film is pressed against the sprocket by an aluminum roller. Because of the friction of the teeth in the perforations, there is a considerable tendency for the film to stick to the sprocket, and for this reason a metal plow is placed under the sprocket in order to push the film from the teeth. This plow does not touch the film if the film comes off in a normal fashion, since the take-up motor pulls the film off before it reaches the plow. The function of the plow is to keep the film from winding around the sprocket should the take-up motor fail to keep the slack film taut, or should the film break.

Considerable care is required in the construction of the commutator, since the uniformity of framing depends on the perfection of commutator and brush rigging. As shown in Fig. 1, the commutator is on the same shaft as the sprocket and is placed outside the box in order to be readily accessible for inspection. Brush construction is important, since any vibration or bouncing will cause nonuniform spacing of the frames. This camera has small stranded copper brushes about $^1/_{16}$ in. in diameter, which are pressed against the commutator by springs. Adjustment is possible so that the location of the frame with respect to the sprocket holes may be determined. Since there is an inappreciable time lag in the electrical circuit after a segment of the commutator contacts the brushes, the brush adjustment can be made with the camera at rest. Two sets of brushes are shown which make it possible to flash 2 stroboscopic lamps in alternation for high speed pictures.

Driving motors have been selected to give rapid acceleration and to hold fairly constant speed after the film has been accelerated. A series motor is connected directly to the take-up reel at the bottom of the camera; it is operated on overvoltage in order to increase its accelerating torque so that it always tends to overdrive the film. The series motor contributes considerable acceleration to the main sprocket and to the supply reel, besides performing its function of reeling up the film as it comes through the camera. A 3-phase $^1/_4$-hp induction motor is belted to the camera shaft with a V belt, since changing pulleys is a convenient method of changing the speed. The motor is started with overvoltage in order to increase its accelerating torque. The speed-torque characteristics of the induction motor are such that the motor tends to run at a constant speed corresponding to the speed of the rotating field set up by the current in the armature windings. Since the load is small after the accelerating period, the motor will run close to synchronous speed, and the rate of taking the pictures is thereby fairly constant and known. Figure 4 shows speed-time curves of film in the camera for different conditions, and the amount of film used in the accelerating period.

Uses of the Camera and Examples

As has been mentioned before, motion pictures taken at a high rate of speed and projected at the normal rate of 16 per second show an action on the screen slowed down by the same factor by which the camera was speeded up. Pictures taken at the rate of 1,600 per second of an event having a duration of 0.1 sec show a projected movie of that event lasting

100 times longer, or 10 sec. This ability of high speed motion pictures to reduce the speed of action is one of the most important uses. Furthermore, the pictures may be projected as many times as desired, such a repeated study permitting the eye to become familiar with the motion. Often inconspicuous but important motions are not noticed until a film has been projected several times.

A high-speed motion-picture camera, especially the stroboscopic-light type just described, is useful for obtaining engineering data of the time relationships of displacements, velocities, accelerations, and the forms of objects. Such a camera is an instrument analogous to the oscillograph; it furnishes a time record of mechanical motion to the mechanical engineer, while the oscillograph plots a time record of electrical quantities for the electrical engineer.

Motion pictures taken with an ordinary camera or with high-speed motion-picture cameras of the moving-optical-system type have the disadvantage of a relatively long exposure time, resulting in blurred pictures of rapidly moving objects when close-up views are made for purposes of accurately measuring velocities and accelerations. A blurred image is an advantage when the pictures are projected on the screen as movies (since the images are blended in a natural way as seen by the eye), but it is not desirable when a study of individual frames is made by enlargements from the movie negative. The short exposure time of the stroboscopic light gives splendid pictures for enlargement and analysis, since the blur resulting from motion of the subject is negligible except for extremely high velocity.

Since velocity is the ratio of displacement to the time interval, the accuracy of determination of velocity depends upon the accuracy of measurement of the displacement on the film and the accuracy of the measurement of the elapsed interval of time. Usually the former is the most inaccurate because of the small size of the pictures, the grain size of the film emulsion, and blur resulting from motion during the time of exposure. An accuracy of 2 per cent is realizable using 35-mm film, and a comparator for measuring the displacement on the film. One method of determining the time is to put a timing record on the film by any of several well-known and often-used methods. Often the speed of the film is sufficiently constant because of the tendency of the induction motor to run at constant speed. Pictures taken purely for analysis and never to be projected may be taken with the flashing frequency controlled from a synchronously driven commutator or by an oscillator, as was done in determining the velocity of a golf ball. No definite relationship is needed between the flashing frequency and the speed of the film except that the film is made to move fast enough to prevent the pictures from overlapping.

A very good example to illustrate the method of measuring velocities is the analysis of a golf stroke. A series of instantaneous pictures taken at a rate of 960 per second is shown in Fig. 5. The velocities of the ball and club are determined by measuring the displacement of the ball and club from one picture to the next by means of a comparator. An analysis of the pictures shown in Fig. 5 resulted in the following data, which are accurate to within about 2 per cent for the translational velocities:

Initial club velocity just before impact	151 ft per second
Final club velocity just after impact	113 ft per second
Ball velocity	186 ft per second
Spin of the ball	5,000 rpm

Since the masses of the ball and club are known there is sufficient information to calculate the energy lost by the club head and that gained by the ball, as well as to calculate the energy consumed in rotation of the ball. The pictures show definitely that the ball and club are in actual contact for less than 1/1,000 sec.

As a second example, the variations in angular velocity of the tap in an automatic tapping machine are plotted. A light aluminum disk attached to the chuck is divided into numbered sectors. Figure 6 shows this, as well as the set of cross wires that served as a reference for both angular and vertical linear motion. The instantaneous speeds during the working cycle, which lasted about 1 sec, are shown in Fig. 7.

These 2 examples chosen from several studies already made serve to demonstrate the great practical possibilities of this type of camera in the study of transient high speed motions in engineering apparatus.

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Step Type Feeder Voltage Regulators

A step type voltage regulator for electric power feeders has been designed, built, and tested in service, which is provided with steps so small as to give an operating curve as smooth as can be obtained with the induction regulator. In addition, the step type regulator has the advantage of lower cost, higher efficiency, lower exciting current, quieter operation, higher impulse strength, and suitability for high voltage applications.

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DEVELOPMENT of the step-type feeder-voltage regulator is a natural result of the development of tap-changing-under-load equipment for power transformers. It is interesting to note that in the early stages of the industry the problem of feeder voltage regulation was attacked first by using transformers and tap-changing-under-load equipment. The Stillwell regulator is an example of this. These early regulators were in general not successful because of trouble with burning of contacts and other mechanical difficulties, and after a relatively short time the induction regulator using a stationary winding and a rotatable winding came into use. This form of construction overcame the disadvantages of the early Stillwell regulator, and superseded the latter even though it had certain other less serious disadvantages. Development of the feeder regulator using the transformer and tap-changing-under-load principle practically ceased.

During these early years the possibility of changing taps under load on large power transformers was not even seriously considered. Even as late as 1921 and 1922 the application of tap-changing-under-load equipment to such a large unit of investment as a power transformer was a subject for considerable discussion. Transformer designers themselves were loath to "complicate" such a reliable piece of apparatus as a power transformer with tap-changing-under-load devices.

Starting about 1922, however, the demand for voltage regulation of large capacities for system interconnections and other applications became so pressing that manufacturers started to build tap-changing-under-load equipments for use with large transformers. The early units for this purpose were large, bulky, and very expensive, but in general they served their purpose well. Development during the intervening years has been rapid, and today there is no hesitation about applying tap-changing-under-load equipment to the largest transformers and for the highest operating voltages.

As soon as tap-changing-under-load equipment became commercially practicable for large power transformers, the demand became active for less expensive equipment for small power transformers. Naturally, the equipment designed for large power transformers could be used with small power transformers except that the cost became an unduly large percentage of the cost of the transformer. In answer to that demand, smaller, lighter, less expensive, tap-changing-under-load equipment using contactors or dial switches opening the circuit without the help of auxiliary circuit breakers was developed.

Development of equipment for small power transformers still left the need for still less expensive equipment for use in the equivalent of large distribution transformers or separate regulating units for regulating small and moderate capacity feeders of all voltages. The automatic feeder voltage regulator described in this paper was developed to meet this demand. The equipment has been designed with steps so small as to give as smooth an operating curve as can be obtained with the induction regulator; hence this equipment can meet the demand for regulation not only for applications where the cost of induction regulators has been prohibitive, but also for 2,400-volt applications where heretofore the induction regulator has been used exclusively.

Experience in the design and application of tap-

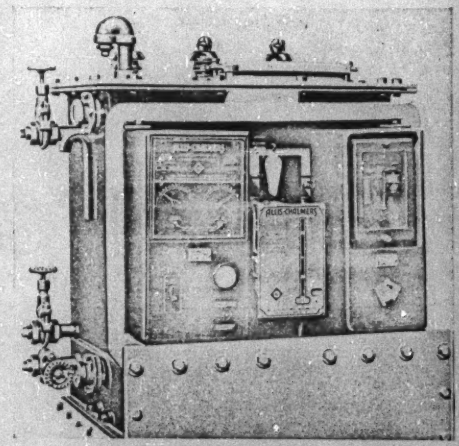

Fig. 1. Upper half of a 12-kva 50-ampere 2,400-volt outdoor regulator with cover over control panel removed

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changing-under-load equipments to large power transformers has been utilized fully. It is interesting to note that after all these years of development the tap-changing-under-load equipment as furnished by all manufacturers all over the world operates on substantially the Stillwell regulator principle, with the actual mechanical mechanisms, of course, quite different. The development therefore has been from the larger sizes back down to the smaller sizes with the fundamental scheme of operation the same, but with the mechanical operating means perfected through years of development.

With this step type regulator operating on the transformer and tap-changing-under-load principle, the usual range of plus and minus 10 per cent in voltage control under load is made in 32 $^5/_8$ per cent steps, which gives as smooth a voltage curve as can be obtained with the induction regulator and its associated relay. In other words, if the primary relay or contact making voltmeter is set at, say, plus or minus 1 per cent of the desired voltage, the induction regulator with its theoretically infinite steps can do no more than keep within this band of plus or minus 1 per cent. This step-type regulator with its $^5/_8$ per cent steps likewise can keep within this same band. Hence while the unit is theoretically a step type regulator, practically it is just as "stepless" as an induction regulator, judged by results obtained.

Advantages of the Step Type Regulator With Small Steps

The step type regulator with small steps has the following outstanding advantages over the induction regulator: First, it is lower in first cost, particularly in the larger sizes and the higher operating voltages, and can be built economically for higher voltages than could even be considered with an induction regulator. In addition the step type regulator has lower core and copper loss, and much lower exciting current. The exciting kilovoltamperes of an induction regulator is approximately 25 per cent of its kilovoltamperes rating, whereas the exciting kilovoltamperes of a step type regulator is less than $^1/_{10}$ of that amount. This represents an appreciable reduction in the exciting kilovoltamperes required to supply feeder regulators, and may be a very substantial item in a large system. Since the step type regulator uses transformer construction instead of motor construction, the impulse strength of the windings is much higher than can be attained with a winding lodged in slots, as in the induction regulator.

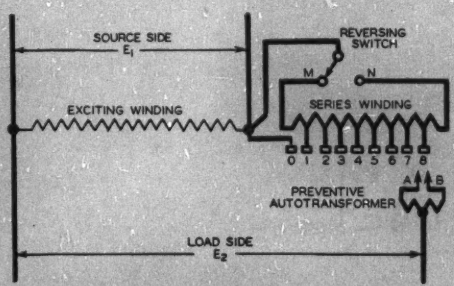


Fig. 2. Schematic diagram of single-phase step-type regulator

E_2 = 110 to 90 per cent of E_1 in 32 $^5/_8$ per cent steps

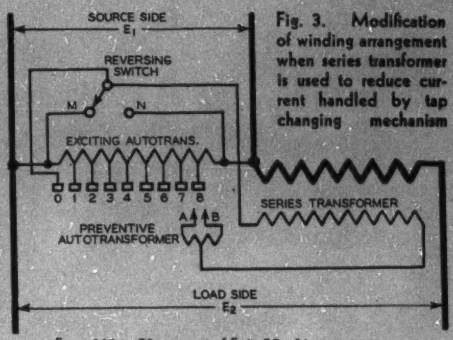


Fig. 3. Modification of winding arrangement when series transformer is used to reduce current handled by tap changing mechanism

E_2 = 110 to 90 per cent of E_1 in 32 $^5/_8$ per cent steps

The bushings of the step type regulator may be coordinated readily with the winding of the unit so that the bushings will flash over and prevent failure of the windings.

Figure 1 illustrates the upper half of a typical single phase unit with the control compartment cover removed. The tap changing mechanism is arranged in the lower portion under oil; this is separate from the oil in the upper portion which contains all the necessary transformers.

Scheme of Operation

A simple schematic diagram for a single phase unit showing the functioning of the various windings and mechanisms is shown in figure 2. The exciting winding of the transformer is shown connected across the line to be regulated. The series winding is provided with 8 taps which are connected to a tap-changing-under-load mechanism provided with an automatic mechanically operated reversing switch.

The 8 taps from the winding are connected to wide stationary contacts on the tap changing mechanism. Two moving contacts, A and B, which are connected to opposite ends of a midtapped autotransformer, are a fixed distance apart, and move as a unit with a snap action from one operating position to the next. The fixed space between these contacts is such that in any operating position either both are on the same wide stationary contact, or one is on each of 2 adjacent stationary contacts. The space between the stationary contacts is much greater than the width of moving contacts so that it cannot be bridged by the moving contacts.

To change taps from position 33, where contacts A and B are both on contact 8, to position 32, the moving contacts snap to a position where A is on

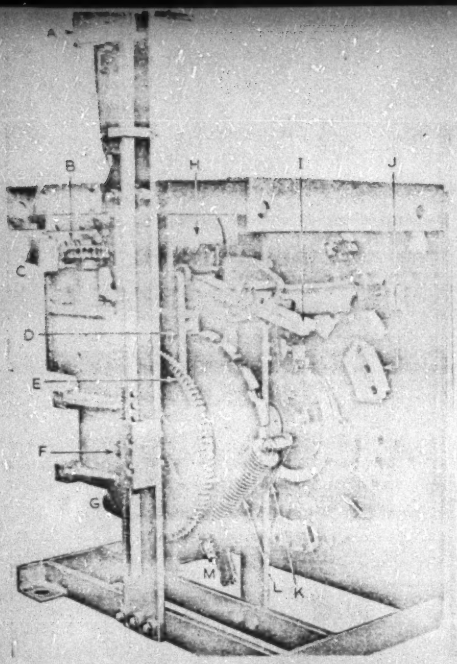


Fig. 4. Complete operating mechanism of single-phase step-type automatic feeder regulator

A. Position indicator
B. Worm and gear reduction
C. Provision for manual operation
D. Reversing switch operating arm
E. Worm gear reduction
F. Rack and pinion for operating position indicator
G. Driving spring
H. High-torque capacitor-type driving motor
I. Reversing switch operating mechanism and mechanical stop
J. Stationary contacts
K. Moving segment
L. Driving spring
M. Latch of quick-break mechanism

contact 7, but B is still on contact 8. During the instant that A is crossing the gap between contacts 8 and 7, the load current is carried entirely by the half of the autotransformer winding connected to B; but as soon as A is in contact with 7, the load current again will be divided equally between the 2 halves of the autotransformer winding, and the voltage obtained will be that midway between that of taps connected to contacts 7 and 8.

If the mechanism is moved on in a similar way until both A and B are on stationary contact 0, the voltage boost is reduced to zero, and no part of the tapped winding is in the circuit. If a still lower voltage is required, the reversing switch, which is now not in the circuit, is moved automatically from M to N while contacts A and B are still both on stationary contact 0. As the stationary contacts are arranged in a circle, the next movement will cause contacts A and B to snap to a position where A is on contact 8, but B is still on contact 0. This

Table I—Sequence of Operation of Regulator Shown in Figure 1 for ±10 Per Cent Range in Voltage

E_2 in Per Cent of E_1	Position No.	Contact A Connected to Tap No.	Contact B Connected to Tap No.	Reversing Switch on Contact
110	33	8	8	
109 4/8	32	7	8	
108 4/8	31	7	7	
108 1/8	30	6	7	
107 1/8	29	6	6	
106 7/8	28	5	6	
106 4/8	27	5	5	
105 5/8	26	4	5	
105	25	4	4	M
104 3/8	24	3	4	
103 4/8	23	3	3	
103 1/8	22	2	3	
102 1/8	21	2	2	
101 7/8	20	1	2	
101 4/8	19	1	1	
100 5/8	18	0	1	
100	17	0	0	
100	17	0	0	
99 4/8	16	8	0	
98 4/8	15	8	8	
98 1/8	14	7	8	
97 1/8	13	7	7	
96 7/8	12	6	7	
96 4/8	11	6	6	
95 5/8	10	5	6	
95	9	5	5	N
94 3/8	8	4	5	
93 4/8	7	4	4	
93 1/8	6	3	4	
92 1/8	5	3	3	
91 1/8	4	2	3	
91 1/8	3	2	2	
90 5/8	2	1	2	
90	1	1	1	

is position 16 in table I, and is the first buck position as the reversing switch has reversed the polarity of the tapped winding. The mechanism can be moved on until A and B are both again on contact 1, which corresponds to position 1 and which gives the maximum buck, or lowest voltage.

If it be desired to change the voltage in the other direction at any time, it is merely necessary to reverse the direction of the mechanism. Figure 3 shows the modification of the connections when a series tranformer is used to reduce the current handled by the tap changing switch.

Construction of Tap Changer

The tap-changing-under-load switch consists of an outer circle of 9 wide stationary segments and 2 inner concentric collector rings all mounted on a heavy bakelite plate, and 2 rotating contacts, A and B, mounted on a single bakelite arm (see figure 4). These moving contacts are a fixed distance apart and are insulated from each other, but each is connected to its collector ring. Each connection between these moving contacts and the stationary parts is made through a pair of contact fingers that wipe on both sides of the stationary members. The dynamic forces caused by heavy short-circuit currents therefore will increase the contact pressure. All contacts are renewable, and are made of non-arcing metal. The rotating arm is driven by an insulating shaft.

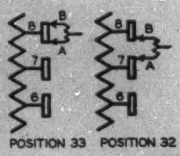
An important step in the development of this step type regulator was the development of a quick-break mechanism of unusual simplicity. The quick-break mechanism moves the contacts from one po-

sition to the next at a uniformly high speed, reducing contact deterioration. The design is such that when the quick-break mechanism operates, it automatically advances the moving contact assembly to the next operating position. Any tendency to pass beyond the normal operating position is arrested by the braking action developed by the driving spring for operation in the reverse direction. This provides an important self-centering feature without complication.

The entire tap changing mechanism, including the motor, operates under oil. This eliminates the necessity of oiling any parts of the mechanism. The oil in the tap changer compartment is entirely separate from the oil in the transformer compartment.

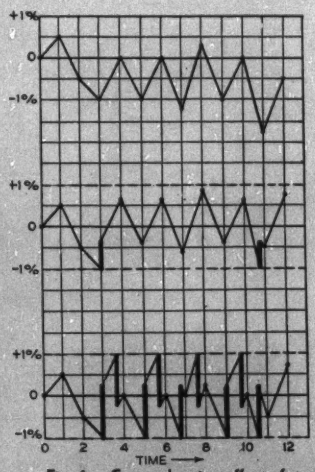
Determination of Size of Step

In the design of the step type regulator $^5/_8$ per cent steps with half-cycling operation were selected as representing the best engineering and economic solution to the problem. The smaller the step the smaller the voltage and kilovoltamperes to be interrupted, and hence the smaller the contact deterioration.



Position No.	Connections A to Tap No.	Connections B to Tap No.
33	8	8
	Open	8
32	7	8
	7	Open
31	7	7

Fig. 5. Diagram illustrating full-cycling and half-cycling operations



A. Typical voltage fluctuations on source side of regulator

B. Regulated voltage on load side, with $^5/_8$ per cent steps

C. Regulated voltage on load side, with $1^1/_2$ per cent steps

Fig. 6. Curves showing effect of step size on number of tap changing operations

Tap change operations indicated by heavy vertical lines

Whether half-cycling or full-cycling operation is used also has an important bearing on the subject. With full-cycling operation a physical tap is used for each operating voltage. With half-cycling operation the bridging position between 2 physical taps is used to provide an additional operating position. The 2 conditions are illustrated in figure 5. It may be seen that for $1^1/_4$ per cent steps with full-cycling operation there are 2 circuit openings and 2 circuit closings for each tap change. The duty is just twice what it is for a regulator using half-cycling operation and giving $^5/_8$ per cent steps.

The use of $^5/_8$ per cent steps is advantageous also because with the fluctuating voltages encountered in the average regulator service, the smaller steps will result in fewer tap changing operations.

When comparing the size of step and the number of operations the same setting of the primary relay or contact making voltmeter naturally must be considered. If the relay is to be set for close control on one regulator, the operation of the other regulator must be considered for the same setting.

Figure 6*A* indicates a succession of typical voltage fluctuations at the source side of a feeder regulator. In other words, there is first a fluctuation of $^1/_2$ per cent in voltage above the normal or desired voltage, then there is a change of 1 per cent in the opposite direction, and so on. Figures 6*B* and 6*C* indicate the voltages developed on the load side of a regulator under the conditions given in figure 6*A*. In both cases the relays are assumed to be set to operate at 1 per cent above or below the desired value to be maintained. Figure 6*B* indicates the effect with $^5/_8$ per cent steps, and 6*C* the effect with $1^1/_4$ per cent steps. By following through step by step it may be seen that the output voltages of the 2 regulators fluctuate in a different manner because of the fact that one step is $^5/_8$ per cent and the other is $1^1/_4$ per cent. Both regulators in this case keep the voltages within the band determined by the setting of the primary relay, but the number of operations is greater with $1^1/_4$ per cent steps than it is with $^5/_8$ per cent steps. There are 9 tap changes with the $1^1/_4$ per cent step regulator and only 2 with the $^5/_8$ per cent step regulator. If a regulator with $2^1/_2$ per cent steps were used, it is obvious that a relay setting as

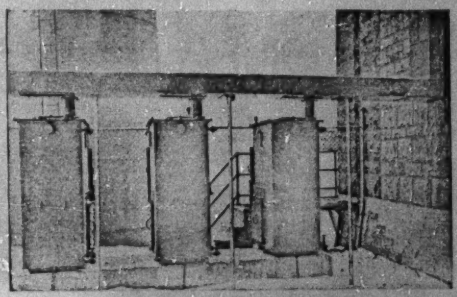


Fig. 7. Installation of 3 72-kva single-phase 300-ampere 2,400/4,160-volt regulators

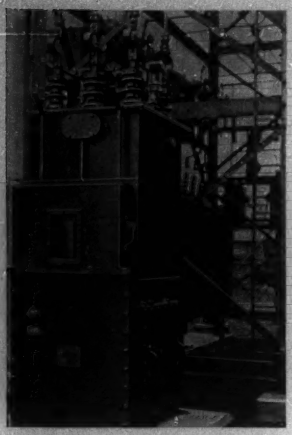


Fig. 8. Installation of 6,900-volt 50-ampere 60-kva 3-phase feeder regulator

close as plus or minus 1 per cent could not be used practically, because if the "lower" contact of the relay closed and caused the tap changer to move, the step would be so large as to cause the "raise" contact to close and make a tap change in the opposite direction. The regulator therefore would "hunt" and the relay contacts would have to be set farther apart to prevent this.

It may be seen from this analysis that the reason for $1^1/_4$ per cent steps giving more operations than $^5/_8$ per cent steps is that $1^1/_4$ per cent steps overcorrect the voltage condition so that a change in system voltage in the reverse direction calls for a tap change sooner than it otherwise would. The effect is similar to the condition that prevails when the brake on an induction regulator fails to hold properly and the regulator coasts.

Automatic Control

The step type regulator readily may be arranged for full automatic voltage regulation, with line drop compensation if desired. A primary relay responsive to the feeder voltage controls a time delay contactor, which in turn controls the main driving motor. If the primary relay is unbalanced and makes contact without interruption for the length of time required by the time delay contactor, the latter will close the main motor circuit for the direction of rotation required to correct the feeder voltage, and in a few more seconds the mechanism will move one step. If the resulting change in feeder voltage does not balance the primary relay, a second step and as many more as are required will follow at intervals of a few seconds each. Whenever the primary relay balances, the time delay contactor resets instantly and the motor stops. The motor cannot start again until the primary relay again has been unbalanced without interruption for the period required by the time delay contactor.

The equipment for automatic control is enclosed in the housing on the front of the regulator tank. In the center of this housing, and visible through a safety glass window, is the mechanical position indicator. On each side of the position indicator is a steel cabinet panel. The control devices are housed in these cabinets.

Antihunting Control

In order that the regulator will operate only when a tap change is really necessary, a time delay is interposed between the closing of the primary relay contacts and the starting of the tap-changing operating motor. The primary relay starts the geared time-delay contactor. After an interval that may be set up to 55 or 60 seconds, which is sufficient to indicate that the voltage change is not a momentary fluctuation, the time delay contactor closes its "raise" or "lower" contact to run the operating motor in the proper direction. If normal voltage is restored during the initial time delay, the contactor will reset.

The use of a time delay contactor eliminates needless operations of the regulator due to line fluctuations that shortly would correct themselves without operation of the regulator, but causes the voltage to be brought back to normal if the correction actually is needed. Should the voltage change on the line be large and require more than one tap change to correct it, the use of this separate time-delay contactor permits the regulator to make as many tap changes as are necessary, one after the other, without repeating the initial time delay between operations. The time delay could be built directly into the operating mechanism of the tap changing device, but this would introduce the time delay mentioned between each 2 successive tap changes, and also cause the mechanism itself to be operated needlessly.

Figure 7 illustrates an installation of single-phase regulators, and figures 8 and 9 illustrate typical 3-phase installations.

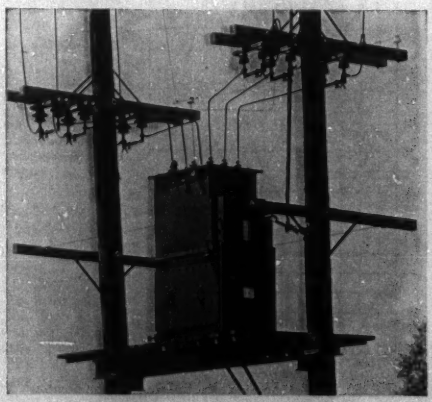


Fig. 9. Platform installation of 54-kva 3-phase 4,160-volt feeder regulator

Experimental Analysis of Double Unbalances

Double unbalances in 3-phase electric power networks may be analyzed experimentally on the network "calculating board" by applying the method of symmetrical components; 2 such methods of analysis are presented in this paper. Although intended primarily for use with the a-c calculating board, some of the material is applicable to the d-c board and to the purely mathematical solution of networks.

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ANALYSIS of 3-phase networks under unbalanced conditions, such as single-phase short circuits, is important to power system engineers who are called upon to deal with the problems of stability and of the operation of protective relays. Before the development of the method of symmetrical components,[1,2] short-circuit studies commonly were confined to 3-phase short circuits, and the currents during single-phase short circuits were estimated by multiplying the 3-phase short-circuit currents by an "experience factor."

Present methods of dealing with single unbalances on 3-phase networks by the method of symmetrical components are well known and widely used.[2] However, the methods of analyzing double unbalances (this term is defined later in the paper) are not so well known, although Edith Clarke has written an excellent paper on "Simultaneous Faults."[3] The purpose of the present paper is to elucidate further the treatment of double unbalances and to present the author's contributions to the subject, which include: (1) the connection of the sequence networks by transformers and by phase converters; (2) the modified π equivalent circuit; (3) application of the theory to simultaneous faults on opposite sides of a Δ-Y transformer bank; (4) application of the theory to combined series and shunt unbalances.

Networks may be analyzed either mathematically or experimentally. Several mathematical methods are available: (1) solution of simultaneous equations based upon Kirchhoff's laws; (2) cut-and-try method; (3) simplification of the network by repeated Y-Δ and Δ-Y transformations. When the network is complicated the calculations are very laborious by any of these methods, and the experimental method becomes preferable. In the experimental method the power network is represented to scale by a miniature network, the required currents and voltages being measured with instruments. Such miniature networks, also called "calculating tables" or "calculating boards" are made in both d-c and a-c forms. In using the d-c board the resistance and capacitance of the a-c power circuits are neglected, and their reactance is represented by resistance; generator voltages, which must be assumed to be in phase with each other, are represented by d-c voltages. In the a-c board[4,5] resistors, reactors, and capacitors are provided, and generators are represented by phase shifters, which give a-c voltages adjustable in both phase and magnitude. Obviously, the a-c board is more accurate and also more expensive than the d-c board.

In this paper double unbalances will be discussed primarily from the viewpoint of their solution on the a-c calculating board. However, some of the material is applicable to the d-c board and to the purely mathematical solution of networks. By either of 2 methods, the connection method or the equivalent circuit method, the currents and voltages in all parts of a 3-phase network on which there is a double unbalance (either 2 shunt unbalances, or a combined series and shunt unbalance) may be determined conveniently on an a-c calculating board.

In using the connection method all 3 sequence networks are set up at the same time and the unbalance is represented by appropriate connections between the networks, whereupon the currents and voltages in each sequence network represent to scale the corresponding symmetrical components of current and voltage in the unbalanced 3-phase system. In making the connections between the sequence networks, insulating transformers are sometimes necessary, and phase converters must be used for unbalances not symmetrical with respect to any phase.

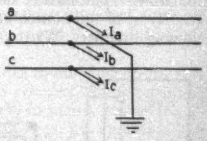

Fig. 1. Line-to-ground short circuit on one phase of a 3-phase network

In the equivalent circuit method the sequence networks may be set up separately. The unbalance is represented in the positive sequence network by the connection of a 3-terminal equivalent circuit to the 2 points of unbalance and to the ground terminal. If the unbalance is not symmetrical with respect to any phase, its equivalent circuit cannot be passive, but must contain either phase converters or adjustable electromotive forces. Some equivalent circuits

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The writer wishes to acknowledge his indebtedness to Prof. H. L. Hazen, who gave a great many helpful suggestions.

1. For all numbered references see list at end of paper.

contain negative resistances, which may be obtained practically in several ways.

Single Unbalances

Before proceeding to the discussion of double unbalances, the meaning of the terms "connection method" and "equivalent circuit method" will be illustrated by reviewing the application of each method to the solution of a network having a single unbalance. The notation used throughout the paper will be as follows:

E = voltage to ground at point of unbalance

I = current flowing into unbalance

Z = impedance of balanced network, measured from point of unbalance

x and y, as subscripts, indicate the 2 points of unbalance, that is, the points at which a double unbalance is connected to the balanced network

a, b, and c, as subscripts, indicate phases of a 3-phase system

0, 1, and 2, as subscripts, indicate phase sequence of symmetrical components

Primes (′) denote calculating board quantities where it is necessary to distinguish them from actual power system quantities

$a = \epsilon^{j\frac{2\pi}{3}}$ is an operator rotating a vector 120 deg forward

All quantities are complex.

Connection Method. First, the 3-phase network is represented on the calculating board by setting up its 3 sequence networks (positive, negative, and zero sequence). The positive sequence network contains electromotive forces, which may be adjusted to conform to normal operating conditions before the occurrence of an unbalance, but the negative and zero sequence networks are dead. Second, to represent the unbalance, a connection is made between the sequence networks at the point of unbalance. The nature of this connection depends on the type of unbalance and may be found in the following manner: Write 3 equations giving particular values of, or relationships between, the currents flowing into the unbalance and the voltages to ground at the point of unbalance. For example, for a line-to-ground short circuit on phase a (Fig. 1), the voltage of the grounded phase is zero and the currents flowing into the unbalance from the 2 ungrounded phases are zero:

$$E_a = 0 \qquad I_b = 0 \qquad I_c = 0 \tag{1}$$

Convert these relations into 3 equivalent relations between the symmetrical components of current and voltage by making the mathematical substitution that is the basis of the method of symmetrical components. The result is:

$$E_0 + E_1 + E_2 = 0 \qquad I_0 = I_1 = I_2 \tag{2}$$

These relations are satisfied by a series connection of the 3 sequence networks at the point of short circuit (Fig. 2).

In a similar way it may be shown that a parallel connection of the 3 sequence networks represents a double line-to-ground short circuit on phases b and c, while a parallel connection of the positive and negative networks only represents a line-to-line short circuit on phases b and c.

Having made the appropriate connections between sequence networks on the calculating board, the voltages and currents are measured at the desired points. The positive sequence voltages and currents are measured in the positive sequence network and the negative and zero sequence quantities in their respective networks. (On the a-c board the measurements include phase angle, as well as magnitude.) The actual voltages and currents then may be found by properly combining the symmetrical components.

Equivalent Circuit Method. There are 2 reasons why the connection method may not always be suitable: (1) the unbalance may be of a type not readily represented by a connection between the sequence networks; or (2) the 3-phase network may be so large that not enough impedance units are available to set up the 3 sequence networks simultaneously. In such cases the second or "equivalent circuit" method may be used. The procedure is as follows: Set up the negative and zero sequence networks and measure the impedance of each between line and ground at the point of unbalance. Then set up the positive sequence network, and at the point of unbalance shunt it with an impedance the value of which depends on the measured impedances and on the type of unbalance. For a line-to-ground short circuit this impedance is $Z_0 + Z_2$, for a line-to-line short circuit it is Z_2, and for a double line-to-ground short circuit $\frac{Z_0 Z_2}{Z_0 + Z_2}$, where Z_0 and Z_2 denote the measured impedances of the zero and negative sequence networks, respectively. The expression for this equivalent fault impedance may be written from inspection of the connections between sequence networks used in the connection method; or it may be found by reducing 5 equations in E_0, E_1, E_2, I_0, I_1, and I_2 to one equation of the form

$$E_1 = ZI_1 \tag{3}$$

in which Z is the impedance sought. The 5 equa-

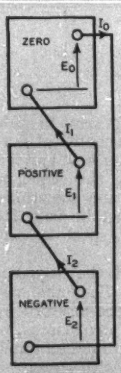


Fig. 2 (left). Series connection of the 3 sequence networks for representing a line-to-ground short circuit

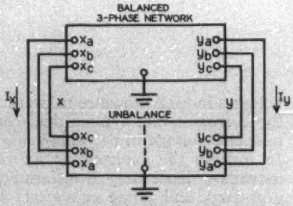


Fig. 3. Double unbalance, connected to a balanced 3-phase network at the 2 points of unbalance x and y

tions consist of 3 pertaining to the unbalance itself and independent of the rest of the network (for example, eqs 2 for a line-to-ground short circuit) and the following 2 pertaining to the balanced portion of the network and independent of the type of unbalance:

$$-E_0 = Z_0 I_0 \qquad -E_2 = Z_2 I_2 \tag{4}$$

After connecting the proper impedance in shunt with the positive sequence network, the positive sequence currents and voltages are measured at the point of unbalance and wherever else they are desired.

Next the negative sequence network is set up again, and a voltage is applied to it at the point of unbalance. This voltage is adjusted until either the voltage or the current at this point bears the proper relation to the positive sequence voltage or current which already has been measured. Thus for a line-to-ground short circuit $I_2 = I_1$, while for a double line-to-ground fault $E_2 = E_1$. After the applied voltage has been adjusted, negative sequence currents and voltages may be measured throughout the network. The zero sequence network is solved in a similar manner.

In short, by the connection method the 3 sequence networks are solved simultaneously, whereas by the equivalent circuit method they are solved separately.

Series Unbalances. The foregoing discussion of single unbalances deals primarily with short circuits and other shunt unbalances. Open circuits and other series unbalances are handled in a similar way, but with the following difference: Each sequence network presents 2 terminals at the point of unbalance, these terminals being used for connecting the networks in applying the connection method or measuring network impedances, connecting equivalent fault impedances, and applying voltages in using the equivalent circuit method. When dealing with shunt unbalances these terminals are *line* and *ground* at the point of unbalance, but when dealing with series unbalances they are the line side of the circuit on each side of the series unbalance.

Double Unbalances

Sometimes short circuits occur simultaneously at 2 or more points of a power system, or open circuits and short circuits may exist concurrently. Again, one may wish to investigate the effect of 2 or more single-phase or unbalanced loads. All these conditions may be classed as double (or multiple) unbalances.

A double unbalance may be defined as an unbalance that is connected to a balanced polyphase network at 2 points (Fig. 3) provided that both the currents and the voltages differ at the 2 points. If the currents are equal the double unbalance reduces to a single series unbalance; if the voltages are equal it reduces to a single shunt unbalance. There are 2 principal classes of double unbalance: (1) 2 simultaneous shunt unbalances, and (2) combined series and shunt unbalances. In class 1 the unbalanced portion of the network can be divided into 2 independent parts, as shown by the dotted line in Fig. 3, while in class 2 it cannot.

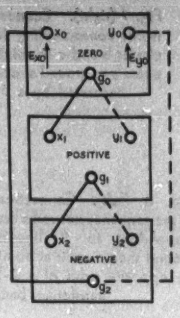


Fig. 4. Wrong method of connecting the sequence networks to represent 2 line-to-ground short circuits on phase a

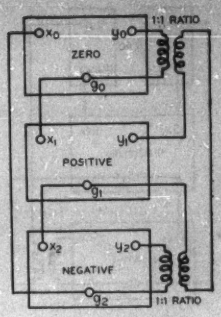


Fig. 5. Correct method of connecting the sequence networks to represent 2 line-to-ground short circuits on phase a. One of the series connections is made through insulating transformers

In solving double unbalances on the calculating board, either the connection method or the equivalent circuit method can be used.

Connection Method. When the balanced portion of a 3-phase network having a double unbalance is represented by its sequence networks, each of the latter has 3 terminals to be considered: the ground terminal (g, Fig. 4) and the line terminal at each of the 2 points of unbalance (x and y). The current flowing out of terminal x will be denoted by I_x, and that flowing out of terminal y by I_y; the voltages of x and y with respect to g will be denoted by E_x and E_y, respectively. Subscripts a, b, and c will be added to denote phase, or 0, 1, and 2 to denote phase sequence.

In applying the connection method to double unbalances it is necessary to connect the 9 terminals (3 on each sequence network) in such a way as to represent the particular unbalance in question. In doing so some problems arise that did not arise in the case of a single unbalance.

Consider the specific example of 2 line-to-ground short circuits, one at point x and one at y, both on phase a. The current and voltage relations at each point are the same as those already written for a single short circuit of this kind:

$$\begin{array}{lll} \text{At } x, & E_{x0} + E_{x1} + E_{x2} = 0 & I_{x0} = I_{x1} = I_{x2} \\ \text{At } y, & E_{y0} + E_{y1} + E_{y2} = 0 & I_{y0} = I_{y1} = I_{y2} \end{array} \tag{5}$$

Since a series connection of the sequence networks corresponded to a single ground fault, it is only natural to try making a series connection at each point, as shown in Fig. 4. These connections certainly satisfy the voltage equations, but there is no assurance that they satisfy the current equations; this is because there is no longer a simple series circuit, but rather 2 series circuits interconnected at several points. This difficulty may be avoided by making one of the series connections through the medium of in-

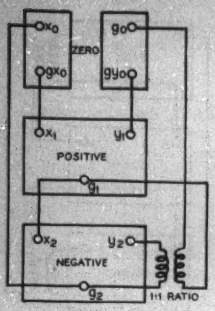
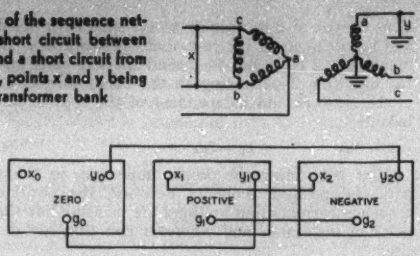


Fig. 6 (left). Connections of the sequence networks corresponding to 2 line-to-ground short circuits at points on opposite sides of a Δ-Y transformer bank

Fig. 7 (right). Connections of the sequence networks corresponding to a short circuit between phases b and c at point x and a short circuit from phase a to ground at point y, points x and y being separated by a Δ-Y transformer bank



sulating transformers of 1 to 1 ratio (Fig. 5). Such a connection satisfies the requirements given by eqs 5, and, the connection having been made, the rest of the procedure for solving the network is exactly the same as for a single unbalance.

In the example just considered both short circuits were on the same phase. Suppose now that the short circuit at point x is on phase a as before, but that the one at y is on phase b. The equations for point x are the same as before, but those for y now become:

$$E_{y0} + a^2E_{y1} + aE_{y2} = 0 \qquad I_{y0} = a^2I_{y1} = aI_{y2} \tag{6}$$

differing from the previous equations for point y by the presence of the operators a and a^2 which signify phase advances of 120 and 240 deg, respectively. The equations for point x are satisfied by the series connection as before, while those for point y are satisfied by a series connection made through phase converters instead of through transformers. The phase converter is a device having 2 pairs of terminals and so designed that the current and voltage of one pair of terminals are equal in magnitude to, but 120 deg in phase from, the current and voltage, respectively, of the other pair. The design of such a device is discussed in a later section of this paper.

By the use of transformers and phase converters in conjunction with the a-c calculating board, it is possible to apply the connection method to the solution of a 3-phase network having any number and any combination of types of simultaneous short circuits. Each short circuit is represented by a connection between the sequence networks at the point of fault. In making the connections, transformers are used where necessary to insulate circuits from one another without shift of phase, and phase converters where it is necessary to shift phase. Phase converters are required only for those short circuits not symmetrical with respect to phase a. In dealing with a single short circuit, it is always possible to name the phases so that the short circuit is symmetrical with respect to phase a (that is, to take a line-to-ground fault on phase a, and double line-to-ground or line-to-line fault on phases b and c). In dealing with simultaneous short circuits, however, it is generally impossible to name the phases in this manner for each short circuit, but it can be done for at least one of them. A few simultaneous short circuits require neither transformers nor phase converters. For such faults the connection method can be used on the d-c calculating board.

Simultaneous Faults on Opposite Sides of a Δ-Y Transformer Bank. A slight change of procedure is required for representing 2 short circuits on opposite sides of a Δ-Y transformer bank, because of the 90-deg phase shift produced by the transformers which does not have a counterpart in the representation of the transformers on the calculating board. (See p. 65 of reference 2.) The phase shift may be regarded as 30, 90, or 150 deg, depending on the designation of the phases of the 2 circuits; but the choice of 90 deg is most convenient for computation with complex numbers. Positive sequence currents and voltages are shifted 90 deg ahead (or behind, depending on the actual transformer connections) in passing through the bank, whereas negative sequence currents and voltages are shifted 90 deg in the opposite direction. Zero sequence currents and voltages are not transmitted through a Δ-Y bank. The net result is a phase reversal of the negative sequence quantities with respect to the positive sequence quantities on one side of the transformer bank. Arbitrarily taking the phases on side x as standard, and denoting calculating-board quantities by primed letters and actual system quantities by unprimed letters:

$$\begin{aligned} &\text{On side } x, \quad E_{x0} = E_{x0}',\ E_{x1} = E_{x1}',\ \text{and } E_{x2} = E_{x2}' \\ &\text{On side } y, \quad E_{y1} = jE_{y1}',\ E_{y2} = -jE_{y2}',\ \text{and } E_{y0} = E_{y0}' \end{aligned} \tag{7}$$

and similarly for currents.

Consider again 2 line-to-ground faults on phase a, one at point x and the other at y, the points now being taken on opposite sides of a Δ-Y transformer bank. The current and voltage relations are given by eqs 5 and the calculating-board current and voltage relations are found by using eqs 7. At point x the calculating-board current and voltage relations are the same as before and are satisfied by the usual series connections, but at y they become:

$$E_{y0}' + jE_{y1}' - jE_{y2}' = 0 \qquad I_{y0}' = jI_{y1}' = -jI_{y2}' \tag{8}$$

or, multiplying by $-j$:

$$-jE_{y0}' + E_{y1}' - E_{y2}' = 0 \qquad -jI_{y0}' = I_{y1}' = -I_{y2}' \tag{9}$$

These equations are satisfied by a series connection at point y, in which the connection to the negative sequence network is reversed and the connection to the zero sequence network is made through a phase converter giving a phase shift of 90 deg. The phase converter is not really necessary, however, and can be replaced by an insulating transformer if the zero

sequence network on one side of the Δ-Y bank is independent of that on the other side, as it practically always is. The 90-deg phase shift is taken into account later. Even the transformer can be dispensed with if the zero sequence network is set up in 2 parts with separate ground terminals, the connections then being as shown in Fig. 6.

The rules for handling any simultaneous faults on opposite sides of a Δ-Y transformer bank are: Set up the zero sequence network in 2 separate parts, each having its own ground terminal. Make connections between the networks just the same as usual except that on one side (say y) the negative sequence network is connected with reversed polarity. Multiply the measured negative sequence currents and voltages on this side of the transformers by $-j$ and the positive and zero sequence quantities by j before combining them to obtain phase quantities; or, if there is no objection to choosing a different reference axis for quantities on the y side, simply multiply the negative sequence quantities on this side by -1, leaving the positive and zero sequence quantities unchanged.

Another example is shown in Fig. 7. This example could be solved on the d-c board, since no special apparatus is required.

Combined Series and Shunt Unbalances. Unbalances of this type may be solved on the calculating board in the same way as simultaneous faults. It is always possible to write 6 relations between the sequence currents and voltages at points x and y, and the connections between the sequence networks must conform to these relations. Two examples follow, in which the connections corresponding to combined series and shunt unbalances are derived.

In Fig. 8 is shown a kind of unbalance that might occur if one conductor of a 3-phase line should break and one end of it should fall onto the ground. Such an unbalance might occur also during a line-to-ground short circuit on a line equipped with single pole switching, assuming the circuit-breaker at the end of the line nearest the fault to open sooner than the one at the far end. The unbalance consists of a short circuit next to an open circuit. The current and voltage relations are as follows:

For the ground on phase a:

$$E_{xa} = 0 \qquad I_{xb} + I_{yb} = 0 \qquad I_{xc} + I_{yc} = 0 \tag{10}$$

For the open circuit on phase a:

$$I_{ya} = 0 \qquad E_{xb} - E_{yb} = 0 \qquad E_{xc} - E_{yc} = 0 \tag{11}$$

In terms of symmetrical components the relations become:

For the ground,

$$E_{x0} + E_{x1} + E_{x2} = 0; \quad I_{x0} + I_{y0} = I_{x1} + I_{x2} = I_{y1} + I_{y2} \tag{12}$$

For the open circuit,

$$I_{y0} + I_{y1} + I_{y2} = 0; \; E_{x0} - E_{y0} = E_{x1} - E_{y1} = E_{x2} - E_{y2} \tag{13}$$

The connections of Fig. 9 meet the requirements. The short circuit is represented by a series connection of the networks between x and ground, the open circuit by a parallel connection between x and y.

Another type of unbalance, which could occur if a cable were incorrectly spliced and then switched into service, is shown in Fig. 10. The relations between phase currents and voltages are:

$$\begin{aligned} E_{xa} &= E_{ya} & I_{xa} &= -I_{ya} \\ E_{xb} &= E_{yb} & I_{xb} &= -I_{yb} \\ E_{xc} &= E_{yb} & I_{xc} &= -I_{yb} \end{aligned} \tag{14}$$

The corresponding relations between symmetrical components are:

$$\begin{aligned} E_{x0} &= E_{y0} & I_{x0} &= -I_{y0} \\ E_{x1} &= E_{y2} & I_{x1} &= -I_{y2} \\ E_{x2} &= E_{y1} & I_{x2} &= -I_{y1} \end{aligned} \tag{15}$$

Connections between the sequence networks satisfying these relations are shown in Fig. 11. These connections can be made on either the a-c or the d-c board. Although the zero sequence network is shown in the figure, it is not necessary to set it up because the zero sequence currents and voltages are all zero.

Many other examples of combined series and shunt unbalances could be given, but it is believed that enough have been given to illustrate the application of the connection method. Attention now will be turned to the handling of double unbalances by the equivalent circuit method.

Equivalent Circuit Method. The equivalent circuit for representing a single unbalance in the positive sequence network is a single impedance connected in shunt (or series) with the positive sequence network at the point of unbalance. The equivalent circuit of a double unbalance must be some form of 3-terminal network. The simplest forms are the T and the Π. The ordinary T or Π may be used as an equivalent circuit for a double unbalance that is symmetrical with respect to any one phase. If, however, the double unbalance is unsymmetrical, the T or Π circuit must be modified by the addition of one or more phase converters or sources of electromotive force.

The equivalent circuit for any particular unbalance may be derived readily in some cases by "boiling down" the circuits used in the connection method, first replacing the negative and zero sequence networks by their equivalent T's or Π's (based upon impedance measurements at terminals x, y, and g). The equivalent circuit of a double unbalance may be derived also by the following procedure developed by Miss Clarke:[3] 10 equations are written in the 12

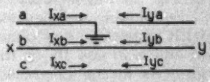


Fig. 8. Unbalance consisting of an open circuit and a ground

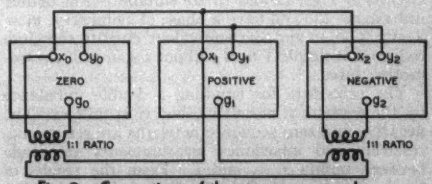


Fig. 9. Connections of the sequence networks corresponding to the unbalance of Fig. 8

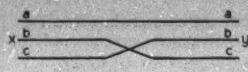


Fig. 10. Unbalance in which phases b and c are interchanged

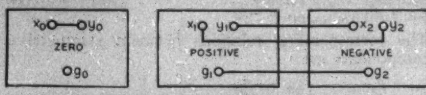


Fig. 11. Connections of the sequence networks corresponding to the unbalance of Fig. 10

unknown currents and voltages E_{x0}, E_{x1}, E_{x2}, E_{y0}, E_{y1}, E_{y2}, I_{x0}, I_{x1}, I_{x2}, I_{y0}, I_{y1}, and I_{y2}. Of these equations 6 pertain to the unbalance and examples of them have been given in describing the connection method; 4 pertain to the balanced part of the network, 2 for negative and 2 for zero sequence. The 10 equations then are reduced to 2 equations in E_{x1}, E_{y1}, I_{x1}, and I_{y1}, which may be written in the form

$$E_{x1} = kI_{x1} + mI_{y1} \qquad E_{y1} = nI_{x1} + lI_{y1} \tag{16}$$

or in the alternative form

$$I_{x1} = pE_{x1} + qE_{y1} \qquad I_{y1} = rE_{x1} + sE_{y1} \tag{17}$$

An equivalent circuit based upon eqs 16 is shown in Fig. 12. This is the modified T circuit. The agreement of this circuit with eqs 16 may be verified by adding the IZ drops from terminal g to terminal x or y. In order to obtain the current $I_{y1} - I_{x1}$ in the impedance $(m-n)/2$, it is necessary to shunt this impedance with a source of electromotive force adjusted in phase and magnitude until the current from this source is $2I_{x1}$, which subtracts from the current $I_{x1} + I_{y1}$ otherwise flowing in this branch. In making this adjustment on the a-c calculating board, it has been found convenient to have a stabilizing impedance in series with the source of electromotive force and to use a current transformer and ammeter for balancing the current $2I_{x1}$ in this source with the current I_{x1} in impedance $k-n$. When the adjustment is correct the ammeter reads zero.

A second form of equivalent circuit, the modified Π, may be derived by analogy with the modified T. This circuit, based upon eqs 17, is shown in Fig. 13. One branch has a series electromotive force which must be adjusted in phase and magnitude to $2E_{x1}$. A potential transformer and voltmeter connected as in Fig. 13 will facilitate the adjustment.

For double unbalances that are not symmetrical with respect to any phase, the mutual impedances, m and n in eqs 16, or the mutual admittances, $-q$ and $-r$ in eqs 17 are unequal, and the equivalent circuits of Figs. 12 and 13 are suitable. For double unbalances that do have a phase of symmetry, $m = n$ and $q = r$, and the equivalent circuits therefore reduce to a simple T or Π without a source of electromotive force.

The procedure for handling a double unbalance by the equivalent circuit method is as follows: The negative and zero sequence networks are set up successively and impedance measurements are made between points x, y, and g. From the results of these measurements the impedances of the branches of the equivalent circuit are computed. The positive sequence network then is set up, the equivalent circuit of the unbalance is connected to it at points x, y, and g, and its voltage, if any, is adjusted. Readings of current and voltage may then be taken throughout the positive sequence network, including points x and y. The negative sequence network then is set up, and voltages are applied from x to g and from y to g. Both applied voltages are adjusted in phase and magnitude until either the voltage or the current at each point is correct, according to a known relation between it and the positive sequence current or voltage measured at the corresponding point of the positive sequence network. (For example, in line-to-ground short circuits on phase a at x and on phase b at y, make $I_{x1} = I_{y1}$ and $I_{y2} = aI_{y1}$.) The zero sequence network is solved similarly.

Comparison of Connection Method and Equivalent Circuit Method. Suppose that a study of relay operation during simultaneous faults is being made on the calculating board, and that 4 or 5 circuit breakers must open in order to clear the faults. The first readings are taken with all breakers closed, and from these readings is determined which breaker will open first. Then the power system is represented with this breaker open and, from the readings taken under this condition and under the original condition, the second breaker to open is determined. The system is represented for the new condition, and so on until the complete sequence of relay and breaker operations has been found.

In using the connection method the 3 sequence networks are set up and connected together in an appropriate manner at each point of fault. The opening of each circuit breaker is represented by opening each of the sequence networks at the breaker location. No other change is necessary. In using the equivalent circuit method, however, it is necessary to measure the impedance of the negative and zero sequence networks from the points of fault, to calculate the impedances of the equivalent circuit, and to set up the equivalent circuit and adjust its voltage, if any. These steps must be repeated for each change of circuit connections or fault location.

Although the procedure of the equivalent circuit method is longer, the method has the advantages that the sequence networks can be solved separately, and that transformers and phase converters are not necessary. It is not a simple method to apply to multiple unbalances (unbalances connected to the balanced network at 3 or more points).

Accessories to the A-C Calculating Board

Transformers. The ideal transformers for use with the connection method would have both current ratio and voltage ratio exactly equal to unity—a requirement that cannot be fulfilled perfectly. However, transformers can be obtained that meet the conditions well enough to give reasonably accurate results. Transformers of 1 to 1 ratio are already standard equipment on some a-c calculating boards, being used for representing the mutual reactance of parallel transmission lines.

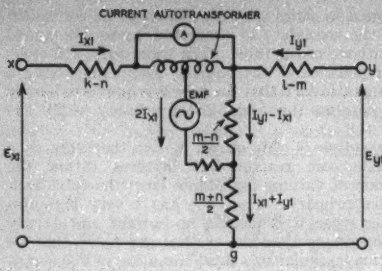


Fig. 12 (left). Modified T equivalent circuit to be connected to the positive sequence network for representing a double unbalance

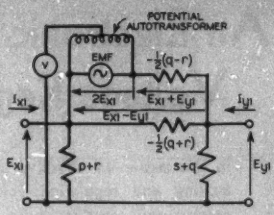


Fig. 13 (right). Modified π equivalent circuit

Phase Converters. The use of phase converters was suggested in the foregoing discussion of the application of the connection method to double unbalances having no phase of symmetry. The ideal phase converter for this purpose is one that will give a secondary voltage and current exactly equal in magnitude to, and 120 deg out of phase with, the primary voltage and current, respectively. Such a converter may be specified in terms of its impedance to currents of various phase sequences in this way: Its positive sequence impedance should be infinite, and its negative and zero sequence impedances should be zero. Suppose now that all 3 phase windings of such a converter be used instead of only 2, making it analogous to a 3-circuit transformer. The current and voltage relations of the ideal converter are then, denoting the 3 circuits as *a*, *b*, and *c*:

$$I_a + aI_b + a^2I_c = 0 \qquad E_a = aE_b = a^2E_c \tag{18}$$

Compare these with the corresponding relations for an ideal 3-circuit transformer or for 3 circuit branches in parallel:

$$I_a + I_b + I_c = 0 \qquad E_a = E_b = E_c \tag{19}$$

Suppose that another type of converter is desired giving current and voltage relations analogous to a series connection:

$$I_a = aI_b = a^2I_c \qquad E_a + aE_b + a^2E_c = 0 \tag{20}$$

The requirements for such a converter are that its negative and zero sequence impedances be infinite and that its positive sequence impedance be zero.

A 3-phase induction machine driven at or near synchronous speed roughly satisfies the requirements for either type of converter. Its zero sequence impedance may be made either zero or infinite by connecting the external circuits in Δ or Y, respectively. (The connection of the converter stator windings themselves is immaterial.) The positive sequence impedance of the machine is high and the negative sequence impedance low, or *vice versa*, depending on the direction of rotation. However, the induction phase converter is less "ideal" than a good transformer; and in its natural state its current and voltage ratios are not accurate enough for it to be of much practical use in connection with the calculating board. Its characteristics may be improved by (1) driving its somewhat above synchronous speed by another motor in order to annul its positive sequence resistance, and (2) connecting series and shunt capacitors in each phase to compensate for its reactance.

Negative Resistance Devices. In applying the equivalent circuit method to unsymmetrical double unbalances, usually one or more of the branches of the equivalent circuit are required to have negative impedances (that is, negative resistance and negative reactance). The negative reactance obviously can be furnished by capacitors, but negative resistance presents a problem. Several artifices can be used for representing it.

If the negative impedance is in the mutual branch of the equivalent circuit (that is, in the pillar of a T circuit or the architrave of a Π circuit) it may be replaced by an equal positive impedance, provided that one pair of terminals of the equivalent circuit be connected to the circuit through a transformer in such a way as to reverse the polarity of current and voltage at the terminals. This means is of no avail, however, for negative impedances in the other branches of the circuit.

The negative impedance in any branch may be replaced by an equal positive impedance shunted by an electromotive force which is adjusted in phase and magnitude until the current in the impedance is equal and opposite to the current in the main circuit;[6] or, the positive impedance may be n times as large as the desired negative impedance and the current in it $1/n$ as large. In either case the required voltage drop is introduced into the circuit. The adjustment of the electromotive force is facilitated by the use of a current transformer and ammeter, as described in connection with the modified T circuit. The principal objection to this means of obtaining a negative impedance is the necessity of adjustment—an adjustment not difficult in itself, but one that usually must be made simultaneously with the adjustment of other electromotive forces in the circuit. It would be preferable to have the adjustment made automatically.

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An Electronic Voltage Regulator

In this paper an effective means of controlling and regulating voltage with an external-grid rectifier tube is discussed. Four applications of the basic principles are shown, including a low voltage, wide range control, and a primary distribution voltage automatic regulator. Main features are: instantaneous response which enables this regulator to be used in such applications as welding with a pulse of only a few cycles, absence of heavy moving parts as well as absence of contacts for load currents, and low cost.

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A REGULATOR for maintaining constant voltage or constant current has been developed* which makes use of an electron tube to vary the voltage across an impedance in the circuit to be controlled. The tube is a grid controlled gaseous rectifier in which the grid is external to the tube. (For a description of this tube see "The Kathetron—A Controlled Rectifier" by P. H. Craig, *Electronics*, v. 6, March 1933, page 70–2.) It operates in a manner similar to other grid controlled rectifiers by inhibiting striking of the arc during the positive alternation of the anode potential, and after the arc has struck exerts no further influence upon it for the remainder of that half cycle. It can be used in practically any application where other grid controlled rectifiers may be used and in some applications has a considerable advantage over the other types due to the fact that the grid draws practically no current (being of the order of a few microamperes), and to other circuit advantages to be described.

In the fundamental voltage control circuit of the regulator, a reactor, or impedance in the form of a 2 winding transformer is used to reduce the load voltage by any desired amount, depending upon the effective value of the current through the grid controlled tube which is placed across this reactor or transformer. The primary of this transformer is connected in series with the circuit to be controlled while the secondary is connected across the anode and cathode of the tube. The tube varies the effective impedance of the reactor, which may have a winding ratio such that the tube is required to handle lower currents than exist in the primary of the circuit.

The action of this circuit is not the same as a saturable core reactor but involves rather the reflection of varying impedance from the tube back into the primary. The tube has a very high impedance when it is passing no current and a very low impedance after the arc has struck, so that its operation is similar to a short circuiting switch across the secondary of the impedance transformer. The time during which the tube is passing current, corresponding to the time during which the switch is closed, is varied by the action of the grid to inhibit the striking of the arc during the positive alternation of the anode potential. Thus, the tube cannot be thought of as a variable resistor in which heat losses must be dissipated, but rather as a switch which opens and closes, the time of remaining closed being variable.

Series Impedance Control

In the first application of this method a low voltage circuit is controlled directly to give reduction of voltage (see figure 1). Control of the circuit voltage is effected by varying the grid potential. Because of the negligible grid current the leads from the tube to the control point can be very small and the control can be from a considerable distance.

A similar circuit is used for a constant current supply, such as for street lighting circuits. A series reactor with a high voltage primary winding is used.

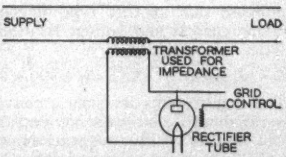

Fig. 1. Series impedance circuit for wide range control of voltage

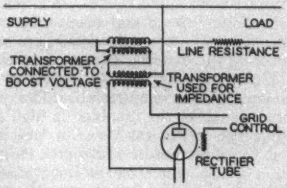

Fig. 2. Electron tube control of voltage boost for distribution line or industrial load

The grid control rheostat is adjusted by a small motor which is operated forward or reverse by the contacts of a current relay. Adjustment of this relay is such that a constant current of 6.6 amperes (or other desired value) is maintained in the primary

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* U. S. Patent No. 1,992,146.

circuit by varying the voltage on the output side of the reactor.

Controlled Boost Regulator

A most satisfactory method for regulation of primary distribution circuits is a controlled boost method. The reactor, or impedance transformer,

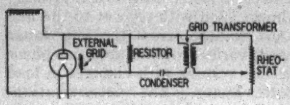


Fig. 3. Automatic grid control applied to impedance transformer secondary of voltage boost circuit shown in figure 2

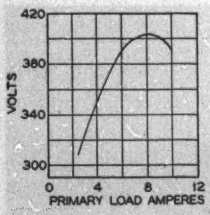
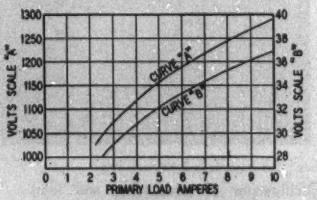


Fig. 4. Variation of voltage to primary of grid transformer to give perfect regulation (circuits of figures 2 and 3)

used in the 2 methods mentioned above is here placed in the primary or shunt circuit of a standard transformer connected for boosting the line voltage. The method then is to control the boost effect of the booster transformer by varying the voltage of its primary. A similar control circuit can be used for lower voltage circuits, such as power feeders of an industrial load, welding equipment, etc.

As in the constant current control, the voltage on the grid can be adjusted by a small motor driven mechanism. A standard contact-making voltmeter and a line drop compensator in the circuit to this motor control gives a boost control and, hence, a voltage regulation, to the load center of the primary feeder line. While this method gives an automatic control, with several operating advantages, the characteristics of the apparatus are such that an entirely static, automatic grid control can be used with very marked improvement in several features.

The static grid control can be obtained directly without the use of motor or contacts, by taking the



Curve A (left scale). With tube not in circuit

Curve B (right scale). With tube in circuit but with zero grid voltage

Fig. 5. Voltage on secondary of impedance transformer

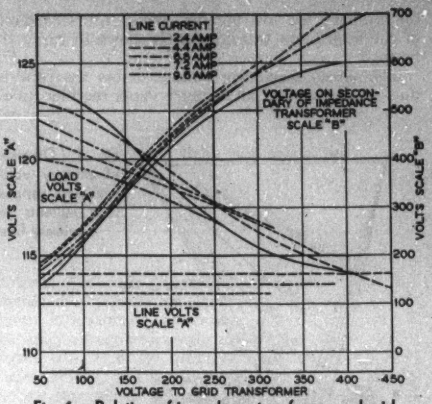


Fig. 6. Relation of impedance transformer and grid voltage for various values of line current. Regulator not operating

grid supply from one of several points of variable voltage in the complete circuit. With one arrangement an increase of line current causes a decrease of grid voltage and thus causes a greater short-circuiting effect on the secondary of the impedance transformer. This in turn reflects less impedance back into the primary winding and allows more boost to offset the tendency of the load voltage to drop. In this application, the grid potential is taken directly from across the secondary of the impedance transformer. The primary connections of this control are shown in figure 2. A somewhat different control is obtained by connecting the grid circuit across the supply line either directly or from a potential transformer. A tendency for supply voltage to drop then produces a lower grid potential and, as in the other case, allows more boost to the output voltage.

Operation of Tube Control

The tube control circuit of the controlled boost regulator with no moving parts is shown in figure 3. The potentiometer is connected directly across the anode-cathode of the tube (and of the secondary of the impedance transformer) and the grid voltage obtained from a portion of the potentiometer. The grid voltage necessary to maintain load voltage constant with a particular line condition (approximately 5 ohms) is shown in figure 4. These values were obtained with a manually controlled grid and they indicate the range necessary for automatic control. It was found that characteristics of the tube and impedance transformer circuit are such that a remarkably close approximation to the curve of figure 4 is obtained for the grid control.

The voltage across the secondary coil of the impedance transformer, without the tube control, is shown in curve *A*, figure 5, for increasing load current in the 2,400 volt line. With a half-wave mercury vapor rectifier tube in the circuit, the voltage as read

on ordinary a-c instruments, across the secondary of the impedance transformer, is shown in curve *B*, figure 5.

The slowly increasing voltage across the tube is due to the fact that all mercury vapor rectifier tubes when not controlled by a grid exhibit the characteristics of a constant voltage drop in the forward direction of current. However, the voltage read on ordinary a-c instruments across a single half-wave rectifier is a combination of the inverse voltage across the tube (i. e., the voltage across the tube during the negative alternation of the anode potential when the tube is passing no current) which may be quite high, and the forward potential drop during the half cycle in which the tube is passing current. Normally, the inverse voltage is very much larger than the forward potential drop, and consequently, what is read on the meter is largely inverse potential, unless special metering methods are used.

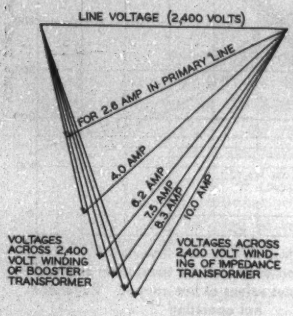


Fig. 7. Diagram of primary voltages with various load currents in primary line

Inasmuch as the tubes, even without a controlled grid, tend to maintain a constant voltage in the forward direction, they have an inherent regulatory characteristic since the only way that the tubes can have a constant drop maintained across them for higher current is to decrease their impedance. It is clear from the impedance transformer voltage characteristic that a higher voltage is impressed across the tube for higher load currents and, consequently, there is a larger current through the tube for increasing load. Therefore, for the tube to maintain constant voltage drop in the forward direction for increasing anode currents it must decrease its impedance so that the product of impedance and increasing current is a constant. This decreasing tube impedance for higher loads reflects a lower impedance back into the primary of the impedance transformer and thus allows more boost for increasing loads, which results in some degree of regulation. It is apparent that if 2 such tubes were employed, operating on different half cycles, some inherent regulation would be achieved without any grid at all or with a fixed value of grid potential, because in that case one tube would maintain a constant voltage drop in one half cycle and the other in the reverse.

The rate of increase in the impedance voltage decreases for the higher value of grid voltage as shown in figure 6, giving an approximation to the shape of the curve in figure 5. Impedance voltage versus grid voltage curves were obtained by holding the line current constant and varying the grid voltage. As shown in curve *B* of figure 5 the voltage across the impedance transformer also is not linear and a combination of the 2 gives a still closer approximation to the curve of figure 4.

The phase angle of the booster transformer primary voltage remains almost fixed with respect to the line voltage, whereas the voltage across the impedance transformer primary varies considerably in phase with respect to the line voltage with changes in load current of fixed power factor. The vector relations are shown in figure 7 for several values of line cur-

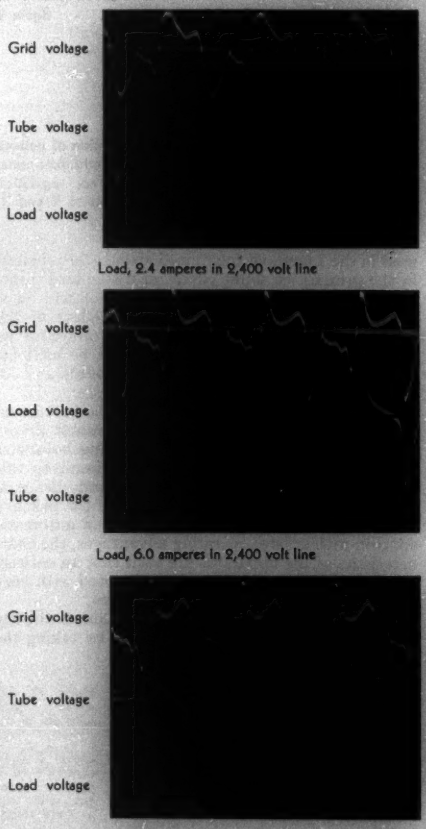


Fig. 8. Oscillograms of grid, tube, and load voltages during the operation of the automatic regulator

Table I—Load Test for Automatic (Static Type) Feeder Voltage Regulator

Load Amperes (in 2,400 volt line)	Load Voltage	Voltage Immediately Following Regulator	Watts Loss: Impedance Transf. Primary	Watts Loss: Impedance Transf. Sec. and Tube	Watts Loss: Booster Transf. Core	Watts Loss: Booster Transf. Copper	Watts Loss: Total	Kw Input	Kw Output	Efficiency % (neglecting grid losses)
2.3	121.0	123.0 × 20	62	40	10	2	114	6.02	5.91	98.1
3.0	121.5	123.5 × 20	60	30	17	3	110	7.78	7.67	98.6
4.2	121.5	124.0 × 20	80	40	24	5	149	10.81	10.66	98.6
5.3	121.5	124.5 × 20	70	30	28	7	135	13.62	13.49	99.0
6.6	121.0	124.7 × 20	80	20	31	10	141	16.94	16.8	99.2
8.45	120.0	124.3 × 20	100	37	33	17	187	21.45	21.26	99.1
9.8	119.5	124.5 × 20	90	30	34	22	168	24.85	24.68	99.3

rent. Since the voltage across the primary winding of the impedance transformer is not a sine wave, it is not possible to represent accurately the operation of the circuit by a vector diagram. However, the apparent vector relations as shown in figure 7 serve to

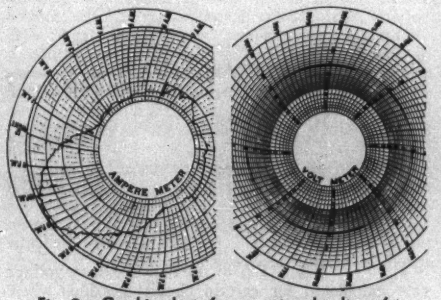


Fig. 9. Graphic charts for current and voltage (at load center) on a typical suburban type feeder regulated with the electron tube regulator

Although the current varied between 1 and more than 5 amperes, the voltage is shown to vary only between 120 and 118 volts. Without regulation the voltage dropped 8 volts with the same load variation

indicate why it is possible to obtain increasing voltage across both the primary winding of the booster transformer and the primary winding of the impedance transformer, while the line voltage remains substantially constant.

The tubes are used commercially well under rating so that their life is increased. It is a general characteristic of such tubes that they will stand tremendous overloads for short periods of time. This point is important in considering the short-circuit capacity of regulators using this type of tube. These tubes will stand 25 times normal current for very brief periods, and are usually equipped with a slow acting fuse which will not operate in the case of a line short circuit unless the ordinary line protection fails. In the event of tube failure or opening of the tube fuse, service is not interrupted, but there occurs only a drop in line voltage equal to the percentage boost at that time. A relay could be provided which would short-circuit the impedance transformer and supply full boost in the event of tube failure, but the condition of lowered voltage is usually thought better.

Table II—Test Results for Voltage Regulator With Mechanically Operated Grid Control

Amperes: Load in Primary Line	Voltage: Supply (20/1)	Voltage: Load	Power Factor: Input %	Power Factor: Load %
2.4	123	120.5	91	90
6.8	121	120.3	97	95
11.2	119	119	98	96
13.6	118.5	119	96	98
16.0	117.5	119.5	97	100
18.4	117	119.2	99	100

Results With Controlled Boost

The oscillograms of figure 8 show the grid voltage, tube voltage, and load voltage on an experimental 2,400 volt line having about 5 ohms resistance to load center. The regulation at the load, on the secondary of a 2,400/120 volt distribution transformer, was within 2 volts at all times. In this set-up the grid controlled circuit of the tube and the filament transformer were immersed in oil. The slight distortion in output wave-form is generally not sufficient to produce any appreciable detrimental effect as regards motor core losses and the like. Relatively simple filters have been devised which seem to eliminate any undesirable telephone and radio inter-

Fig. 10. This electron tube regulator gives voltage increase within same half cycle that current increases

ference due to the presence of harmonics, as it can be seen from the oscillograms that these harmonics are small in magnitude. The data for a load test are given in table I. Tables II and III give load test results for the mechanically controlled grid circuits, when applied to constant voltage and to constant current control, respectively.

In figure 9 are shown graphic charts for current and voltage (at load center) of a typical 24 hour run on a suburban type feeder regulated by the automatic arrangement of figures 2 and 3. The resistance of the line from regulator to load center was approximately 5 ohms.

One of the most outstanding characteristics of the automatic tube regulator is its instantaneous response in control during changes of load, as shown in the oscillogram of figure 10. The regulator responds during the same half cycle to give an increase of voltage at the load with the increase in current.

Summary

The use of tube controlled regulators offers a number of advantages which warrant careful consideration. The absence of heavy moving parts is one of the outstanding features.

The instantaneous response of the controlled boost regulator described here is a very important point in consideration of short duration loads, such as welding. With the ordinary type of regulator these loads cause a continual pumping effect as the regulator is not able to keep up with the rapidly changing load conditions.

Because of the low cost of tube control, this type of regulator may be found economical for installations on individual industrial or commercial loads where other means of regulation are found too expensive, or where, because of the rapid fluctuation of the load, the other types of regulators may be ineffective.

Tube replacement, particularly on rural distribution lines, is worthy of consideration. However, the life of indirectly heated tubes of this type is of the order of several thousand operating hours. On this basis an annual inspection and changing of these low priced tubes should be all that is necessary. In any case the failure of a tube does not mean interruption of service, but would be noticed by the absence of regulation on the circuit.

Table III—Test Results for Constant Current Regulator With Mechanically Operated Grid Control

Load			Power Factor		
Amperes	Volts (20/1)	Kw	Input %	Load %	Efficiency %
6.65	36	4.6	37.7	95.5	76.5
6.6	45.5	5.6	44.3	93.0	80.0
6.55	54	6.6	51.5	93.0	81.5
6.5	65	8.0	60.5	94.5	85.2
6.4	79	9.6	72.0	95.0	87.2
6.65	95	11.7	81.7	92.5	90.0
6.6	106	12.8	90.0	91.5	90.2

Oil Circuit Breaker and Voltage Recovery Tests

A series of tests on a circuit breaker of the oil blast type was conducted at the Richmond station of the Philadelphia Electric Company. Particular attention was given to the rate of recovery of voltage following the actual interruption of the circuit. Unusual details in the operation of the cathode ray oscillograph also were worked out. These, and other features of the tests, are described in detail in this paper.

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IN VIEW of the high recovery voltage rate calculated for certain circuit locations where circuit breakers were to be installed in the Richmond station of the Philadelphia Electric Company, this company decided to make interrupting capacity tests on the circuit breakers in the field for the 2 purposes of determining the breaker performance and verifying calculations of the recovery characteristics. (The recovery voltage rate of an a-c power circuit is the term given to the rate, in volts per microsecond, at which the voltage rises across the terminals of a circuit breaker immediately following the interruption of current by that breaker.)

It is the purpose of this paper to record these tests with special notes on the recovery voltage phenomena and their calculation and on the theory and performance of a novel method of initiating the operation of a cathode ray oscillograph for their measurement. Comparisons are given between calculated recovery voltage curves and cathode ray oscillograms and between the recovery rates determined from these curves and oscillograms.

Due to the fact that all the equipment was not yet installed at the time the tests were made, it was impossible to make the tests under the exact conditions of the final installation. For the tests, the circuit breaker was therefore set up in a temporary

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shelter outside the building, and temporary buses were run to it. Recovery rate calculations were made both for the final installation and for the test set-up and particular pains were taken to make the test as severe in this respect as the final installation.

The following conclusions may be drawn from the material presented in this paper:

1. The oil-blast circuit breaker is so uniform as regards arc length that the time of interruption can be indicated within one half cycle by an auxiliary contact attached to the operating rod.

2. A properly designed saturated-core current transformer may be used to supply a voltage impulse for the purpose of initiating the record of the cathode ray oscillograph a short time before the current zero.

3. A reasonably accurate estimate of the recovery voltage rate was obtained by calculation.

4. The circuit breaker appears capable of performing satisfactorily under the worst recovery rate conditions to be encountered in the installation.

The Circuit Breaker

The circuit breaker was a type *FHK*-330-32*B*, rated 15,000 volts, 5,000 amperes, and 1,500,000 kva interrupting capacity. This is an indoor circuit breaker with 32 inch diameter round tanks, one for each phase, down break, and explosion chambers. A photograph of it, mounted on the test frame, is shown in figure 1. It should be noted that in the final installation, an isolated phase arrangement is to be used with the 3 phases on different floors, so that the mounting of the circuit breaker would be quite different.

A view of the circuit breaker with the tanks down is shown in figure 2. Here may be observed the explosion chambers and the massive contacts required for carrying the high continuous current for which the breaker is rated. A detailed view of the blades for carrying the continuous current is shown in figure 13.

A view of the interior of the explosion chamber is shown in figure 10. The chamber has a throat bushing with a vertical center hole through which the contact rod moves and the arc is drawn, and in

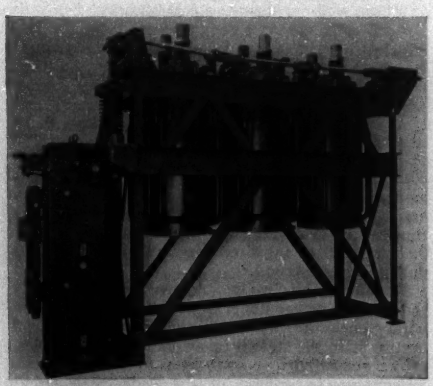

Fig. 1. Oil circuit breaker, type FHK-330-32B, 15,000 volts, 5,000 amperes, mounted as for the tests

Fig. 2. Test oil circuit breaker with tanks lowered

addition, a horizontal hole passing directly across the vertical hole and communicating at one end with the oil pocket and arcing space at the top of the throat bushing, and at the other end with the oil in the tank outside the explosion chamber. Metal gates are mounted on the throat bushing in such a way as to close off the top of the vertical hole when the contact rod is not in the closed position. At the top of the explosion chamber is mounted a female contact of the conventional segment type with a metal bell immediately below to protect the segments from the arc.

The operation of this chamber is as follows:

On closing, the contact rod pushes up through the center hole of the throat bushing, opens the gates, and finally enters the female contact at the top of the explosion chamber, completing the circuit. After the contact rod has entered the female contact far enough to assure a good contact, a parallel circuit is completed through the main contacts outside the explosion chamber.

On opening, the circuit through the main contacts is broken while there is still a good contact in the explosion chamber, transferring the current to these contacts. The contact rod then pulls out of the segments and down through the throat bushing, and the gates close behind it. This divides the arc into 2 parts, one about $^3/_4$ inch long between the gates and the arcing bell above, and the other in the throat bushing between the gates and the contact rod. The upper arc generates pressure which forces oil out through the horizontal hole and thus across the lower arc, which is thereby extinguished.

Arrangement of the System; and Recovery Voltage Calculations

A. In the Final Installation. Richmond station is of the isolated phase type, with the switching and protective equipment of the different phases on different floor levels. As is usual in large metro-

politan stations, each generator, tie line, or other connection to the main bus has its own reactor and a circuit breaker corresponding to each bus. These reactors, of course, serve the intended purpose of limiting the short-circuit current, but they also make for high natural frequencies of oscillation of the power circuit when the electrostatic capacitance of the bus-work is small. In this station all the buses are of the open type, with consequent low capacitance.

In the final installation the 15,000 volt, 5,000 ampere circuit breakers are generator breakers, situated between the main bus and the 0.087 ohm generator reactors, which are in turn connected to the 183,333-kva double-winding generator. The system diagram, with reactance values given on a 100,000 kva base, is shown in figure 3. In making up this diagram, no attempt has been made to segregate the reactances outside of the ring bus according to their nature. The reactances are divided in all cases into 2 parts: the reactance appearing before a large capacitance is reached, and the remainder of the reactance of the circuit.

For the circuit breaker in question, ruling out the improbable case of a short circuit between breaker and generator reactor, a 3-phase ungrounded fault between the 183,333 kva generator and its reactor gives the most severe fault with respect to both current and rate of rise of recovery voltage. Using the values given in figure 3 the system reduces to that shown in figure 4. In simplifying the circuit for a recovery rate calculation it is necessary to preserve with at least moderate accuracy the distribution of reactance and capacitance of the system. The capacitance C_1 is that of the bus and connected bushings between the circuit breaker and the generator reactor L_1; C_f is the capacitance of the short-circuit point, including that of the generator; C_3 is the capacitance of the main bus and its connected bushings, and L_2 is the parallel reactance of the reactors between the bus and points of large

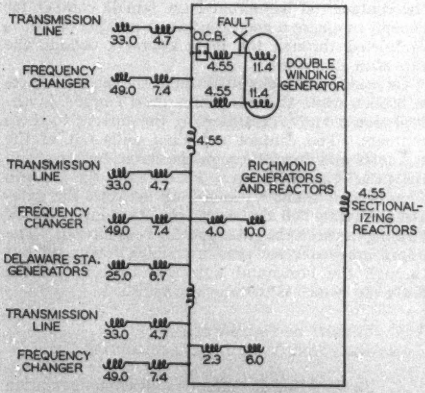

Fig. 3. Reactance diagram of Richmond station and connected apparatus

Reactance values are given on a 100,000 kva base

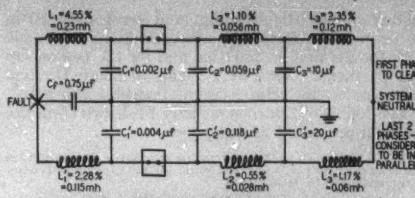

Fig. 4. Simplification of figure 3 as required for solving for recovery rates

μf—microfarad mh—millihenry

capacitance, such as long cables and generators. C_3 is the capacitance of these cables and generators, while L_3 is the remaining system reactance. C_3 and C_f are very large compared to C_1 and C_2, while the reactances are all of the same order of magnitude, so that C_3 may be considered as a short circuit as regards the oscillation of L_2 and C_2, and C_f similarly as regards the oscillation of L_1 and C_1.

The only high oscillating frequencies are those of L_1C_1 and L_2C_2 which are 234,000 and 88,000 cycles, respectively. The fractions of system voltage associated with these frequencies are as L_1 and L_2 to the total reactance, L_0. For a double frequency oscillation, the rate of rise of recovery voltage is given very closely by the expression

$$r = k_g k_q k_\delta e \delta\, 10^{-6} \frac{f_1}{L_0}\left[4.55L_1 + 2.85L_2\left(1 - \cos\left(\frac{f_2}{f_1} \times 133 \text{ degrees}\right)\right)\right]$$

where

r = recovery rate, volts per microsecond
k_g = ground connection factor
= 1.5 for a 3-phase ungrounded fault
k_q = quadrature reactance factor = 1.0 (approximately)
k_δ = ratio of voltage at inception of short circuit to voltage at the time of interruption
= 1.0, assumed momentarily
e = peak leg voltage
δ = high frequency decrement, assumed 0.95 from inspection of previous cathode ray oscillograms
f_1 = higher oscillating frequency of L_1 and C_1
f_2 = lower oscillating frequency of L_2 and C_2

Substituting values into the equation

$$r = 1.5 \times 1.0 \times 1.0 \times \frac{13{,}800}{\sqrt{3}} \times \sqrt{2} \times 0.95 \times 10^{-6} \times \frac{234{,}000}{12.00} \times \left[4.55 \times 4.55 + 2.85 \times 1.10\left(1 - \cos\left(\frac{88{,}000}{234{,}000} \times 133 \text{ degrees}\right)\right)\right]$$

= 6,800 volts per microsecond

This recovery rate is the maximum possible, and assumes no d-c component of short-circuit current and no decay of flux in the generators. For interruption in 8 cycles, the decrement would lie between 0.85 and 0.90, giving a recovery rate of 5,800 to 6,100 volts per microsecond.

B. In the Test Set-Up. As mentioned previously, the circuit breaker under test was placed in a temporary enclosure, with cambric-covered cables connecting it to the station bus-work. The use of lead cables was avoided so as to keep to a minimum the capacitance to ground of the leads. The circuit breaker neutral was ungrounded since this gives a higher recovery rate than otherwise.

The tests were made in 3 groups, each comprising

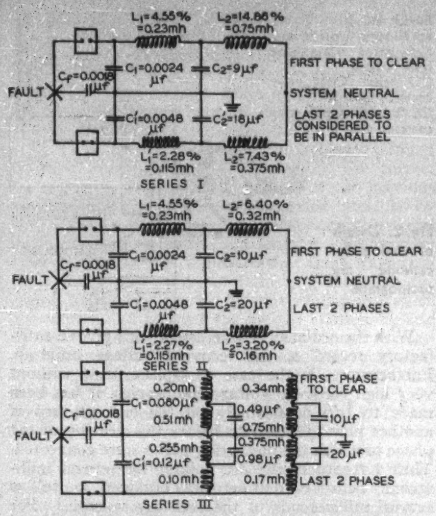

Fig. 5. Simplified diagrams of the 3 test set-ups

μf—microfarad mh—millihenry

CO and OCO operations. (A *CO* operation is one in which the short circuit is thrown on outside the circuit breaker while the breaker is in the closed position and the breaker has only the duty of opening the circuit. In an *OCO* operation, the circuit breaker closes upon the short circuit and then opens immediately.) First, preliminary tests of approximately 260,000 kva were made, utilizing only generators at Delaware station, connected to Richmond station by the tie cables, and with the 4.55 per cent reactor connected between the bus and the test breaker. Next, all the Richmond generators available for test purposes were added to the bus, and as in the first series the fault was applied through the 4.55 per cent reactor. In the last series the full available generating capacity was applied to the circuit breaker, with the 4.55 per cent reactor short-circuited.

The circuit constants for the 3 series are given in figure 5. The recovery rates calculated from these constants will be found in table II, column 4.

In order to insure the recording of the recovery characteristic of the first phase to clear, which was expected to have the highest recovery rate, the contact rods of the *C* phase, to which the cathode ray oscillograph was connected, were made one inch shorter than the contact rods of the other 2 phases. This was sufficient to cause this phase to clear first in every case.

Determination of Recovery Characteristic From the Oscillogram

These tests exemplify a type of modification of the inherent recovery voltage characteristic of the circuit caused by the circuit breaker that to date has received little discussion. Where the recovery voltage characteristic consists of a single oscillation at a given frequency, the effect of arc voltage will be simply to increase the amplitude of oscillation by a fraction never greater than the ratio of arc voltage to normal peak voltage. This will cause an increase in recovery rate which will usually be quite small.

If the characteristic is a combination of 2 or more oscillations at widely different frequencies, however, the result may be quite different. In this case, if there is no arc voltage, the higher frequency oscillation starts from zero; but if there is appreciable arc voltage, the higher frequency oscillation starts from a negative value equal to the arc voltage. If the higher frequency oscillation has less than half the total amplitude, this results in a reduction in the positive voltage of the first peak of the high frequency oscillation and a corresponding reduction in recovery rate, the latter being defined as the steepest tangent to the voltage curve from the zero of voltage and time. This reduction may be considerable, and is so in the present case, even without very high values of arc voltage.

In a given test, the recovery rate may be influenced by the following factors in addition to that just mentioned:

a. Displacement of the current wave.

b. Decrement of the a-c component of current.

c. Conduction of a small amount of current by the circuit breaker for a very short time after the last normal current zero.

In these tests, the effect of the first and third items above was negligible in most cases. The decrement reduced the amplitude of the characteristic by about 15 per cent.

The combined effect of decrement and arc voltage is illustrated in figure 14 by the 2 calculated curves corresponding to connection number 2 of the tests. Here the dotted curve corresponds to the ideal condition and, in the case of the solid curve, an arc

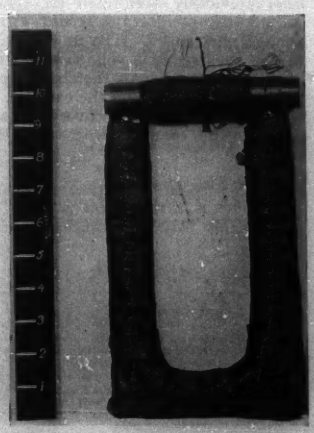

Fig. 6. Current transformer used for precise timing

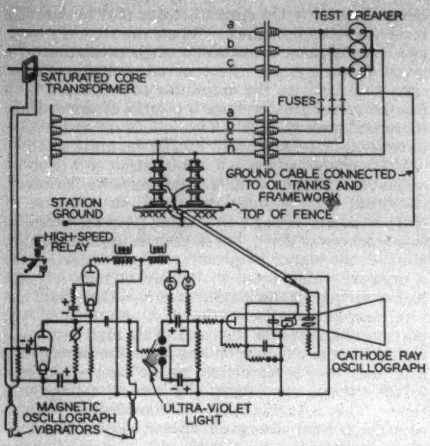

Fig. 7. Diagram of cathode ray oscillograph circuit

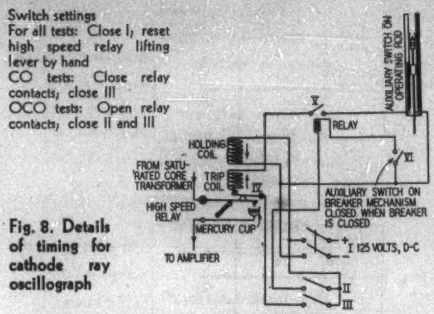

Fig. 8. Details of timing for cathode ray oscillograph

voltage of about 6 kv, together with the generator flux decay, reduces the positive voltage of the first peak from 13 kv to 8 kv, resulting in a reduction of recovery rate from 6,600 volts per microsecond to 4,500 volts per microsecond.

In table II are given the recovery rate values as measured directly from the oscillograms (column 2) and the inherent rates for the system as determined by correction of the above values for arc voltage and current decrement (column 3). The latter values are comparable to the calculated figures in column 4.

Method of Timing the Oscillograph

A. Schemes Previously Used. Several schemes have previously been used for synchronizing the cathode ray oscillograph record with the recovery voltage phenomena. The most obvious method is to use the recovery voltage surge itself to break down a 3-electrode gap, thereby completing a circuit which places voltage on the cathode. This method was used for the first recovery voltage records obtained by the company with which the authors are associated.

With the ordinary characteristic, this gives a satisfactory record of the recovery voltage build-up. Furthermore, in the case of 3-phase tests without very high recovery voltage frequencies, it has been made to trip occasionally on the current zero of another phase 60 degrees before the clearing of the phase to which the measuring plates were connected. Thus a record of the arc voltage for several milliseconds before current zero was obtained, as well as several milliseconds of the recovery voltage.[1] For the present case, however, the existence of a 200,000 cycle oscillation involving only a part of the recovery voltage ruled out tripping as much as 60 degrees early, and at the same time made it appear very doubtful that the above scheme could be made sufficiently sensitive to obtain the early part of the record without a serious risk of losing the record entirely through tripping at an early current zero.

Some investigators[2] have used a revolving drum, recording for several cycles at normal system frequency. This has a number of advantages in that it not only records the arc voltage immediately before current zero, but also gives a record of several current zeros for the same test; but it was quite out of the question for the present application as, in order to extend one cycle of the highest frequency oscillation over 0.1 inch, a film speed in excess of the peripheral speed of turbine buckets would be required.

A mechanical contact-making device has also been attached to a synchronous machine on the power system supplying the short-circuit current.[3] This permits precise and reliable synchronization with

1. For all numbered references, see list at end of paper.

Table I—Circuit and Breaker Performance

Test Group No.	Circuit Condition	Number of Tests	Average R. M. S. Current: First Cycle	Average R. M. S. Current: Initial in Arc	Time from Trip Impulse to Interruption—Cycles	Arc Length*: Cycles	Arc Length*: Inches per Break
1	Power only over cables from Delaware station. Reactor in circuit at Richmond	5	13,800	10,800	8	1.0	1.6
2	Power from Delaware station and from all available generators at Richmond. Reactor in circuit at Richmond	4	26,000	18,100	8	1.0	1.6
2a	Same as 2	4	34,000	19,500	8	0.7	1.3
3	Power from Delaware and Richmond. Reactor removed from circuit	4	31,000	24,000	8	1.0	1.7

* Measured from bottom of gates.

the current zero after the d-c component of short circuit current has died away, but before that time it is useless. Furthermore, this scheme is just as likely to operate on any current zero as on any other and, therefore, without some auxiliary means of selecting the correct current zero, it could not be applied successfully.

B. The Scheme Selected. The scheme selected required auxiliary means of selecting the correct current zero, just as in the scheme of the previous paragraph. This selection was made possible by one of the salient features of oil-blast circuit breakers; the short and consistent arc lengths. Preliminary tests in Schenectady indicated that there was but a very slight probability of failure to interrupt the circuit on the first current zero after a gap of $^3/_4$ inch was established between the moving contact tip and the bottom of the gates, and likewise there was not a very great probability that the breaker would clear before that time. Hence, a relay closing at the time when a $^3/_4$ inch gap was established would select the correct current zero with a fairly high degree of reliability. A relay was made to close at this time by connecting an auxiliary contact, outside the circuit breaker, directly to the wooden operating rod of one pole by means of a small steel rod passing through the top of the circuit breaker. This contact operated a high speed relay situated close to the cathode ray oscillograph and electrically in the tripping circuit for this oscillograph. The auxiliary contact was set ahead far enough to allow for the time required to close the contacts of the high speed relay. The allowance made was correct on CO tests, but the opening speed of the breaker was somewhat lower on OCO tests, and in a number of cases this threw the timing out. The contacts of the high speed relay were of special design in order to eliminate any possibility of bouncing contacts breaking the circuit on the closing stroke; they consisted of a pin and a pool of mercury.

The second unit of the timing system had the function of predicting with precision the time of occurrence of the selected current zero. It consisted of a substantially open-circuited current transformer (see figure 6) with a single-turn primary winding formed by a short section of the conductor feeding the pole of the breaker to which the cathode ray oscillograph deflection plates were connected. The core was a rectangular frame of high grade 0.014 inch iron with a cross section of 0.28 square inch, a mean length of 27 inches, 2 interwoven and 2 butt joints. The secondary winding had 50 turns and was connected in series with the contacts of the high speed relay to the grid of a 3 electrode vacuum amplifying tube, whose output voltage was fed to the mid-sphere of a 3 electrode gap.

C. Anticipated Performance. During that part of the cycle in which the primary current was high, it was anticipated that the core of this transformer would be saturated. Hence, although the primary current might be changing at a high rate, the flux in the core would remain practically constant and there would be no secondary voltage. When the current decreased, however, to a value insufficient to maintain saturation in the iron, the flux would begin to decrease very rapidly, and a comparatively high voltage would be induced in the secondary winding. Time was not available before the tests to obtain any experimental data on the shape of the hysteresis loop for such high values of magnetization as would be encountered, but a study of such curves as were available indicated that the following assumptions might be sufficiently accurate for a preliminary estimate of performance:

1. The magnetization curve might be considered a straight line from zero up to 80,000 lines per square inch at 10 ampere turns per inch and any increase in flux density beyond 80,000 might be neglected.

2. A 5 mil air gap appeared sufficient to reduce the residual magnetization to about 16,000 lines per square inch so that 40 per cent of the flux change from positive maximum to negative maximum would appear before current zero.

On the basis of these assumptions, it was estimated that a voltage surge would appear at a time of the order of 50 microseconds before current zero. In the

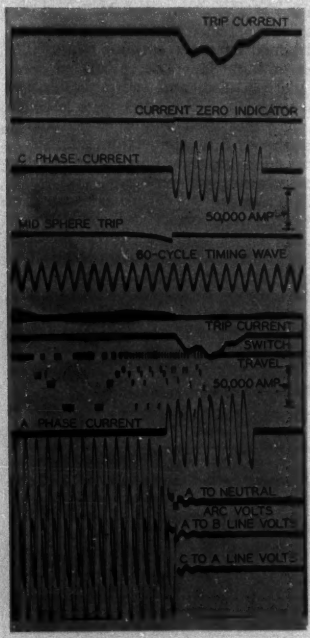

Fig. 9. Two oscillograms from one test of group number 3

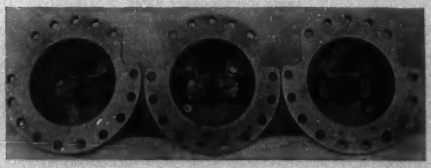

Fig. 10 (right). Top view of 3 explosion chambers after tests

Gates shown were in use for test group number 3 only

actual construction, no air gap was inserted, as it was anticipated that the 2 butt joints would be roughly equivalent to a 5 mil gap.

With the specification that one cycle of a 200,000 cycle oscillation shall be spread over 0.1 inch, a sweep speed of 20,000 inches per second is required, and the available record length of 4.5 inches would be covered in 225 microseconds. Tripping about 50 microseconds before current zero gives a good location of the current zero on a record of this length. It was found when this arrangement was tested that in the case of the higher currents there was a sufficiently rapid change in flux linkages above the density of 80,000 lines per square inch to cause earlier tripping than was anticipated. Thus with currents of about 10,000 amperes, tripping occurred at about the anticipated point. At 20,000 amperes, however, tripping occurred about 100 microseconds before current zero and at the highest currents, considerably earlier. A longer sweep was desired for the highest current tests, however, so this performance was considered satisfactory.

The wiring diagram for the complete circuit is shown in figure 7 and the details of the circuit for current zero selection in figure 8.

The use of an amplifying circuit was dictated not so much by inability to generate sufficient voltage in the current transformer to trip the 3 electrode gap as by the inconvenience of handling on a high speed relay not only the 3 or 4 kv necessary for tripping, but also the 25 kv which would be present on the mid-sphere during the operation of the cathode ray oscillograph.

The performance of the various elements of the cathode ray oscillograph circuit can be traced in the second oscillogram of figure 9. Here a slight discontinuity on the "current zero indicator" record just before the end of the last half cycle of short-circuit current indicates the closing of the high speed relay, a sharp surge on the record very soon afterward shows the reaction of this circuit to the current zero, and a disturbance in the "mid-sphere-trip" record indicates that the sphere gap broke down, initiating the operation of the cathode ray oscillograph, at the same time.

Fig. 11. Contact rod tips after test group number 3

Fig. 12. Segments from female contacts of 3 explosion chambers after tests

Table II—Recovery Rates

Connection Number	Recovery Rate Measured From Cathode Ray Oscillogram	System Recovery Rate Determined by Correction of Cathode Ray Oscillogram	Calculated Recovery Rate of System	Approx. Short-Circuit Kva
1	1,500	4,600	3,700	270,000
2	3,800	5,600	6,600	500,000
3	1,050	1,600	1,200	600,000

Results

A. Circuit and Breaker Performance. The circuit and breaker performance, except for recovery rates, is summarized in table I. At the conclusion of test group number 2*a*, the tanks were lowered for inspection of the contacts. Approximately $^3/_8$ inch was burned from the contact rod tips, and the gates were burned moderately but were still serviceable. New contact tips and gates were installed and the segments of the female contacts were smoothed up slightly.

Two of the 3 oscillograms from one test of group number 3 are shown in figure 9. After group number 3, the contact tips were burned away about $^1/_4$ inch. The gates were again moderately burned, but still serviceable.

Figures 10 to 13 show, respectively, a top view of 3 of the explosion chambers, the contact rod tips, segments from 3 of the female contacts, and the blades of the current carrying contacts after test group number 3.

B. Comparison of Calculated and Measured Recovery Characteristics. The recovery rates as calculated and as obtained from the cathode ray oscillograms are given in table II. The calculated characteristics are plotted, also, and shown beside the oscillograms in figure 14. The agreement between the calculated and measured values is reasonably good, except in the case of connection number 3, which was not considered of great importance because of the comparatively low recovery rate, and which was a very difficult circuit to calculate because of the difficulty of estimating correctly all the elements of bus capacitance.

The frequencies of the various oscillations as given by the cathode ray oscillograms and by calculation are shown for the purpose of comparison in table III.

C. Timing of the Cathode Ray Oscillograph. On the CO tests, the selection of the correct current zero was achieved with success most surprising to

Table III—Oscillating Frequencies

	Highest	Second	Third	Fourth
Connection number 1				
By cathode ray oscillograms	190,000	160,000	*	
By calculation	220,000	190,000	2,000	
Connection number 2				
By cathode ray oscillograms	190,000	160,000	2,700	
By calculation	220,000	190,000	2,700	
Connection number 3				
By cathode ray oscillograms	190,000†	75,000	28,000	2,400
By calculation		59,000	14,000	2,400

* Record not long enough to determine frequency.
† Extremely low amplitude.

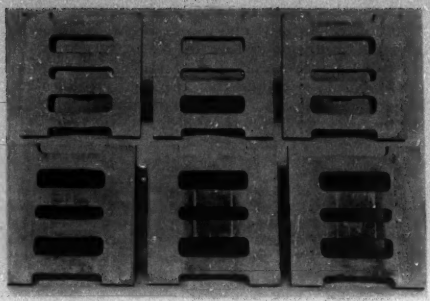

Fig. 13. Blades for carrying continuous current after tests

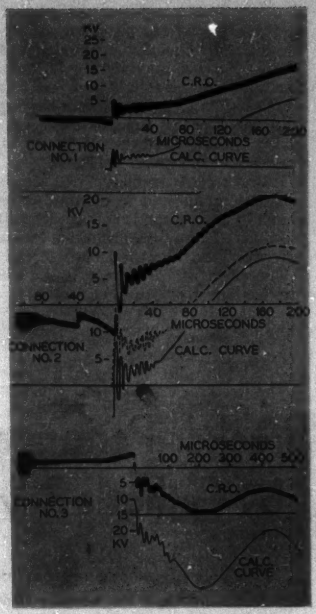

Fig. 14. Cathode ray oscillograms and calculated recovery voltage characteristics for the 3 connections

The dotted curve in the connection number 2 diagram is the calculated curve without allowance for flux decay or arc voltage

one familiar with the inconsistencies in arc length associated with circuit breakers of the past. On the OCO tests, sufficient allowance was not made for the lower opening speed of the breaker, with the result that the timing, while just about as consistent as on the CO tests, was a half-cycle early in most cases.

There were, likewise, very few irregularities in the precision timing, the current zero occurring in most cases slightly before the mid-point of the record.

The results obtained in the timing of the cathode ray oscillograph, with CO and OCO tests segregated, are summarized by table IV.

Comments

The currents obtained in groups 2, 2*a*, and 3 were considerably less than anticipated. Subsequent measurements of the reactance from bus to short-circuit point and calibration of the current transformers at high current account for a part of the difference, but there remains a discrepancy of about 20 per cent which is apparently attributable to the use of conservative values of alternator reactance. Designers of turbine-alternators have been handicapped in the development of formulas for the calculation of transient reactances by the lack of short-circuit test data on large machines. Furthermore, the transient reactance is subject to wide variation in any one machine. Due to magnetic saturation of the reactance flux paths, which is especially prominent in large solid rotor alternators, any increase in the amount of external reactance or decrease in the operating voltage makes a considerably greater percentage reduction in the initial short-circuit current. In this situation it has been the practice of designers to give reactance values that are conservatively low for short-circuit calculation, thus ensuring a reasonable margin of safety in the protection of these large machines.

On account of this reduction in short-circuit current, the tests failed in one respect; that of determining the performance of the circuit breaker when operating near its rated interrupting capacity.

With respect to recovery rate, however, it is felt that the test connections closely parallel the conditions of the final installation, and that in this respect the circuit breaker has been thoroughly tested and proved capable of performing its duty.

It should not be assumed from these tests that the performance of the circuit breaker would continue to be unaffected by the recovery rate if this rate were increased indefinitely. The performance of the breaker may be well described by the statement that, almost without exception, interruption was obtained on the first current zero after a gap of $^3/_4$ inch had been established between the contact tip and the gates. High as the recovery rates were carried, therefore, they remained in the range where the breaker was interrupting the circuit at the earliest point at which interruption could be expected with any circuit of appreciable power. But how far this range extends beyond the point to which tests were carried no one can say.

As is often the case with oscillograms, the pecu-

Table IV—Timing of Cathode Ray Oscillograph

	CO Test	OCO Tests	Total
Number of tests	9	8	17
Number of correct current zeros	8	2	10
Per cent of selections of correct current zeros	89	25	59
Number of successful records	7	1	8
Per cent successful timing by current transformer	87	50	80
Successful records, per cent of total	78	12	47

liarities of the records are of interest. In the films of the first and second series a beat is apparent in the highest frequency component; this is due to a slight difference in oscillating frequency between the first phase to clear and the last 2 phases to clear, which oscillate together when the first phase clears. Additional circuit-breaker bushings cause the last phases to have higher capacitance to ground, while the reactances remain the same.

In the records from group 2, the behavior of the cables is manifested in discontinuities appearing at about 70 microseconds and again at about 140 microseconds. These discontinuities are caused by waves reflected back from the Delaware end of the cables.

The effect of arc voltage in reducing the recovery rate has already been discussed.

The authors wish to acknowledge the suggestions made by E. B. Shew and others of the Philadelphia Electric Company and by J. K. Ostrander of the United Engineers and Constructors, Inc., toward the preparation of the paper and the courtesy of the Philadelphia Electric Company in making available the magnetic oscillograph records.

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Breaker Performance Studied by Cathode Ray Oscillograms

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Analyses of cathode ray oscillograms of circuit interruptions reveal characteristics of the circuits that are significant in the study of circuit breaker performance. While a complete analysis of such an oscillogram involves much detailed work, the study of several typical oscillograms reveals the significance of certain types of voltage variations and thus makes possible the analysis of similar oscillograms without detailed measurements. Several oscillograms made on typical laboratory circuits are presented and analyzed in this paper.

EXTENSIVE studies of circuit breaker performance by means of cathode ray oscillograms have disclosed significant phenomena of arc interruption. The studies have been facilitated by the great range of frequency response and the large time scale of these oscillograms, which permit accurate studies to be made based upon the voltage across the breaker terminals during the arcing period and during the recovery transient. A complete analysis of such an oscillogram involves a large amount of detailed work, but a study of several typical oscillograms reveals the significance of certain types of voltage variations and makes possible a quick and reasonably satisfactory analysis of other similar oscillograms without the necessity of making detailed measurements. Some typical oscillograms already have been discussed before the A.I.E.E.[1]; additional ones showing other types of phenomena are included in this paper.

The oscillograms selected were made on laboratory circuits, but apply also to field circuits having similar characteristics. Such circuits consist of 1 or 2 generators supplying power through reactors either directly or through transformers to a circuit breaker. The oscillograms chosen cover low currents, interrupted by normal and high speed breakers, high currents, and moderate currents on circuits having different natural frequencies.

Since the criterion of circuit severity is the rate of rise of recovery voltage, and since the time interval and voltage range used in the calculation of this rate are not specified by the term itself, a discussion of the method of measuring cathode ray oscillograms and determining circuit characteristics is included. Typical circuit characteristic curves of a high power laboratory also are given.

Briefly summarized, the principal points brought out in this paper and the conclusions reached are as follows:

1. The method of calculating the rate of rise of recovery voltage from cathode ray oscillograms of circuit interruptions should eliminate the effect of the breaker; a method accomplishing this is described here.

2. Circuit characteristics can be determined from cathode ray oscillograms of interruptions, supplemented by frequency measurements with oscillators and possibly by calculations. Calculations

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1. For all numbered references see list at end of paper.

of a simple circuit show that the published formulas do not give curves fitting those determined experimentally.

3. A circuit breaker opening a small current may have an unstable arc which causes the current to pass in a series of rapid impulses.

4. Breakers having arc extinguishing devices that make low current arcs unstable and build up the dielectric strength between contacts too rapidly during a half cycle produce high overvoltages.

5. The capacitance associated with circuits having a low natural frequency assists arc extinction not only by reducing the rate of rise of recovery voltage, but also by diverting current from the arc when the arc voltage rises at the end of the half cycle of arcing. This diversion of current tends to make the arc unstable and to cause the extinction of the arc to take place before the negative peak of voltage is reached at the beginning of the recovery voltage transient.

Methods of Measuring Cathode Ray Oscillograms of Circuit Breaker Performance

Circuit breaker performance is a function not only of voltage and current, but also of the circuit characteristics. Consequently, for any discussion of breaker performance it is desirable to have some simple measure of these characteristics. The criterions that have been proposed are based upon either the natural frequencies of the circuits or the rate of rise of recovery voltage. Those based upon frequency are not adequate, but are the easier to determine, the most common of these being simply a statement of the natural frequency of the circuit. This method of expressing the characteristics is satisfactory only if the circuit has but 1 natural frequency or if 1 predominates. Circuits that have

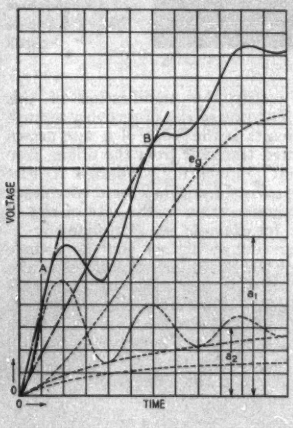

Fig. 1. Typical reconstructed recovery voltage transient

a_1—Amplitude of lower frequency component

a_2—Amplitude of higher frequency component

e_4—Normal frequency voltage

2 or more natural frequencies and circuits that are aperiodic, are not easily assigned an equivalent frequency; hence, such circuits are not readily compared on this basis. Moreover, a 132 kv circuit having a natural frequency of 10,000 cycles per second represents a relatively "difficult" circuit, but a 13.2 kv circuit having the same natural frequency represents a relatively "easy" circuit; hence, the significance of the natural frequency varies with voltage. For these reasons, criterions based upon natural frequency are being used less and less.

The other criterion, expressed as the rate of rise of recovery voltage, is not determined as easily as the natural frequency, but is applicable to all types of circuits and, when applied to individual tests, takes into account the magnitude of the restored voltage and the asymmetry of the current. In this

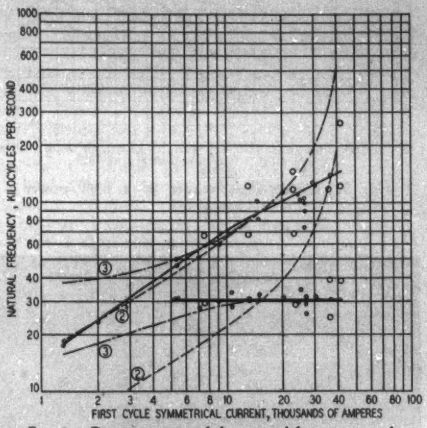

Fig. 2. Determination of the natural frequencies of a high power laboratory circuit

13.2-kv single-phase ungrounded circuit
o—From cathode ray oscillograms
O—From oscillator measurements
2—From Park and Skeats formulas (see reference 2)
3—From Juillard formulas (see reference 3)

method the rate at which voltage appears across the contacts of a circuit breaker is stated. Since this rate is not constant, but varies almost continuously during a transient, the value given is an average value derived by arbitrary assumptions.

Measurements of the average rate of rise of recovery voltage on a given test directly on the oscillogram are not satisfactory because of the effect of the breaker on the recovery transient as has been shown in a previous A.I.E.E. paper.[1] Sometimes the breaker causes only a slight increase in the amplitude due to the arc voltage, but at other times it causes an increased amplitude of the voltage wave produced either by a high arc voltage or by a sudden extinction of the arc, a shifting of the current zero due to high arc voltage, and/or a change in the whole nature of the transient due to the passage of a small current through the space between contacts after the arc is extinguished.

These effects of the breaker should be eliminated in determining the rate of rise of recovery voltage. The result should be the rate of rise in the circuit after a current interruption by an ideal breaker having zero arc voltage and passing no current after

the arc is extinguished. This should be done so that the breaker will receive credit for opening a difficult circuit even though its action reduces the rate of rise of recovery voltage, and so that it will not be given undue credit if it increases the rate of rise.

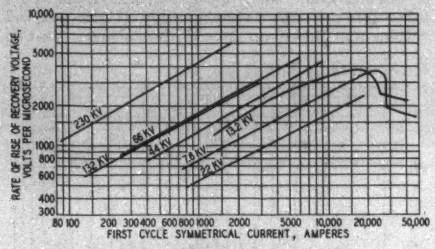

Fig. 3. Circuit characteristics of a high power laboratory

To eliminate the effects of the breaker, it is necessary to reconstruct the transient with data on the frequencies f_n, amplitudes a_n, and decrements x_n of the n components taken from the oscillogram. For oscillatory circuits the following formula is used, which gives the instantaneous voltage of the recovery transient, v, as a function of time t:

$$v = \Sigma a_n(1 - e^{-x_n t} \cos 2\pi f_n t)$$

As given by this equation, the initial voltage at the beginning of the transient is zero, corresponding to the assumed arc voltage. The amplitudes of the component frequencies have the same relative magnitudes as in the oscillogram and their sum equals the restored voltage. The restored voltage is taken as the instantaneous value of the normal frequency voltage at the time the current normally would have reached zero at the end of its last half cycle if the voltage across the breaker had been zero. This definition is worded so that a breaker is given full credit for opening a circuit even though it brings about the interruption by first changing the phase angle of the current by the introduction of a resistance or high arc voltage, thereby reducing the actual rate of rise of recovery voltage. An example of a reconstructed transient is shown in figure 1. The amplitude of the higher frequency component (a_2) is assumed to be 30 per cent of the restored voltage and the amplitude of the lower frequency (a_1) the remaining 70 per cent.

After the transient voltage has been plotted, the rate of rise can be determined. This is done by taking the slope of a line from the origin to a point on the transient. If the transient has a single frequency the line chosen will be a tangent that gives the maximum slope. However, when a high frequency component of relatively small amplitude is present, the maximum rate is associated with a tangent to the curve at less than a half cycle of this frequency (see A in figure 1). The actual voltage impressed on the breaker at this time, however, is small in comparison with the peak of the restored voltage (e_r), so this rate probably has little or no significance and should be neglected. How high this voltage should be in order to be significant is probably a function of the voltage of the circuit and the circuit breaker. On test circuits, voltages less than 80 per cent of the peak value of the normal frequency voltage (e_r) are neglected, but additional experience may justify the modification of this arbitrary limit. The rate of rise of recovery voltage for oscillatory circuits is the slope of a line drawn on the reconstructed transient from the origin, zero voltage, to a point representing a voltage at least 80 per cent of the normal frequency restored voltage and giving a maximum value to the rate of rise of recovery voltage; for example, see B in figure 1.

Fig. 4. Cathode ray oscillogram of the interruption of a single-phase 20-kv 6-ampere circuit

Some circuits are not oscillatory and the voltage rises on an approximately exponential curve to the restored voltage. For such a curve it is probable that the corresponding arbitrary minimum voltage limit used should be less than 80 per cent, but more data are required before it can be chosen so it will give measured rates of rise that will indicate the same severity of service as the same values obtained on oscillatory circuits.

Determination of Circuit Characteristics

The method used in determining the rate of rise of recovery voltage from cathode ray oscillograms of circuit interrupting tests has been described. The results obtained are a function of the circuit and of the particular test. The test determines the magnitude of the restored voltage and the asymmetry of the current. The circuit determines the frequencies, relative magnitudes, and damping of the components

of the transient. If the characteristics of the circuit alone are to be determined, the voltage can be assumed to be the value obtained with nominal system voltage and a symmetrical current.

On circuits where considerable testing is to be done, for example, those of high power laboratories, it is desirable to know the circuit characteristics so that by applying corrections for restored voltage and asymmetry the rate of rise can be determined for individual tests without cathode ray oscillograms being taken and analyzed. The characteristic curves can be obtained by measuring cathode ray oscillograms, but, unless tests are made particularly for this purpose, considerable time is required before the entire range of current is covered at each voltage. Consequently, it is desirable to have another method for calculating supplementary data. In laboratory circuits consisting of a generator and reactors there are usually 2 principal frequencies the amplitudes of which are approximately proportional to the inductances of the generator and the reactors, the higher frequency being associated with the inductance of the reactors. The frequencies can be determined by the use of an oscillator which impresses a voltage between the breaker terminals. This method has been used and has given results that have been in agreement with cathode ray measurements.

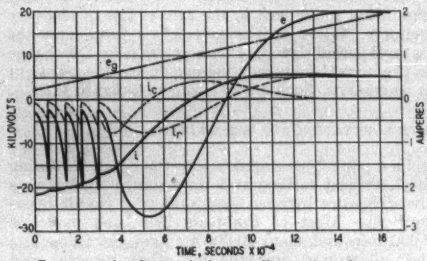

Fig. 5. Analysis of the oscillogram in figure 4

i —Total current
i_c—Current taken by capacitance
i_r—Current taken by cathode ray oscillograph
e—Recovery voltage transient
e_g—Normal frequency voltage

Curves of natural frequency as a function of the first cycle symmetrical current in a laboratory circuit are shown in figure 2. Data from cathode ray oscillograms are plotted as small circles, data from oscillator measurements as large circles, and 2 full-line curves are drawn to fit these points. Neither the cathode ray oscillograms nor the frequency measurements gave data that fit the curves exactly. In drawing a curve to fit such experimental data there is a big advantage in knowing the probable or theoretical shape of the curve. In some types of work if the shape of the curve is known and a few points are located the curve can be drawn. To try this method on the determination of the natural frequencies of laboratory circuits, curves derived from formulas were compared with the experimental data. The curves were calculated from published formulas.[2,3] These formulas give the natural frequencies as functions of the inductances and capacitances of the circuit. The inductances of the generator and reactors had been measured at 60 cycles by means of oscillograms which were taken to determine the reactance-current-time calibration. These values were used although they may not be correct for frequencies from 20,000 to 200,000 cycles per second. The capacitances had been measured by a portable bridge. As the accuracy of the capacitance measurements was subject to some doubt, and as only the shapes of the curves were desired, the values of capacitance used were calculated for each set of formulas from the frequencies found at 15,000 amperes. Therefore, all 3 sets of curves give the same values of frequency at this current. The earlier formulas[2] give a fixed ratio between the higher and lower frequencies, and curves derived from them do not fit the experimental data well except for the higher frequency at low currents. Curves derived from the other formulas[3] likewise do not fit the data, except for the lower frequency in the high current range. In calculating these curves

Fig. 6. Cathode ray oscillogram of the interruption of a single-phase 70-kv 20-ampere circuit

the assumption was made that the inductance of the reactors was the only variable. Probably the capacitances were not constant for the various reactor combinations, but only very large variations could change the shapes of the curves sufficiently to make them fit the experimental data. From the differences in the shapes of the curves, apparently there is considerable difficulty in making assumptions when deriving formulas for calculating the frequencies of circuits, and calculations should be used very cautiously even when only the shape of the curve is to be obtained. The natural frequencies can be obtained more accurately from cathode ray oscillograms and oscillator measurements.

After the natural frequencies of the circuits have been ascertained, the rate of rise of recovery voltage can be determined. For circuit characteristic curves, standard conditions are assumed to be a restored voltage equal to the nominal circuit voltage and an interruption at the time of peak voltage, corresponding to the zero of a symmetrical current in a reactive circuit. The voltage transients are plotted for several circuit conditions and the corresponding rates of rise determined by the method previously described. Some typical calibration curves of a high power laboratory with the work of which the author is associated are shown on figure 3. The curves for the circuits containing transformers are straight lines and a single frequency predominates at each current value. The curves for the 13.2 kv and 7.6 kv circuits are more complicated because of the presence of 2 frequencies. The effects of neglecting voltages below 80 per cent of the crest value of the normal restored voltage are discontinuities at 25,000 and 28,000 amperes and modifications of the curves at currents just below and above these values.

Fig. 7. Cathode ray oscillogram of the interruption of a single-phase 7.6-kv 75,000-ampere circuit

A smooth transition would be more desirable but an elaborate formula for the transition stage is not justified until the effect of high rates reaching only low values of voltage have been subjected to more study.

These circuit characteristic curves are used for determining the rate of rise on individual tests by reading the value corresponding to the laboratory setting and multiplying by a factor that corrects for the reduction in the actual normal frequency restored voltage. This factor is equal to the quotient of the instantaneous value of the normal frequency restored voltage at the time when the current would have reached zero if uninfluenced by the breaker, and the peak value of the nominal circuit voltage.

This factor may be split into 2 components: one is the ratio of the normal frequency restored voltage to the initial voltage; the other is a function of the asymmetry of the current. The following tabulation illustrates the effect of the asymmetry:

Ratio of Direct Component of Current to Peak Value of Alternating Component	Factor
0.00 (symmetrical current)	1.0
0.31	0.95
0.44	0.9
0.60	0.8
0.72	0.7
0.80	0.6
0.87	0.5
0.92	0.4
0.96	0.3

Only the very large degrees of asymmetry produce significant reductions in the rate of rise of recovery voltage. When the asymmetry is large and the natural period slow another correction for the change in the normal frequency voltage during the transient is necessary. Such a case is shown in figure 4.

Interpretation of Oscillograms

In a paper[1] presented before the A.I.E.E. during 1933, typical oscillograms were shown to illustrate the difference between good and poor circuit interruptions. Most of the tests had been made at 7,600 volts and about 10,000 amperes, but the points they illustrated are true for other currents and voltages. The oscillograms presented in the present paper illustrate additional phenomena occurring at low currents, an interruption by a breaker having a very high rate of deionization, the interruption of very large currents, and the effect of circuits of different natural frequencies.

The oscillograms presented here were made on a rotating-drum cathode-ray oscillograph which was described previously.[1] The oscillograph is connected to record the voltage across the terminals of a single pole of a circuit breaker interrupting single phase short circuits. The film which is 5 inches wide and 18 inches long is fastened to a rotating drum revolving at high speed and is exposed for a few cycles which include the time of interruption. As the drum has made several revolutions during this time, the beam has made several traces on the film. Since the phenomena at the time of arc extinction is the item of principal interest here, the oscillograms have been trimmed and only parts used in the illustrations. In both figures 4 and 6 the part is sufficiently large to show the entire period of interruption. Time varies linearly from left to right. The straight line through the middle of each oscillogram was traced while the contacts were still closed so that there was no voltage across the ter-

minals of the pole unit of the breaker. In both tests, the contacts separated at a time corresponding approximately with the left hand edges of the illustrations. The current wave went through zero in the first quarter, the circuit finally was opened at a point in the third quarter, and the recovery transient is shown at the right hand side. In figures 7 and 9 only the periods including the final current zero and the recovery transients are shown.

Interruption of a small current in a reactive high voltage circuit is shown in figure 4. The effective value of the symmetrical component at the time of interruption was 5.8 amperes and the normal frequency voltage 20 kv. However, the current was asymmetrical and was interrupted during the small half cycle which had a maximum of about 3 amperes. At this low current the arc in oil was unstable and, although the magnetic oscillogram did not indicate it, the current through the breaker after the contacts parted was intermittent, the time between impulses being less than 0.0001 second. This resulted in a succession of voltage peaks which took the place of the usual arc voltage as can be seen on the cathode ray oscillogram, figure 4.

For a better study of the conditions existing during this circuit interruption, 4 periods during which the current through the breaker was interrupted momentarily are shown in figure 5 with the low-amplitude high-frequency component of the recovery transient omitted. During these periods, the current flowing through the inductive part of the circuit caused the small capacitance across the breaker (the capacitance of the leads, bushings, etc., amounting to about 4.05×10^{-9} farad) to be charged to a voltage of 18 to 21 kv at which time the gaps between contacts broke down and again passed current. Final extinction occurred when the current no longer was large enough to charge the capacitance to a voltage higher than the dielectric strength of the gaps. The current i, taken by the resistance-coupled cathode-ray oscillograph was of importance in the low current interruption as it caused the rapid damping of the oscillation. The equation for the recovery transient between $t = 3.2 \times 10^{-4}$ and $t = 16 \times 10^{-4}$ second is

$$e = \epsilon^{-\frac{1}{2RC}t} \times A \sin \sqrt{\frac{1}{CL} - \frac{1}{(2RC)^2}}\,(t - 3.2 \times 10^{-4})$$

where

e = voltage of transient
R = 36,000 ohms
C = 4.05×10^{-9} farad
L = 9.1 henries
A = 97 kv
t = time in seconds

The resistance, 36,000 ohms, corresponds to the resistance of the potential dividers for the oscillograph. It reduces the frequency from 828 cycles to 627 cycles per second in addition to causing the rapid damping.

This typical oscillogram shows that the interruption of a low current is accomplished easily because the arcs are unstable in oil. After the contacts part a series of short discharges occur between contacts, until the voltages impressed across the gaps no longer rise above their dielectric strengths. The voltages across the gaps are a function of the current flowing in the circuit at the instant of arc extinction, the inductance and capacitance of the circuit, and time.

When a breaker is equipped with very effective arc rupturing devices and designed for high speed operation, the deionization activity may be so great that if the breaker is used on voltages lower than its rating very high overvoltages are produced. Figure

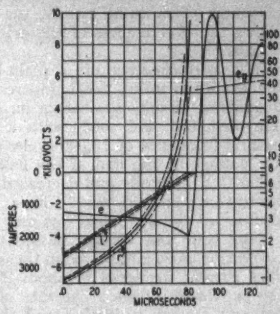

Fig. 8. Analysis of the oscillogram in figure 7

i—Current through circuit breaker
e—Recovery voltage transient
e_n—Normal frequency voltage
r—Effective resistance of arc space

6 shows a test on which an experimental 287 kv breaker designed for high speed operation interrupted a current of 20 amperes at 70 kv, single phase. During the half cycle of arcing the arc was unstable, the current intermittent, and voltages as high as 276 kv appeared 10 times. Higher voltages are not recorded on the film but a calculation of the peak value from the rate of rise and the time indicates that a voltage of 360 kv was reached. This is more than 3.5 times the peak of the normal frequency voltage. The test brings out an important point in circuit breaker design: It indicates that in striving for the rapid clearing of short circuits, care must be taken that excessive overvoltages are not produced. As has been pointed out by Slepian,[4] the formation of an arc in a circuit breaker prevents the current from being interrupted abruptly when the contacts part and permits the current to be reduced gradually to zero. However, if the interrupting means is so effective that the arc is not stable and the dielectric strength of the gap is increasing very rapidly, the arc cannot exist until the magnetic energy stored in the circuit is low and high overvoltages must be expected.

The interruption of a very heavy current is shown in figures 7 and 8. The first cycle symmetrical current was about 75,000 amperes at 7,600 volts. The current, i, approached zero at a rate of 31 amperes per microsecond. The magnitude of the current was so great that the current charging the capacitance and the current taken by the oscillograph were negligible. The rate at which the effective resistance (e/i) of the arc space increased is shown by the curve r. The exact instant at which the current reached zero is not determined easily, but fortunately the effect of an error in locating it makes no great differ-

ence in the results obtained. On either side of the current curve are dashed curves that correspond to current zeros occurring before and after the instant chosen, and the corresponding resistance curves are on either side of curve *r*. These curves demonstrate that a small error in locating the current zero does not change the general character of the calculated resistance curve. Because of the greater rapidity with which the current approaches zero at these high currents, the deionizing activity must be much greater than is necessary for good operation at lower currents. The rapid rise of the resistance curve shows the effectiveness of the deionizing grids used on this test.

The performances of a plain-break oil circuit breaker interrupting 2,400 amperes at 6,850 volts on 2 different circuits are shown on figures 9 and 10. The first test was made with a circuit having a natural frequency of 13,500 cycles per second. The arc voltage at the end of the half cycle was about 1,800 to 2,000 volts and decreased gradually as the current approached zero. Since the effective resistance of the arc space was only about 240 ohms at the time the voltage passed through zero, the current reversed and flowed in the opposite direction. This current increased to about 22 amperes before the gap broke down. The rate of dionization was not high enough to bring about the interruption of the arc at this contact separation on a circuit having a natural frequency of 13,500 cycles per second.

In contrast to this is the interruption during the second test of the same current and voltage at approximately the same contact separation on a circuit having a natural frequency of 5,250 cycles per second. In this test, as the current approached zero the arc voltage, which was lower than on the first test, increased causing the current through the breaker to be reduced by the amount of the charging current of the capacitance across the breaker terminals. This current was about 5 amperes and caused the arc current to reach zero earlier than it would have otherwise, and then caused the voltage across the breaker to increase for about 5 microseconds before the negative peak of the 5,250-cycle sine-wave recovery transient was reached. This relatively slow transient then permitted the dielectric strength of the gap to increase for about 100 microseconds before the maximum voltage was applied across it. From these tests it can be concluded that the lower frequency circuit aids the extinction in 2 ways: the larger capacitance diverts more current from the arc if the voltage starts to rise at the end of the half cycle, thereby making possible the interruption of the arc before the current normally would have reached zero; and the lower frequency causes the voltage to be applied less rapidly to the arc space. In these 2 tests, the difference was sufficient to make the arcs restrike on the 13,500 cycle circuit and extinguish on the 5,250 cycle circuit.

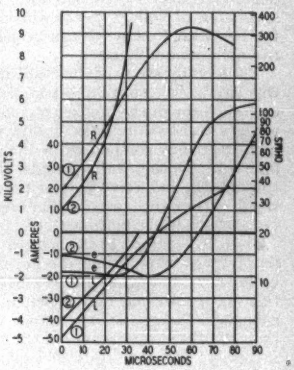

Fig. 10. Analysis of the oscillograms in figure 9

1—Natural frequency of circuit 13,500 cycles per second
2—Natural frequency of circuit 5,250 cycles per second
i—Current through circuit breaker
e—Recovery voltage transient
R—Effective resistance of arc space

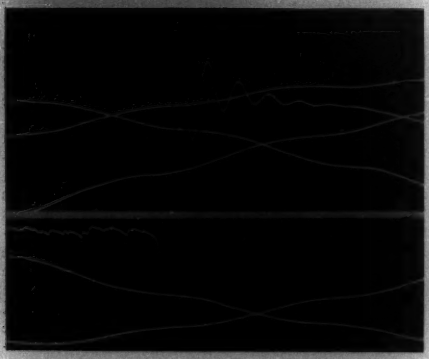

Fig. 9. Oscillograms of interruptions of single-phase 6,850-volt 2,400-ampere circuits having natural frequencies of (left) 13,500 and (below) 5,250 cycles per sec

References

1. Arc Extinction Phenomena in High Voltage Breakers Studied With a Cathode Ray Oscillograph, Van Sickle and Berkey. A.I.E.E. Trans., v. 52, 1933, p. 850–60.

2. Circuit Breaker Recovery Voltages, Park and Skeats. A.I.E.E. Trans., v. 50, 1931, p. 219.

$$\frac{1}{2\pi}\sqrt{\frac{(3C_1 + C_2) + \sqrt{9C_1^2 - 2C_1C_2 + C_2^2}}{2L_1C_1C_2}}$$

$$\frac{1}{2\pi}\sqrt{\frac{(3C_1 + C_2 - \sqrt{9C_1^2 - 2C_1C_2 + C_2^2}}{2L_1C_1C_2}}$$

3. Conference Internationale des Grands Reseaux Electriques A Haute Tension June 1933, Report 31—Report of the committee on high voltage breakers, E. Juillard.

$$f_{01} = \frac{1}{2\pi\sqrt{(L_1 + L_2)\,C_2 + L_1\,C_1}}$$

$$f_{02} = \frac{1}{2\pi}\sqrt{\frac{(L_1 + L_2)\,C_2 + L_1\,C_1}{L_1\,C_1\,L_2\,C_2}}$$

4. Discussion by J. Slepian. A.I.E.E. Trans., v. 49, 1930, p. 445.

Stability of the General 2-Machine System

The transient tability of the general 2-machine system is considered in this paper. Introduction of an equivalent system with concentrated inertia at one end is shown to facilitate the direct application of the equal area method of analysis to the general 2-machine system. Heretofore the equal area method has been confined to certain special 2-machine systems.

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CONCLUSIONS regarding transient stability of 2-machine systems are frequently based upon the first swing-apart of the machines. This involves the assumption that if the machines once come to rest with respect to each other the system will survive the shock caused by the disturbance in question, and gives rise to the "equal area" criterion of stability. (See, for instance, references 1 to 4, and other papers.) Although the general mathematical formulation of the latter has been established (see reference 2, eq 5, followed by a formula involving its application to a general 2-machine system when the clearing of the fault is either instantaneous or long-delayed), its practical application as a simple and actually visualizable criterion has so far been confined to such 2-machine systems as those where:

(1) One end of the system definitely is an infinite bus; or,

(2) With retention of the actual machine inputs and the actual circuit, the inertia can be concentrated at one end so that an infinite bus is obtained at the other.

Concentration of the inertia at one end of the system under the conditions imposed in point 2 above requires that (*a*) the network connecting (and including) the machines contains reactance only; and (*b*) one machine operates as a generator and the other as a motor. [Evidently (*b*) is a consequence of (*a*).]

It is the purpose of this paper to call attention to the fact that also the general 2-machine system may be represented by an equivalent system with the inertia concentrated in an equivalent machine at one end of an equivalent circuit, and with an infinite bus at the other. The input to the equivalent machine will differ from that of either machine and is a function of the actual inputs and the inertia constants. Similarly, the equivalent circuit (including the equivalent machine) and the corresponding equivalent power-angle curve depend upon the actual circuit and the inertia constants of the machines.

The equivalent system may be used for complete point-by-point analyses of relative motion equally as well as the actual general 2-machine system which it represents. Moreover it lends itself to solutions by the equal area method and hence makes the direct application of this stability criterion practical also to problems involving general 2-machine systems. The equivalent system, on the other hand, is not applicable to the determination of the absolute accelerations and speeds of the machines.

The General 2-Machine System

The general 2-machine system involves 2 synchronous machines connected by a dissipative network which may or may not contain static loads (or their equivalent). It represents an important case and, quite frequently, practical transient-stability analyses are based upon this layout. It may be identical to the system actually at hand but is more often the result of a simplification of the actual system.

The stability of such a system (for instance, the one in Fig. 1), when its equilibrium is upset by a disturbance, may in general be examined by inspecting the swing curves of the machines. Such swing curves are obtained by solving the differential equation (see Appendix for the meaning of symbols)

$$M\frac{d^2\delta}{dt^2} = P_i - P = \Delta P \tag{1}$$

for each machine by means of a point-by-point process. Either the angle of each machine with respect to some standard reference line or else the angle between the machines (the difference between the separate angles) may be plotted versus time. The former indicate the actual movement of each machine, the latter their relative movement, which of course is of principal interest from the standpoint of stability. Swing curves for a general 2-machine system are illustrated in Fig. 3.

The primary thing during a point-by-point analysis is the determination of the output at each point as the calculations progress. Neglecting damping and assuming that the entire circuit, including the machines, is linear, i. e., the saturation in the machines is neglected, the output may be determined

(1) by direct calculation; or

(2) from power-angle curves; or

(3) from circle diagrams.

The outputs of the machines are given by

$$P_1 = \frac{E_1^2}{Z_{11}}\cos\theta_{11} - \frac{E_1E_2}{Z_{12}}\cos(\delta + \theta_{12}) \tag{2}$$

and

$$P_2 = \frac{E_2^2}{Z_{22}}\cos\theta_{22} - \frac{E_1E_2}{Z_{12}}\cos(\delta - \theta_{12}) \tag{3}$$

Full text of a paper recommended for publication by the A.I.E.E. committee on power transmission and distribution. Manuscript submitted Oct. 26, 1933; released for publication April 9, 1934. *Not published in pamphlet form.*

1. For all numbered references see list at end of paper.

(The 2 equations just given apply to non-salient-pole machines, and may be found in several places in the literature, for instance, see reference 2.)

Three sets of these equations must in general be available: (*a*) for operation with the system intact; (*b*) for operation with the system faulted; and (*c*) for operation with the faulty section cleared. (If the faulty section is cleared by sequential switching part (*c*) may require 2 sets of equations. In systems with reactance compensation by series capacitors additional sets may also be necessary.) Discontinuities in the outputs occur when the fault comes on and when it is cleared. The initial operating angle is obtained from the first set. Using this angle in the second set gives the outputs immediately after the occurrence of the fault. These outputs in connection with the inputs to the machines fix the initial power differentials, assumed constant during the first interval. (Modification in regard to this assumption is evidently possible and depends, in general, on the accuracy desired.) The outputs for successive intervals are obtained from the same set of equations by substituting the proper system angles. When the time elapsed equals the clearing time, the third set of equations supersedes the second. The outputs immediately following the clearing of the fault are determined by using the "clearing angle," i. e., the system angle at the instant of clearing, in these equations.

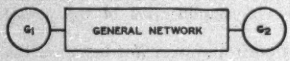

Fig. 1. General 2-machine system

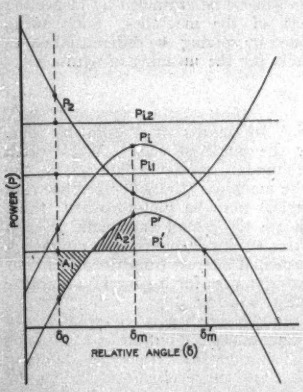

Fig. 2. Actual and equivalent power - angle curves and input lines for a general 2-machine system

The maximum angle δ_m is reached when the areas A_1 and A_2 are equal

Representation of Performance of the General 2-Machine System by a Single Equivalent Power-Angle Curve

As previously stated, it has been shown that in the special case of 2-machine systems where one machine operates as a generator and the other as a motor and the circuit contains reactance only, it was permissible to concentrate an equivalent mass at one end of the system and consider the other as an infinite bus. (See references 1 and 2, and other papers.) The circuit itself was to be retained as in the actual layout and the input to the equivalent machine was to be the same as the input to the actual machine.

A somewhat similar procedure is possible also with the general 2-machine system. It is possible also here to locate a machine with an equivalent mass at one end, and to consider the other end as an infinite bus and hence enable the solution to be based upon a single power-angle curve. In the general case, however—and this distinction should be carefully noted—it is necessary (1) to modify the circuit so as to obtain an equivalent power-angle curve, and (2) to use an equivalent input to the machine.

The relative acceleration of the 2 machines is given by

$$\frac{d^2\delta}{dt^2} = \frac{\Delta P_1}{M_1} - \frac{\Delta P_2}{M_2} = \frac{P_{i1} - P_1}{M_1} - \frac{P_{i2} - P_2}{M_2} \tag{4}$$

which for the purpose of getting an equation of standard form (corresponding to eq 1) may be written

$$\frac{M_1M_2}{M_1 + M_2}\frac{d^2\delta}{dt^2} = \frac{M_2\Delta P_1 - M_1\Delta P_2}{M_1 + M_2} = \frac{M_2P_{i1} - M_1P_{i2}}{M_1 + M_2} - \frac{M_2P_1 - M_1P_2}{M_1 + M_2} = P'_i - P' \tag{5}$$

or, more simply, as

$$M_0\frac{d^2\delta}{dt^2} = P'_i - P' = \Delta P' \tag{6}$$

Here the equivalent input P'_i is given by

$$P'_i = \frac{M_2P_{i1} - M_1P_{i2}}{M_1 + M_2} \tag{7}$$

and the equivalent output P' by

$$P' = \frac{M_2P_1 - M_1P_2}{M_1 + M_2} \tag{8}$$

while the equivalent inertia constant M_0, as in the simpler case, is obtained by "paralleling" the actual inertia constants of the 2 machines, and is hence given by

$$M_0 = \frac{M_1M_2}{M_1 + M_2} \tag{9}$$

Equation 6 is, as seen, of exactly the same form as that for a machine connected to an infinite bus through a circuit of arbitrary constants. The stability of the general 2-machine system may be correctly examined by the solution of this equation by point-by-point or other methods. Hence the general 2-machine case at hand has been reduced to that of an equivalent generator supplying power over an equivalent circuit to an infinite bus. The input to the equivalent machine is a function of the inputs to the actual machines and the inertia constants, while the output of the equivalent machine similarly depends upon the outputs of the actual machines and the inertia constants.

From the standpoint of relative motion, this representation, as well as eq 6 based upon it, is exact in every respect (subject, of course, to the usual limitation resulting from the assumption of constant actual speed of rotation, i. e., constant relationship between torque and power). The inputs may be constant or variable, and the outputs may or may not include the effect of damping. Its use in stability solutions based upon simplified criteria, however, is practical only when the inputs are constant and the damping neglected. Under these conditions the equivalent input is fixed and the output is a function of the internal voltages of the machines and the displacement angle between them (i. e., the displacement angle between the equivalent machine and the infinite bus).

Introducing the expressions for the outputs from eqs 2 and 3 and collecting constant and variable terms, eq 6 becomes

$$M_0 \frac{d^2\delta}{dt^2} = P'_i - \frac{M_2 \frac{E^2_1}{Z_{11}} \cos \theta_{11} - M \frac{E^2_2}{Z_{22}} \cos \theta_{22}}{M_1 + M_2} + \frac{E_1 E_2}{(M_1 + M_2) Z_{12}} [M_2 \cos (\delta + \theta_{12}) - M_1 \cos (\delta - \theta_{12})] \quad (10)$$

By combining the trigonometric functions, this equation again reduces to

$$M_0 \frac{d^2\delta}{dt^2} = P'_i - P' = P'_i - [P'_e - P'_m \cos (\delta + \psi)] \quad (11)$$

Here the displacement term, the amplitude, and the phase angle of the equivalent sinusoidal power-angle curve are given by

$$P'_e = \frac{M_2 \frac{E^2_1}{Z_{11}} \cos \theta_{11} - M_1 \frac{E^2_2}{Z_{22}} \cos \theta_{22}}{M_1 + M_2} \quad (12)$$

$$P'_m = \frac{E_1 E_2}{(M_1 + M_2) Z_{12}} \sqrt{M^2_1 + M^2_2 - 2 M_1 M_2 \cos 2\theta_{12}} \quad (13)$$

and

$$\psi = \tan^{-1} \left(\frac{M_1 + M_2}{M_2 - M_1} \tan \theta_{12} \right) \quad (14)$$

In Fig. 2 are shown actual and equivalent power-angle curves and input lines for a representative general 2-machine system.

Simplified Stability Criterion Applied to the General 2-Machine System

This criterion assumes that if the machines come to rest with respect to each other during their first swing apart, the system is stable. The mathematical formulation (see reference 2), of this criterion is

$$\int_{\delta_0}^{\delta_m} \left(\frac{\Delta P_1}{M_1} - \frac{\Delta P_2}{M_2} \right) d\delta = \int_{\delta_0}^{\delta_m} \frac{\Delta P'}{M_0} d\delta = 0 \quad (15)$$

In this equation the power differentials ΔP_1 and ΔP_2 may be represented by functions with any arbitrary number of discontinuities. Hence the criterion inherently provides for the inclusion of switching, fault clearing, etc. As a matter of fact, its validity definitely depends upon all operations causing discontinuities taking place before the maximum angle is reached. (If this is not the case, however, it is possible to extend the interpretation of the criterion. Not only must the machines come to rest with respect to each other during their first swing apart, but also during subsequent swings together or apart until all discontinuities are included. Not until then may actual conclusions be drawn in regard to the stability situation.) If stability is to be present it is evident that the acceleration (or retardation, as

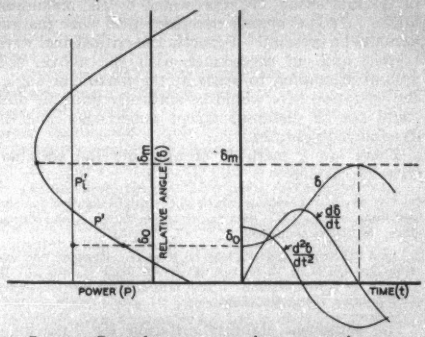

Fig. 3. Equivalent power-angle curve and time curves of relative angle, slip, and acceleration for a general 2-machine system with loading below the critical

the case may be) of the machines with respect to each other must change sign during the first swing apart. In other words, the term $(\Delta P_1/M_1 - \Delta P_2/M_2) = \Delta P'/M_0$ must change sign. If it does not, it is evident that the integral in eq 15 can never be zero, the machines will continuously swing apart, and stability is definitely lost.

Assuming that the acceleration changes sign, and also that the condition given by eq 15 is satisfied so that the system is stable, there are 2 possibilities in regard to the value of the acceleration $(\Delta P_1/M_1 - \Delta P_2/M_2)$ at maximum angle, namely:

(1) The acceleration may have a finite value.

(2) The acceleration may be zero, as indicated by

$$\left(\frac{\Delta P_1}{M_1} - \frac{\Delta P_2}{M_2} \right) = \frac{\Delta P'}{M_0} = 0 \quad (16)$$

or simply

$$\Delta P' = 0 \quad (17)$$

indicating that the equivalent power differential is zero.

In case 1, above, the system is stable with a margin, i. e., the loading is below the critical. Case 2 represents the limiting case. The loading is critical and equal to the transient power limit of the system for the disturbance in question.

Equivalent power-angle curves as well as time curves of angle, rate at which the machines swing apart (relative slip), and acceleration are plotted for the 2 cases in Figs. 3 and 4, respectively. Either

case indicates stability. In the former the machines come to rest with respect to each other while the acceleration still is negative. This would cause the machines to swing together again and oscillate with respect to each other before finally merging into new steady-state conditions. In the second case, where the load is critical, the machines come to rest with respect to each other and the acceleration becomes zero simultaneously. The system is aperiodic and the new steady-state conditions, reached at the end of the first swing, are represented by the maximum angle. (It is evidently necessary that some margin actually be present. If exactly the critical load were carried and, in accordance with the above, the system attempted to settle at the maximum angle, the operation here would be statically unstable and could not be sustained except under conditions of dynamic equilibrium.)

There are 2 methods of applying the stability criterion, namely:

(1) Use eq 15 and examine whether it yields a solution for the maximum angle δ_m. If it does, the system is stable; if no solution exists, the system is unstable.

(2) Find the critical angle δ'_m from eq 16 or 17. Evaluate and examine the sign of eq 15 for this maximum angle ($\delta_m = \delta'_m$) If negative, the system is stable; if zero, critical load conditions exist; and if positive, the system is unstable.

The simplified stability criterion for 2-machine systems expressed by eq 15 may be translated into an "equal area" conception. Evidently

$$\int_{\delta_0}^{\delta_m} \Delta P d\delta = \int_{\delta_0}^{\delta_m} (P_i - P) d\delta \tag{18}$$

represents an area, namely, the area between input and output curves, plotted versus angle, and bounded by the initial and maximum angle. Hence eq 15 may be modified to

$$\frac{1}{M_1}\begin{pmatrix}\text{net area (1)}\\ \text{between } \delta_0 \text{ and } \delta_m\end{pmatrix} = \frac{1}{M_2}\begin{pmatrix}\text{net area (2)}\\ \text{between } \delta_0 \text{ and } \delta_m\end{pmatrix} \tag{19}$$

The system is stable when the two areas thus defined and divided by their respective inertia constants are equal. Making use of it in this form represents the so-called equal-area method.

To apply this equal-area criterion of stability directly on the power-angle curves, however, is not practical when separate power-angle curves are used because the optimum angle to which the system may be permitted to swing is not inherently defined geometrically by the power-angle curves and the input lines (see Fig. 2). With separate power-angle curves the graphical determination of optimum angle requires an auxiliary plot of relative acceleration ($\Delta P_1/M_1 - \Delta P_2/M_2$) versus angle. Explicit use of the equal-area method, therefore, as a criterion of stability in the 2-machine system is especially convenient and practical when the inertia is concentrated at one end so that an infinite bus is obtained at the other, i. e., when the equivalent system previously described is utilized.

With respect to the equivalent power-angle curve, the equal-area method is directly applicable as such. The optimum angle is here fixed by the intersection of the equivalent power-angle curve and the equivalent input line. Referring to Fig. 4, stability requires that the area A_1 be smaller than or—at the limit—equal to the area A_2.

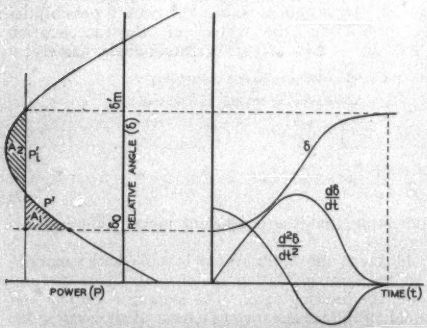

Fig. 4. Equivalent power-angle curve and time curves of relative angle, slip, and acceleration for a general 2-machine system for critical load conditions

Stability requires that the area A_1 be smaller than or—at the limit—equal to the area A_2

Appendix

LIST OF SYMBOLS

E_1 = internal voltage of machine 1 (voltage behind transient reactance)
E_2 = internal voltage of machine 2 (voltage behind transient reactance)
M_1 = inertia constant of machine 1
M_2 = inertia constant of machine 2
M_0 = inertia constant of equivalent machine
P_1 = output of machine 1
P_2 = output of machine 2
P_{i1} = shaft input to machine 1
P_{i2} = shaft input to machine 2
P' = output of equivalent machine
P'_i = shaft input to equivalent machine
P'_s = displacement of the equivalent sinusoidal power-angle curve
P'_M = amplitude of the equivalent sinusoidal power-angle curve
ΔP = power differential (difference between input and output)
$\Delta P'$ = power differential of equivalent machine
Z_{11} = driving-point impedance at machine 1
Z_{22} = driving-point impedance at machine 2
$Z_{12} = Z_{21}$ = transfer impedance between machines
t = time
θ_{11} = angle of driving-point impedance Z_{11}
θ_{22} = angle of driving-point impedance Z_{22}
$\theta_{12} = \theta_{21}$ = angle of transfer impedance Z_{12} or Z_{21}
δ = displacement angle between machines
δ_0 = initial displacement angle between machines
δ_m = maximum displacement angle between machines under stable conditions
ψ = phase angle of equivalent power-angle curve
K = (with appropriate subscripts) a constant
A = (with appropriate subscripts) an area

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Fault and Out-of-Step Protection of Lines

The stability characteristics of a typical high voltage transmission circuit have been considered together with the requirements for short-circuit protection, as a basis for the selection and application of relay protective devices. In this paper, the performance of the 132 kv New York Edison-Niagara Hudson interconnection under fault and swing conditions is analyzed, the characteristics of various protective devices are discussed, and the performance of the selected equipment under both calculated and actual operating conditions is given. A protective scheme involving carrier current control is shown to be highly satisfactory.

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THE rapid expansion during recent years of large capacity high voltage interconnections and the operating experience attendant thereto, have resulted in the promotion of intensive studies along many fronts to improve the operating efficiency and reliability of these interconnections, particularly those studies which have been concerned with the protective features. As a consequence, a tremendous impetus has been given to the development of circuit breakers and relays. In addition there is perhaps a more general appreciation that the power limits of important tie lines under transient and steady state conditions are factors which warrant careful consideration in advance of actual construction commitments.

It is well known, of course, that protective relay equipment was developed primarily and used almost exclusively for protection against faults. To be sure, qualifications have been added from time to time as the requirements became more fully evident and the means of their realization better understood, and these factors have led to the development of many important improvements in such devices both in regard to their reliability and capabilities. While fault clearing with all the modifying requirements now recognized as essential, such as selectivity, reliability, high operating speeds, etc., is highly effective, there is still another important factor which has been given but little publicity. This has to do with relay performance during system oscillations or power swings. This paper is intended to focus attention on this point.

When the 132 kv interconnection of the New York Edison-Niagara Hudson systems was projected it was realized that the exacting requirements which were established required careful consideration of all factors which concerned the service reliability of this important link between 2 large systems. In so far as the authors of this paper are aware it is believed that this is the first instance in which the stability characteristics have been coördinated with requirements for fault protection in designing the relay protective equipment. It is thought, therefore, that a discussion and exposition of the studies which were made in this instance may serve to establish a new approach for the protection of similar important lines and also encourage the development of further refinements and improvement in this branch of electrical engineering as a further step toward broadening the scope of its usefulness.

In presenting this paper it is the intent of the authors to outline the major requirements, to present the results of the short-circuit and stability studies and illustrate how both influenced the choice of the protective equipment selected, and finally to present a summary of actual operating experience. Following are the conclusions drawn as a result of the study presented in this paper:

Conclusions

The proper choice of protective equipment is primarily predicated on an accurate knowledge of the performance of the protected circuit during fault conditions and of the related behavior of the protective devices. For important tie lines, an analysis of line performance during power swings and out-of-step conditions is fully as important as the performance during faults, if the most successful application of protective devices is to be realized. It is, of course, equally important to have a knowledge of the performance of the protective devices under the same conditions for a proper choice of equipment.

With all facts available and by the use of suitable high speed protective equipment it should be possible not only to protect against all types of line faults but also to maintain the line in operation during power swings within its stable power limits and to separate 2 systems at a preferred and predetermined location when out-of-step conditions develop.

Under favorable conditions it may be possible to provide satisfactory protection against faults and also to secure suitable control of swing and out-of-

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step conditions by the same set of relays. Where this cannot be realized a separate relay should be provided expressly for out-of-step protection.

The carrier current system for control of protective relays has demonstrated its superiority to other schemes thus far developed for protection of high voltage, open wire tie lines, and represents the nearest practicable approach to pilot wire or current comparison methods. There is still room, however, for considerable improvement, notably in reduction of the operating time, more positive control of out-of-step protection, adaptation to cable circuits, reduction in first cost, and simplification of testing.

Major Connections

The principal circuits of the Eastern division of the Niagara Hudson system in the State of New York and the twin circuit tie line between the Pleasant Valley substation of this system and Hell Gate generating station of The New York Edison system are shown in figure 1. A major portion of the Niagara Hudson transmission system is operated at 110 kv but this voltage is stepped up to 132 kv at the

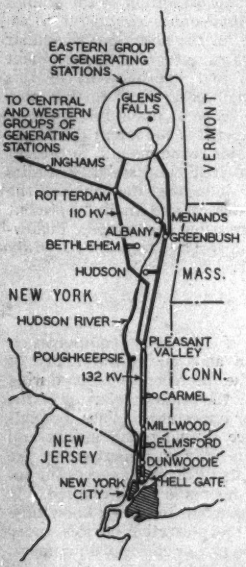

Fig. 1. Principal 110 kv and 132 kv circuits of the New York Edison-Niagara Hudson systems

The 132 kv interconnection is indicated by the heavy lines below Pleasant Valley substation

Pleasant Valley substation for the interconnection with The New York Edison system. This transformation is effected by means of 2 banks of autotransformers each rated at 100,000 kva, 110/132/13.2 kv, the 13.2 kv tertiary windings being used for the supply of 2 30,000 kva synchronous condensers.

The 2 132 kv overhead circuits pass through the territory of the Westchester County Lighting Company and the Yonkers Electric Light and Power Company, stepping down to 13.8 kv at Millwood, Elmsford, and Dunwoodie substations to serve local loads at these points. At Dunwoodie, connection is made to 2 132 kv underground cable circuits which complete the interconnection to the Hell Gate generating station of The New York Edison system, where each cable circuit is stepped down to the 13.8 kv generating bus potential through a 100,000 kva bank of transformers. The system neutral is solidly grounded at Pleasant Valley, Dunwoodie, and Hell Gate.

The interconnection between Pleasant Valley and Hell Gate and the connections to Westchester County substations are indicated in figure 2. The Carmel substation was added subsequent to the completion of the studies discussed in the paper and its effect in acting as a source of fault current is not included. The limited current available from this source may however, be neglected.

Major Requirements

As the 2 132 kv lines constitute the principal source of supply to Westchester County with a total peak load in the order of 75,000 kw served from 18 substations it was especially important that all reasonable steps be taken to insure the continuity of service to this area for all contingencies which could be anticipated as well as to preserve the reliability of the interconnection for power interchange purposes.

The following requirements therefore were established for the relay protective features to serve as a criterion of their effectiveness in maintaining the desired degree of service dependability.

1. All faults must be cleared in the minimum practicable time in order to maintain a high level of transient stability, and to minimize the probability of faults on one circuit communicating to the other.

2. The protective equipment must be adaptable to single circuit or parallel circuit operation as operating conditions might require.

3. In the event of unavoidable loss of synchronism or an out-of-step condition, the point of separation should be restricted to the Millwood-Pleasant Valley section. If the separation should occur between Dunwoodie and Millwood, for example, it would leave the New York Edison-Niagara Hudson systems tied through the 13.8 kv network of the Westchester system which would be inadequate to hold the 2 systems in step. The result of such a contingency would undoubtedly result in tripping a large number of 13.8 kv circuits with attendant service interruptions to an important load area.

4. The substation equipment must be suitably protected against faults with the minimum number of high voltage circuit breakers.

5. In addition to the foregoing, the usual requirements for selectivity and back-up protection to the first line of defense were included in accordance with generally recognized standards for the protection of any circuit of major importance.

Short-Circuit Analysis

As the technique of fault calculations for both balanced and unbalanced conditions is well understood, no details are given here, but the results have an important bearing in 2 respects on the selection of the protective equipment which is responsive to these characteristics:

1. The magnitude of the fault currents and their variation with location and operating conditions.

2. The value of currents which flow during faults relative to those which flow during swing and out-of-step conditions.

Figures 3 and 4 show respectively the 3-phase and single-conductor-to-ground faults for average operating conditions. Similar data were calculated for 2-conductor-to-ground faults. The effect of "bussed" and separate or "unbussed" operation of the 2 circuits at Dunwoodie and Millwood were also investigated and the results plotted in a similar manner.

In connection with the first item it is interesting to note in referring to figure 3 that 2 conditions frequently encountered in relaying are both present. First, in the section between Hell Gate and Dunwoodie there is a comparatively small variation in fault current (2,000 to 2,200 amperes, curve I_H) as the fault point progresses along the circuit between these 2 stations. This practically eliminates any advantageous use of instantaneous overcurrent relays to differentiate between faults near Hell Gate and those at Dunwoodie. Second, in the section between Millwood and Pleasant Valley there is a large variation in current (curve I_L, figure 3) which could be utilized to good advantage in obtaining selectivity between overcurrent or directional overcurrent relays.

Stability calculations for loads just under the transient power limit clearly illustrate the importance of the second item, since they indicate that the line current may attain a value of 1,500 amperes, or twice the minimum 3-phase short-circuit current of 750 amperes shown in figure 3 (current I_L from Pleasant Valley for a fault near Millwood). This will be referred to later in its effect on the selection of relay equipment.

The unbalanced fault analysis data of figure 4 also were used to advantage in a parallel study of the inductive coupling between the transmission lines and communication circuits. After completion of the lines, tests were made as a check on the calculated quantities, and the results were found to be in close agreement.

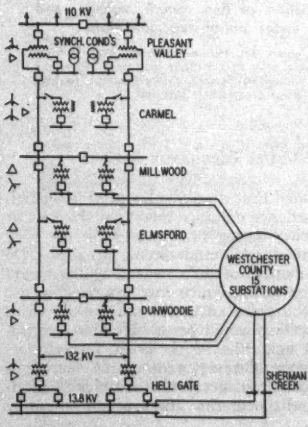

Fig. 2. Single line diagram of 132 kv circuits and the paralleling low voltage ties

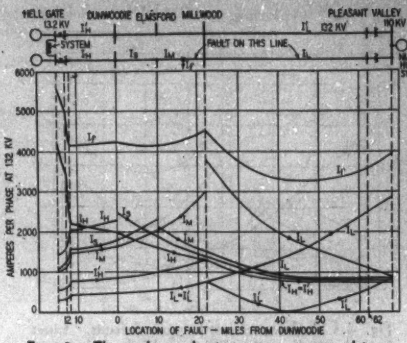

Fig. 3. Three-phase short-circuit currents. Lines "bussed" at Millwood and Pleasant Valley substations

Stability Analysis

The fault clearing time was established by a preliminary study based upon the short-circuit analysis, the use of 8-cycle circuit breakers, and conventional types of high speed relays available at the time. The characteristics of high speed distance relays and balanced current, phase, and ground relays were used for this purpose. These data were used throughout the stability studies, although the time required to clear the first circuit breaker was slightly less and the last circuit breaker somewhat greater than that attainable with the protective equipment finally adopted.

The power limits of the line were calculated for both the steady state and transient conditions and also with the circuits bussed and not bussed at Dunwoodie and Millwood. Substation loads were not taken into account in these calculations.

The calculated transient power limit with a 3 phase fault near Millwood for example, was found to be increased from 122,000 kw with separate or unbussed operation to 166,000 kw with the circuits bussed at all substations, an increase of 36 per cent. From the stability standpoint, therefore, this study definitely removed the question of the advisability of "bussing" the circuits from the realm of conjecture to the secure basis of a demonstrable fact.

With 166,000 kw established as the approximate power limit, the calculations were extended to indicate the performance at loads just over the stable limit, and also at 200,000 kw the latter figure being taken as the maximum power that might be transmitted under emergency conditions.

The quantities which were of greatest importance in the relay studies were the magnitude of the current and voltage, and their angular relation at various locations during stable swings and out-of-step conditions, and the variation of these quantities with respect to time. As indicated by item 3 of the requirements previously mentioned, it was considered essential to limit the separation of the 2 systems to the Millwood-Pleasant Valley section during out-

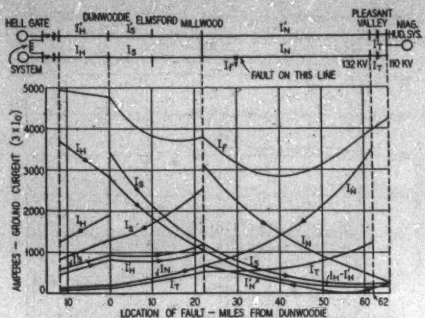

Fig. 4. Single-conductor-to-ground faults. Lines bussed at Millwood and Pleasant Valley substations

of-step conditions. The data obtained from these stability studies were invaluable for this purpose. This is convincingly demonstrated by the curves shown in figure 5.

In this case the 2 circuits were assumed to be bussed at Dunwoodie, Millwood, and Pleasant Valley, with a 3 phase fault imposed on one circuit near Millwood and a load just over the stable power limit, flowing from Pleasant Valley to Hell Gate, being carried just prior to the fault. All of the factors which affect the performance of relays are shown together with their variation with time. With data of this nature available, in conjunction with the short-circuit studies, it remained only to select or specify relay equipment which would meet specific requirements. It will be appreciated that this at once established the selection of the relays on a factual basis in which the boundaries were clearly indicated.

It was also important to determine the allowable maximum time for clearing faults from the low voltage substation busses without lowering the transient power limits of the line below those prevailing for high voltage faults. Study of this point disclosed that the most severe limitation occurred at Millwood substation. As might be expected it was found that low voltage bus faults afforded considerable latitude in fault clearing time. It was estimated that over 200,000 kw could be carried on the high voltage line for a length of time well in excess of that which would ordinarily be required for clearing such faults.

Selection of Relay Equipment

It was evident at the outset that the usual type of overcurrent relays operative on line current could not be used for 3 reasons, as follows:

1. The minimum fault current on 3-phase 2-conductor and 2-conductor-to-ground faults was in some instances less than the swing current obtainable within the maximum stable power limit, as pointed out previously.

2. Because of the small variation in fault current on some sections of the line, selectivity could be maintained only at the expense of time, but this would materially lower the maximum power limits.

3. The point of separating the 2 systems under out-of-step conditions could not be controlled.

It was realized of course that balanced current protection could be used for ground fault protection and also for phase to phase protection, since relays connected in this manner are not affected by balanced power swings. Suitable relays were available which would satisfactorily meet the operating speed requirements for maintaining the desired level of power. This form of protection, however, could not be used when one circuit of a pair was out of service, and its applicability, therefore, would be dependent upon the availability of suitable protection for single circuit operation.

The choice for single circuit protection naturally turned to distance relays of the impedance or reactance type. It was in order, therefore, to determine their performance under 3 major conditions, as follows:

1. The performance during arcing faults.

2. The performance during power swings within stable power limits.

3. The performance during power swings in excess of stable power limits.

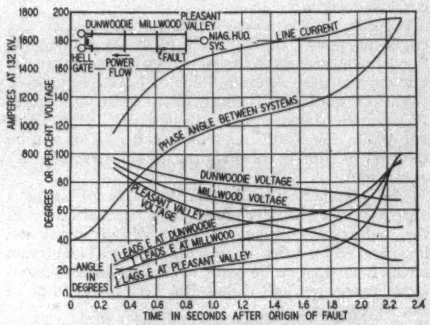

Fig. 5. Variation of line current, voltage, and angle under out-of-step conditions

Power slightly above the transient stability limit flowing toward Hell Gate prior to a 3-phase fault near Millwood on one of the Millwood-Pleasant Valley circuits. Faulted circuit cleared in 0.3 second

Possibility of Using Impedance Relays

It was concluded that no difficulty need be anticipated with impedance distance relays on the first or third steps during arcing faults since on the first step the combined relay and circuit breaker time would be in the order of 0.20 second, which would not be sufficient to introduce any appreciable arc impedance at the point of fault, and on the third step the ohm setting would be so high that arc impedance would again be of no great importance. On the second step, however, with a fault clearing of 0.50 second it was considered that even with moderately high wind speeds that there would be ample

Table I—Calculated Performance of Starting Unit of Type GAX Directional Reactance Relay During Out-of-Step Power Swings

Time After Fault Occurs	Relay at Millwood on the Line to Pleasant Valley: *Relay Current, Amperes	**Relay Voltage, Volts	Angle by Which Line Current Lags Line to Neutral Voltage, Degrees	Will Starting Unit Operate?	Relay at Dunwoodie on the Millwood Line: *Relay Current Amperes	**Relay Voltage Volts	Angle by Which Line Current Lags Line to Neutral Voltage, Degrees	Will Starting Unit Operate?
One Circuit Between Millwood and Pleasant Valley								
0.5	17.4	98	24	Yes	8.7	100	32	No
1.0	21.6	75	38	Yes	10.8	88	48	No
One Circuit Between Millwood and Dunwoodie								
0.3	6.7	103	17	No	13.4	108	23	No
0.4				No	15.6	103	27	Yes
0.5	8.7	98	24	No	17.4	100	32	Yes
0.9	10.6	77	36	Yes				
1.0	10.8	75	38	Yes	21.6	88	48	Yes

* Current transformer ratio—120/1. ** Potential transformer ratio—1200/1.

time for a single-line-to-ground fault to involve other conductors or possibly communicate with the other circuit. With conductor spacings of 15 feet and a 30 mile per hour wind it would require but $^1/_3$ second for an arc to travel the required distance. This factor, and also the influence of arc resistance in shifting the balance point of the relay, led to the conclusion that the reactance type distance relay was fundamentally better suited to clearing faults on the second step. It is interesting to note that subsequent to the time at which these studies were made, relays have been developed which are provided with impedance characteristics on the first and third steps and reactance characteristics on the second step.

The most serious objection, however, to the use of impedance relays was the tendency to operate at undesirable points during heavy power swings or out-of-step conditions. As the angle between the

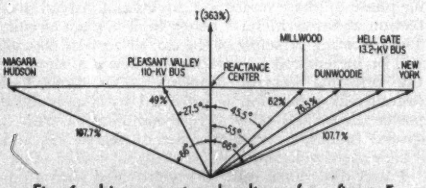

Fig. 6. Line current and voltages from figure 5 shown vectorially 1.5 seconds after origin of fault

100 per cent voltage = 132 kv
100 per cent current = 437 amperes

voltages of 2 generating systems increases, the voltage of all points along an interconnecting circuit gradually diminishes and at one point becomes zero when the 2 systems are 180 degrees out of phase. Where the interconnecting circuit is reactive and the terminal voltages are equal, the point of zero voltage will fall at a point midway between the 2 systems, i. e., at the reactance center of the system. It will be readily understood, therefore, that impedance relays which measure the ratio between line current and voltage, and which are located near the reactance center of the system, will receive low voltage and high current and may be expected to trip when the 2 systems are 180 degrees out of phase.

When one circuit between Hell Gate and Dunwoodie is out of service the reactance center of the interconnection falls south of Millwood. Tripping of the Dunwoodie-Millwood section therefore would probably occur during out-of-step swings if protected by impedance relays.

Possibility of Using Reactance Relays

Attention was next directed to the operating characteristics of reactance relays, which were considered fairly satisfactory for clearing phase faults, when connected for delta current and voltage, although as with impedance relays, open to the objection that only 80 per cent of the line at the best can be cleared on the first, or minimum time, step.

Little was known, however, in regard to their performance during swing and out-of-step conditions. A study of these relays developed that they were also quite susceptible to incorrect operation during heavy swings and during out-of-step conditions and tripping at more than one point could be anticipated. This is shown by the following analysis which was made of the type *GAX* reactance relay for this application. Reference may be made again in figure 5 showing the line current and phase angle between the 2 systems, the Millwood, Pleasant Valley, and Dunwoodie voltages and their angular positions, following a fault at Millwood on one of the Pleasant Valley lines.

In figure 6, the various quantities are shown vectorially, 1.5 seconds after the occurrence of the fault. With power flowing from Pleasant Valley to Hell Gate, the Pleasant Valley voltage leads and the Millwood and Dunwoodie voltages lag the current. For this reason, the directional starting unit of the Pleasant Valley relay is the only one that can trip, as may be deduced from figure 7, showing the pick-up characteristics of the starting element of the type *GAX* relay. As the reactance center in this case is between Pleasant Valley and Millwood and within the first step of the Pleasant Valley relay, the latter

would thus trip as soon as its starting unit closes its contacts. In this case the separation of the 2 systems would be satisfactory.

If power is flowing the other way, the Pleasant Valley voltage lags and the Dunwoodie and Millwood voltages lead the line current. The relay at Pleasant Valley would not trip under this condition. The performance of the starting units of the relays at Millwood as determined from figures 5 and 7, is shown in the upper part of table I. The reactance center is within the first step of the Millwood relay and the latter will trip as soon as its starting unit closes its contacts. In this case, the separation would take place at Millwood on the Pleasant Valley circuit and would therefore also be satisfactory. Thus, under the assumed conditions, the performance of the reactance relays on this section would be satisfactory as far as the location of the point of separation during out-of-step condition is concerned.

If, however, the fault occurs on one of the Dunwoodie-Millwood circuits, after it is cleared there will be one circuit left between Dunwoodie and Millwood, and 2 circuits between all other points. The reactance center is between Millwood and Pleasant Valley, within the first step of the Millwood relay and the second step of the Dunwoodie relay. The performance of the starting unit at these 2 stations with power flowing from Hell Gate to Pleasant Valley is as shown in the lower part of table I. It is seen from this table that the starting unit of the Millwood relay does not start until about 0.5 second after the starting unit of the Dunwoodie relay has picked up. The relay at the latter station would trip first, thus separating the 2 systems at Dunwoodie and leaving them tied through the Westchester low voltage network.

The figures in the lower part of table I are based upon the same out-of-step curves as used for the figures in the upper part of the table. This, of course, is only approximately true; but is sufficiently true to illustrate the point. The chances of the Dunwoodie relay tripping increa e, as, due to system changes, the reactance center is shifted toward Dunwoodie.

A modified design of this relay was next considered. This was arranged so that the angle between current and voltage to which it would respond was automatically shifted with time, and designed to take place during the time interval between the first and second step. Even this arrangement left such a small margin of selectivity between the relays on the Dunwoodie-Millwood section and those on the Millwood-Pleasant Valley section that it appeared extremely doubtful that the relays would operate as desired during out-of-step conditions.

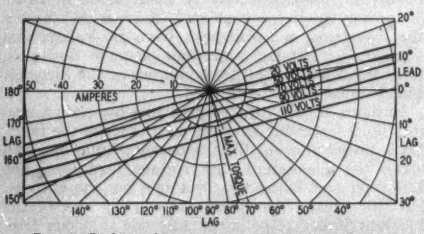

Fig. 7. Pick-up characteristics of the starting element of the type GAX directional reactance relay

The minimum operating current is plotted as a function of relay voltage and the angle between this voltage and relay current. As shown by the curve, the minimum operating current is 12 amperes at 110 volts and maximum torque angle

Carrier Current Controlled Protection

As the recently developed carrier current control system of protection seemed to offer considerable promise the study was extended to include this type of equipment. It may be well to note that the title accurately denotes the operating principle, for the function of the carrier signal is not to operate the protective relays directly but to control their operation by means of carrier operated blocking relays connected in the trip circuits of the protective relays.

While several modifications of this protective scheme are possible, 2 of them are basic:

1. The protective relays are free to trip when no carrier signal is transmitted.
2. The protective relays can trip only when the carrier signal is transmitted.

In this case, the first alternative was selected as being the most desirable. When the fault is on the protected section no carrier signal is transmitted and the relays are free to trip. Failure of the carrier channel or equipment does not therefore interfere with clearing the fault. Failure of the carrier signal during faults on other parts of the system can only mean that the relays are tripped unnecessarily but this is considered to be far less undesirable than failure to trip when essential.

In general, the relay equipment consists of carrier current controlled directional overcurrent protection for phase to phase faults and directional ground protection at the terminals of each high voltage circuit. The operating principle of the carrier current control will be understood by referring to figure 8, showing the principal control elements. The directional overcurrent protection is provided by a polyphase power directional relay (3) in combination with 3 special induction type overcurrent relays (2) and 3 high speed solenoid type overcurrent relays (4).

Power directional relay (3) is provided with a potential restraint which holds the relay contacts closed under normal conditions of power flow in either direction. When a fault occurs, high speed relays (4) operate to remove the restraint in less than one cycle. This arrangement materially increases the speed and sensitivity of the power directional unit. When fault current flows toward the bus, the contacts of the power directional relay open, removing the negative bias from the grid of the transmitting oscillator, thereby starting carrier transmission at once, thus blocking tripping action at the other end of the protected section by opening the receiver relay contacts at that point, and at the same time blocking the tripping action of overcurrent relays (2) at the local station.

Directional ground protection controlled by carrier

current is provided by 2 directional ground relays. The carrier starting relay (5) opens its contacts when fault current is flowing toward the bus and removes the negative bias from the grid of the transmitting oscillator. The tripping directional ground relay (7) is provided with 2 sets of contacts, one set for tripping and the other set, normally closed, in the plate circuit of the master oscillator. The purpose of the latter is to insure that the ground relays will take precedence over the power directional relays with a phase to ground fault on the protected circuit. This arrangement prevents the possibility of the power directional relay starting the carrier current with a heavy flow of power toward the bus at the time of a phase to ground fault on the protected circuit.

The back-up, directional overcurrent ground relay (9) operates independently of the carrier current control and is connected to an independent set of current transformers. This ground relay as well as those controlled by the carrier current is polarized by zero sequence potential derived from bushing potential devices at Dunwoodie and Millwood. The corresponding relays at Pleasant Valley are polarized by the power transformer neutral current.

The definite time back-up relay (10) is used as a protection against switch failure. As indicated in the diagram, the relay is connected in parallel with the trip coil and trips out all other circuits capable of supplying current to the fault, by means of the multi-contact tripping relay (11).

Each section of the transmission circuit is tuned to a different frequency for carrier current transmission to avoid any possibility of false operation, although the range to which the carrier equipment on any section is resonant is confined to a band of approximately 10 kilocycles. Frequencies employed fall within a range of 50 to 150 kilocycles.

When a phase to phase fault occurs on the protected section the fault current flows away from the bus at the 2 terminal points toward the fault. The restraint is removed from the power directional relays (3), which are, however, held in their closed position by the fault current and maintain through their contacts a strong negative grid bias on the transmitting oscillator, preventing the transmission of carrier signals. The receiver relays (1) remain closed, thus maintaining the trip circuit for the tripping relays (2) which act after approximately 0.10 second to clear the fault.

When the phase to phase fault is outside the protected section, overcurrent relays (4) at both stations operate as before to remove the restraint from the power directional relays. But, in this case, the power directional relay at one station opens its contacts starting a carrier signal which operates the receiver blocking relays thus opening the trip circuits before the tripping relays can close their contacts. After the fault is cleared the various relays reset in the proper sequence to prevent false tripping. The necessary selectivity of the resetting action is obtained by introducing a slight time delay in the closing of the power directional and receiver relays after the fault is removed. The directional ground relays operate in a similar manner for ground faults.

The selectivity on the blocking and resetting operations is illustrated in figures 9*a* and 9*b*, respectively, which show typical tracings of oscillographic timing tests.

Carrier Current Control During Swing and Out-of-Step Conditions

It was still necessary, however, to check the performance of the power directional relays during swing and out-of-step conditions, even with the carrier control, as there was no assurance that tripping could not take place on 2 different sections of the line, or that it would take place at the desired points.

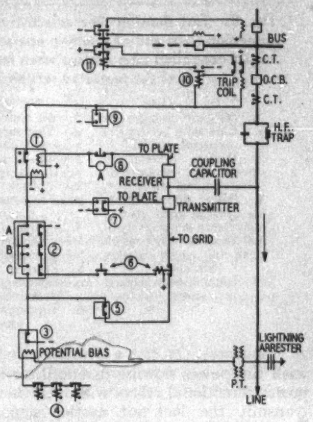

Fig. 8. Simplified diagram of control circuits of relays for carrier current controlled system used with one 132 kv oil circuit breaker

All relay contacts shown in normal position. Arrow shows direction of power in high voltage line to close relay contacts which are normally open, and to open contacts which are normally closed

1. Receiver relay
2. Phase overcurrent tripping relays
3. Power directional relay for starting carrier signal
4. Instantaneous overcurrent relays
5. Directional ground relay for starting carrier signal
6. Push button and contactor for starting carrier test signal
7. Directional ground tripping relay
8. Push button and ammeter for measuring receiver current
9. Back-up directional ground relay. Independent of carrier
10. Definite time back-up relay
11. Hand reset tripping relay

It was found that with all of the power directional elements set alike on timing, and responsive to their maximum torque position at the same angle, the relays on the Millwood-Pleasant Valley section would have insufficient time to trip during out-of-step conditions.

Two means are readily available for suitably modifying the characteristics of the power directional relays: (*a*) Time adjustment; and (*b*) torque angle adjustment.

The carrier current control, as used in this installation, is eminently adapted to the introduction of time selectivity between the power directional relays. As the contacts of the power directional relays are normally closed, the resetting time after an opening operation may be delayed without increasing the time required to clear a fault on the protected section. During out-of-step power swings

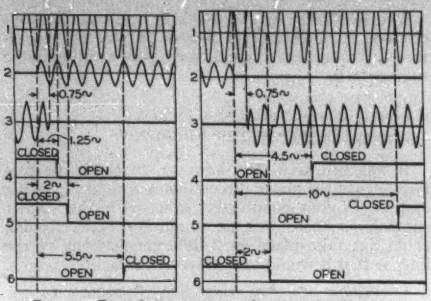

Fig. 9. Test showing time selectivity of blocking operation (left) and of resetting operation (right) of carrier controlled phase relays when fault is outside of the protected section

Fig. 9a (left)
1. 60 cycle timing wave
2. Operating current (12 amperes) applied
3. Voltage restraint removed from power directional relays
4. Power directional relay contacts open, starting transmission of carrier signal
5. Receiver relay contacts open oil circuit breaker trip circuit
6. Tripping relay contacts close

Fig. 9b (right)
1. 60 cycle timing wave
2. Operating current (12 amperes) interrupted de-energizing power directional and tripping relays
3. Voltage restraint applied to power directional relays
4. Power directional relay contacts close, stopping transmission of carrier signal
5. Receiver relay resets, re-establishing oil circuit breaker trip circuit
6. Tripping relay contacts open

with the power flowing in one direction, half of the power directional relays will open their contacts and transmit the lock-out carrier signal. When the power flow reverses in direction the delayed time in the resetting of these relays will afford ample time for the relays at the opposite end of the line to open their contacts and continue the transmission of the signal. This action in maintaining a continuous transmission of the carrier signal prevents tripping the switches at both ends of the section.

The torque angle adjustment provides a further means of adjusting the operating characteristics of the power directional relays on the different sections of the transmission circuit by virtue of the different angular relations which may prevail between voltage and current, and the variation of these quantities with time as the power swing progresses. For example, if the relays on the line section which it is desired to trip under out-of-step conditions are adjusted to have their maximum torque while those on the remaining sections are adjusted to have a smaller torque at the voltages, currents, and angles prevailing on the respective line sections, a still greater degree of selectivity may be attained.

It may not always be possible, however, to modify the relay operating characteristics so that the desired performance can be realized on the particular section which it is desired to trip under out-of-step conditions. In such cases it would be desirable to provide special out-of-step relays which operate on the first swing which passes through an angle in excess of 180 degrees, to trip the desired section of line and lock out all other sections. In this instance it was found feasible to modify the power directional relay characteristics by the methods mentioned, to an apparently satisfactory degree. A clearer understanding of the method employed may be had by referring to figures 10 to 12.

Application to Pleasant Valley-Dunwoodie Sections

Figure 10 shows the conditions calculated for the Millwood-Pleasant Valley section. The vector diagram inserts show the operating angle of the power directional relays at the 2 line terminals as adjusted by potential phase shifting transformers. It will be observed, for example, that the contacts of the Pleasant Valley relay are closed (no carrier signal transmitted) when the position of the line current with respect to the line to neutral voltage varies through an angle of 140 degrees lag to 40 degrees lead while the corresponding angles for the Millwood relay are 124 degrees lag to 56 degrees lead.

The dotted curve shows the angular relation between line current and voltage when the power being transmitted from Pleasant Valley to Hell Gate is just within the transient stability limit (166,000 kw) with a 3-phase fault on one circuit near Millwood. This angular relation is plotted against time, measured from the instant of fault, and assumes the faulted circuit to have been cleared in 0.30 second.

While the Pleasant Valley relay remains in the closed (tripping) position at all times, the Millwood relay is always in the open position, since the line current never lags its voltage by less than 140 degrees whereas this relay cannot operate unless the angle of lag is less than 124 degrees. In this diagram the line current for the Millwood relay is reversed by 180 degrees from its true position in order to show its phase position as "seen" by the relay.

The solid curve shows similar conditions except in this case the power just prior to the fault is just sufficient to throw the 2 systems out of synchronism. The Pleasant Valley relay remains in the closed position for 2.52 seconds. The Millwood relay enters the tripping range after 1.9 seconds, so there is an interval of 0.62 second in which both relays are in the closed position, which is more than ample time to permit tripping the circuit.

Referring next to figure 11, the effect of the same fault and swing on the relays of the Millwood-Dunwoodie section is shown. It will be observed that the relays at both of these points are adjusted for an operating angle of 105 degrees lag to 75 degrees lead. The relays on this section were given the time delayed action in resetting, although this is not illustrated here. At no time are the relays at the 2 line terminals in the tripping range at the same time for 166,000 kw; and for a period of only 0.04 second—or insufficient to cause tripping—during out-of-step conditions.

Similar curves for the Millwood-Pleasant Valley section except for 200,000 kw power transfer are shown in figure 12. While this represents an emergency condition which may seldom, if ever, be en-

countered in actual service, it shows that both relays are in the tripping position for 0.15 second. The chances of effecting the desired tripping are indeed reduced to a very small margin. In this case the stability calculations were carried out to include the second swing. This illustrates the necessity of tripping on the first swing, as the period of the swings becomes faster with elapsed time.

The most unfavorable cases have been shown, since power limits above the normal line ratings have been used in conjunction with 3-phase faults. Operating experience on similar circuits has shown that only a small percentage of the faults are 3 phase. Single conductor and 2-conductor-to-ground faults, of course, provide a wider margin of stability reserve than 3-phase faults for the same amount of power transfer, and the rate at which the 2 systems would approach their maximum angular positions would be correspondingly decreased.

Protection of Dunwoodie-Hell Gate Section

While it was not considered feasible at this time to transmit carrier frequency over the 12 mile section of the 132 kv underground cable circuits between Hell Gate and Dunwoodie, this did not prove to be a serious handicap. This section of the circuit is

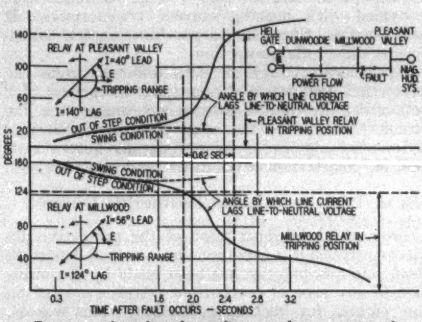

Fig. 10. Angular relation between line current and line to neutral voltage plotted as a function of time during swing and out-of-step conditions for the Millwood-Pleasant Valley section, after tripping one circuit on a 3-phase fault near Millwood

The vector diagram insert shows the tripping range of the power directional relays at Millwood and Pleasant Valley, I representing the line current and E the line to neutral voltage. Power for the "swing" condition is just within the stable power limit but slightly over the stable power limit for the out-of-step condition. The relays on the Millwood-Pleasant Valley section are in the trip position for 0.62 second at both stations during the out-of-step swing

contiguous to one end of the interconnection and the major portion of the impedance is lumped at the generating station terminus, a condition favorable to the use of standard relay equipment.

As shown in figure 2, 2 automatic circuit breakers are in series between the generating station bus and the step-up transformers—the standard switching equipment for all outgoing circuits at this station. No automatic circuit breaker is used on the high voltage side. Each 100,000 kva transformer bank is composed of 2 banks, one being of 3-phase construction and the other consisting of 3 single phase units. The 132 kv cable from the high voltage

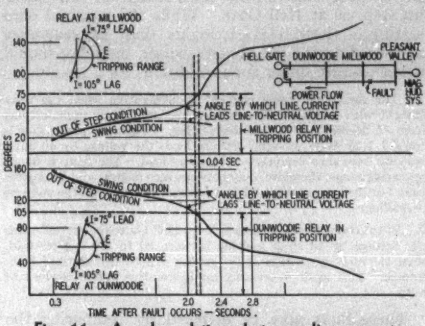

Fig. 11. Angular relations between line current and voltage on the Dunwoodie Millwood Section for the same conditions shown in figure 10

On this section, however, both relays are in the trip position for only 0.04 second, which is insufficient to permit tripping

transformer terminals to the bus at Dunwoodie is single conductor with one conductor per duct, connecting to an automatic circuit breaker at Dunwoodie.

Simple overcurrent ground relays and differential relays were used for the primary protection from the 13.8 kv switch to the high voltage transformer terminals. The 132 kv cable itself was protected by overcurrent ground relays connected in the transformer neutral circuit at Hell Gate and directional ground relays at Dunwoodie. These relays are not affected by balanced power swings. The principal problem was to provide back-up protection, for both relays and switches, which would also be immune from incorrect operation during power swings.

At Hell Gate, back-up ground relay protection for the 13.8 kv connections was provided by the addition of another overcurrent ground relay supplied from a separate set of current transformers and connected to trip the bus selector switch. Since the reactance center of the system was calculated to fall well north of Dunwoodie except under very abnormal operating conditions, it was clear that directional distance relays of the reactance type could be used as a back-up to the Hell Gate transformer differential relays, provided the setting point was limited to a point corresponding to a 3-phase fault only slightly north of Dunwoodie. In addition, therefore, these relays also protect against single-conductor-to-ground faults for a portion of the cable circuit and against phase to phase faults for the entire length including the 132 kv bus at Dunwoodie. Both the

first and second steps of the relay were used to cover the protected section but the third or definite time back-up step was omitted.

Since it was planned to omit high voltage circuit breakers at Hell Gate it was desirable to provide relays at Dunwoodie which would clear phase to phase faults in the transformers at Hell Gate. Directional distance relays of the reactance type were used for the purpose, omitting the third or definite time back-up step, as at Hell Gate. While the required ohm setting of these relays is higher than the reactance measured during out-of-step swings, the relay should never operate under such conditions for 2 reasons:

1. The directional relay element is inoperative when the relay current with respect to the voltage falls within an angle varying from 15 degrees lead to 165 degrees lag. When the power flow is toward Hell Gate the relay current leads the voltage by an angle varying from zero degrees to 90 degrees lead. The relay is in the operating range, therefore, only between zero degrees and 15 degrees lead, but the current is insufficient to cause operation at the voltages prevailing.

2. When the power flow is away from Hell Gate, the current leads the voltage by an angle varying between 90 to 180 degrees lead, since the reactance center of the system is normally north of Dunwoodie. This again represents an inoperative condition for the relay.

These facts may be deduced by comparing the operating angles of the relay shown in figure 7 with the curves given in figure 5, keeping in mind that the relay current transformers are connected in delta in such a manner that the relay voltages are in phase with the corresponding line currents at unity power factor.

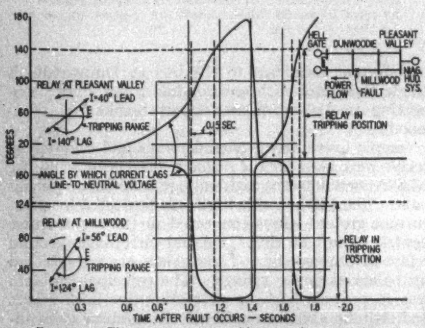

Fig. 12. The same section of line as shown in figure 10, except that the power being transmitted prior to the fault is increased to 200,000 kw or well over the transient power limit for a 3-phase fault at the point shown

The time available for the relays to trip at Millwood and Pleasant Valley is reduced to 0.15 second

Protection at Substations

At Dunwoodie no high voltage circuit breakers were provided for the transformer banks, and no facilities were readily available for mounting current transformers for use with transformer differential relays since current transformers had not been originally provided on the bushings of the existing transformer banks. This protection was provided by adding a scheme of 3 phase overcurrent protection to the 132 kv bus differential circuit—in effect an incomplete bus differential scheme. These relays are provided with instantaneous overcurrent elements to protect against line to line high voltage bus short circuits, and with time delay elements for protection against phase to phase faults in the transformer windings and on low voltage leads.

The 132 kv bus differential ground relays at this substation, as in all others, will operate in 1 to 2 cycles. The pick-up current is set above the normal load currents, to prevent false operation during switching operations.

At Elmsford, the step-down transformers were delta connected on the high voltage side and no high voltage switches were provided. A time delay, zero sequence voltage relay, connected to bushing potential devices, is used to trip the low voltage circuit breakers for 132 kv line to ground faults, as otherwise the line would remain alive until switched manually.

The protection at Millwood is quite similar to that at Dunwoodie. In this case the substation transformers were purchased coincident with the remaining equipment and the high voltage terminals were provided with bushing current transformers. It was possible, therefore, to provide complete transformer differential protection.

At Pleasant Valley the chief difference from the protection used at other points lies in the use of 2 sets of definite time back-up relays, one for the line circuit breaker and the other for the transformer differential and the use of transformer neutral current for polarization of the directional ground relays.

Usual Type of Back-Up Protection Omitted

From the brief description of the protective devices employed it is apparent that a radical departure from common practice has been made by the omission of any type of overcurrent relays operative on line current for back-up protection. This was essential if control of the point of separation under out-of-step swings was to be realized. The justification for this procedure was based upon the following premises:

1. While phase to phase faults not involving ground on the overhead open wire lines are possible, the use of 3 single pole elements for the tripping relay of the carrier controlled equipment is considered to provide a reasonable degree of protection against failure of the relay equipment.

2. Failure of the carrier signal or the relays controlling its transmission does not prevent tripping the faulted section. This does not, of course, protect against failure of the tripping supply, but the reliability of this source is so high that failure may be said to be practically unknown. This hazard, if it may be considered as such, is no greater than the same hazard which exists in generating stations where it has been general practice for many years to provide one tripping source and where the required degree of reliability is higher than in most substations.

3. Protection against circuit breaker failure has been provided for by the use of a d-c definite time auxiliary relay which is energized when the trip coil is energized. If the fault is not cleared by the

circuit breaker on the faulted circuit, this relay acts after a definite time interval to trip off all other circuits capable of supplying fault current.

4. An hourly check of the carrier equipment and a monthly operating check of circuit breakers and inspection of relays is calculated to uncover any defects which are likely to occur in this equipment and to insure its maintenance at a high level of efficiency and reliability.

Operating Experience With Carrier Current Equipment

The complete interconnection with carrier current control protection of the overhead sections was placed in service May 1, 1933, although part of the line was in operation prior to this date. The operating experience cited here covers approximately one year's time, subsequent to placing the equipment in service.

The chief trouble experienced with the carrier current equipment occurred during the period of unusually low temperatures experienced in January and February 1934, when the hourly checks on carrier signal strength revealed an alarming reduction in signal strength during the low temperature periods. After an operating check of the terminal equipment it was concluded that the trouble probably lay in the line traps. This was confirmed by a separate check made by the manufacturer. The cause was found to be a change in capacitance of the line trap condensers at low temperatures. These condensers were replaced by others with a mica dielectric which eliminated further troubles of this nature.

Trouble was also experienced by the receipt of very short stray signals. This was ascribed to insufficient wipe in the normally closed contacts of the relays which control the negative grid bias circuit of the transmitter. A slight readjustment of the relay contacts was sufficient to eliminate most of this trouble.

In some instances when one of the 132 kv circuits was switched out a short carrier signal was transmitted. The cause for this has not been definitely determined but possibly may have been caused by the momentary removal of restraint from the power directional relays.

The operating performance of the various tubes used with the carrier current receivers and transmitters is summarized in table II. The average life does not, of course, represent the time that the tubes are receiving or transmitting signals, since this is limited to a few seconds per hour, but rather represents the number of days in service.

Automatic Operations

During the 16 month period from May 1, 1933, to September 1, 1934, a total of 40 electrical storms were encountered, as recorded by the station logs at Millwood and Pleasant Valley; trip-outs resulting on 3 occasions. This affords a measure of the effectiveness of line insulation and relay protective equipment against lightning. In one instance the fault involved both circuits of the Millwood-Pleasant Valley section. The relay target devices indicated that the fault occurred on the same phase on both lines, but as insufficient evidence of arcing precluded the location of the fault it was not possible to determine the relative position of the 2 line conductors involved. One other fault, not caused by lightning, involved all 3 phases on one circuit and was cleared by the protective equipment. To date, no incorrect relay operations have occurred during faults on the 132 kv circuits nor has there been any

Table II—Performance of Carrier Equipment Vacuum Tubes, May 1, 1933 to August 13, 1934

	Type 83 Rectifiers	Type 210 Receiver and Oscillator	Type 210 Amplifier	Total
1. Number in service	8	16	8	32
2. Average life—days*	211	296	272	
3. Number of failures				
(a) Emission test	10	9	5	24
(b) Filament burn-out	0	1	0	1
(c) Other causes	1	0	0	1
Total failures	11	10	5	26
4. Failures detected on				
(a) Monthly emission tests	7	5	5	17
(b) Hourly push button test	4	5	0	9
	11	10	5	26

Tubes are rejected when they fail to meet the following tests:
(a). *Type 83. Rectifier Tubes.* With filament preheated for 20 minutes at 5 volts alternating current, and 400 milliamperes d-c plate current, drop from anode plate to filament shall not exceed 20 volts.
(b). *Type 210. Receiver and Oscillator.* With plate and grid terminals connected together, filament excited at 6 volts alternating current and 125 volts direct current applied between plate and filament, plate emission shall be over 50 milliamperes.
(c). *Type 210. Amplifier.* Same as test (b) except plate emission shall be over 100 milliamperes.
* Applies only to tubes which have failed.

instance in which the relays have operated incorrectly as a result of numerous faults on the lines north of Pleasant Valley, or on feeders from Hell Gate station.

In all 3 instances where trouble occurred on the 132 kv overhead sections as a result of lightning, the damage to the line was so slight that the fault location could not be ascertained by careful inspection. This is perhaps the most convincing demonstration that could be presented of the effectiveness of high speed protection in limiting damage to the equipment.

No clear cut case of instability has occurred to demonstrate the effectiveness of the relay equipment in separating the 2 systems at the desired points. On one occasion, however, a close approach was apparently made. In this instance a number of circuits north of Pleasant Valley tripped off during a lightning disturbance in that area. There were a number of heavy swings on the tie lines which the operator at Pleasant Valley considered to be sufficient indication of out-of-step operation. One of the Millwood circuits was disconnected manually at Pleasant Valley and at the instant that the second Millwood line was switched out, it opened automatically at Millwood.

An automatic oscillograph has since been installed at Pleasant Valley, and although sufficient elements are not available to record all of the desired quanti-

ties, more definite information than that ascertainable by the usual indicating and recording instruments will be available in the future.

Maintenance

The carrier equipment is checked hourly by the substation operators and readings of carrier signal strength noted on ammeters connected in each receiver relay circuit. The test is quite simple and can be completed in a very short interval, since it requires only the pressing of a button to transmit the signal, and the reading of an ammeter.

A code signal is used to identify the line being tested, and by means of a prearranged schedule, the initiating station transmits a warning signal and receives a "ready" signal by the receiving substation. Signals of approximately 2 seconds' duration are then transmitted by the initiating station and answered by the receiving station, thus permitting a check of signal strength of each circuit at each substation.

Poor condition of any of the tubes is usually indicated by a gradual decrease in signal strength as recorded by several successive hourly tests. About 30 per cent of the failures have been detected on these tests.

At monthly intervals a complete check is made of all tubes by means of a portable test set. At the same time all 132 kv circuit breakers are tripped by the relays to insure that all electrical and mechanical devices are in proper working condition.

At periodic intervals a complete calibration test is made of all line protective relays. As the time settings are very short and the selectivity between various relays is in the order of a few cycles, special high speed timing devices are used for this purpose.

At Pleasant Valley the automatic oscillograph is used for checking the timing of the relays after they have been individually calibrated. The record shows the performance of the combined relay installation, including the time margins between starting of the carrier signal and individual relay tripping and resetting operations.

At other substations an electronic timer is used for checking the calibration of the individual relay units.

Surge Currents in Protective Devices

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Lightning arresters are expected to protect equipment against damage and outage from lightning, and to have an economical life. In order to accomplish these ends effectively, arresters should be able to discharge all surge currents whose probability of occurrence is such that the average life of the arresters will be in an economic balance with their cost. In this paper existing data have been assembled and analyzed in an effort to determine the magnitude of these impulses and the probable frequency of their occurrence.

THERE has been much discussion in the past concerning the principles of operation under which various devices developed to discharge lightning surge currents from transmission lines operate to perform their function, and a great variety of data have been presented to show what may be expected from such devices under given sets of conditions; but information regarding the magnitude of impulse currents these devices may be required to discharge under operating conditions, and the probable frequency of occurrence of these impulses is by no means as plentiful. There has been further discussion, and criticism, of the impulse test in the proposed lightning arrester standards of the A.I.E.E. as falling short of the requirements for certain applications, without convincing data as to the duty to be encountered. In this paper the factors involved are discussed with a view to rationalizing the problem.

It is concluded that lightning disturbances other than those following a direct stroke or streamer to the transmission line impose no very severe duty on the protective device. Direct strokes or streamers to the line at some distance from the device are transmitted to it in the form of traveling waves, the characteristics of which are limited by the minimum flashover voltage to ground of the line itself. Under these conditions the duty imposed on the protective device is moderate and in reasonable agreement with the tests required by the proposed A.I.E.E. standards. The more infrequent direct strokes to the line in the immediate vicinity of the arrester are not necessarily limited by line insulation characteristics and may reach very much higher surge current values.

A paper recommended for publication by the A.I.E.E. committee on protective devices, and tentatively scheduled for discussion at the A.I.E.E. summer convention, Ithaca, N. Y., June 24–28, 1935. Manuscript submitted Oct. 15, 1934; released for publication Nov. 5, 1934.

Various factors governing the discharge of surge current from distribution lines permit of relatively high current values in this class of service as well.

Concerning the frequency of occurrences of these high current surges, present available data indicate the probability of a disturbance involving surge currents of from 5,000 amperes upward, once for every 10,000 to 20,000 feet of exposed line per year. These currents will range up to values in the order of 100,000 amperes with the higher currents occurring least frequently. Since these maximum currents affect only devices within 250 feet of the origin of the disturbance on distribution circuits, the probability of any one set of devices being subjected to a high current operation is once in 20 to 40 years, or conversely one set out of 20 to 40 installed may be subjected to one high current operation each year.

In the present state of the art the full discharge capacity, 100,000 amperes, indicated as necessary if an arrester is to be good for all conditions, cannot be provided without exceeding economic limitations or sacrificing protective ability. The very infrequent occurrence of currents high enough to cause failure of present types of arresters good for limited discharge capacity makes it appear poor economy to sacrifice in either cost or protective ability for higher current capacity. In special cases where the penalty of failure is greater and where the protection requirements are less rigid, a device capable of withstanding the maximum discharge to be expected may be employed.

General

The current to be discharged through a lightning arrester is dependent on several factors such as: the impulse voltage impressed on the line; the distance between the arrester and the point at which the impulse originates; the impedance of the arrester ground; and, to a small degree, the characteristics of the arrester itself. The duty imposed on an arrester by induced voltages such as that caused by a discharge from cloud to earth near by, but not terminating on the line, is relatively light and, for the purposes of this discussion, may be neglected. There remains then for consideration only the direct stroke which terminates entirely or in part on some portion of the line.

The probability of a severe direct stroke on the arrester itself appears relatively remote and may also be neglected since present types of lightning arresters generally are not designed to afford protection against such a stroke. This leaves then 2 major classifications of disturbance to be dealt with, namely: (1) direct strokes to the line at some distance from the arrester, producing a traveling wave that approaches the arrester over the line; and (2) direct strokes to the line close to the arrester. It will be apparent that with the present practice of installing arresters relatively far apart (as compared with the span lengths of a line), the probability of a direct stroke occurring within 1 or 2 spans of an arrester is much less than that of its occurrence outside that region; therefore, a large proportion of arrester discharges will result from disturbances under class 1, that is, as the result of a traveling wave.

Traveling Waves

The maximum impulse voltage that can be transmitted along an overhead line is limited to the impulse flashover voltage from that line to ground, and is roughly proportional to the minimum striking distance from the line conductor to the nearest

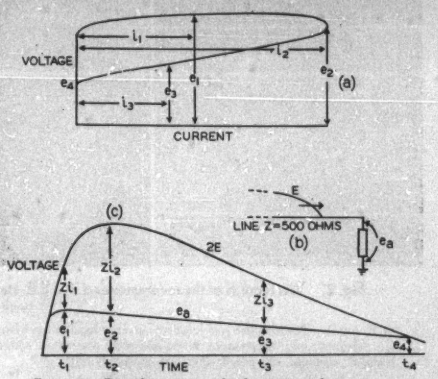

Fig. 1. Development of the equivalent transmission line curve (c) from the volt-ampere curve (a) under the conditions given in (b)

At any instant the arrester voltage plus the iZ potential drop in the line equal the doubled traveling wave voltage

$$i_a = \frac{2E}{Z_1 + Z_a} \quad (1)$$

$$i_aZ_1 + i_aZ_a = 2E \quad (2)$$

$$i_aZ_1 + e_a = 2E \quad (3)$$

grounded object on the structure. For steel towers the flashover voltage will be determined by the characteristics of the insulator string, provided that the clearance from conductor to tower is not less at some other point. On wood pole lines the insulator strings ordinarily are supported by wooden crossarms which, together with the pole itself, form a longer insulating path to ground and raise the impulse flashover voltage above that of the insulator string alone. The presence of guy wires on any wooden pole of a line must be taken into consideration, however, since they will shorten the path to ground very materially and thus be a governing factor in determining the impulse flashover voltage. Several papers have been published giving detailed data concerning the impulse flashover characteristics for different types of line insulation.[1,2,3,4,5] For applications in which specific data are not available, a reasonable approximation may be arrived at by using as the minimum voltage required to flash across

1. For all numbered references see list at end of paper.

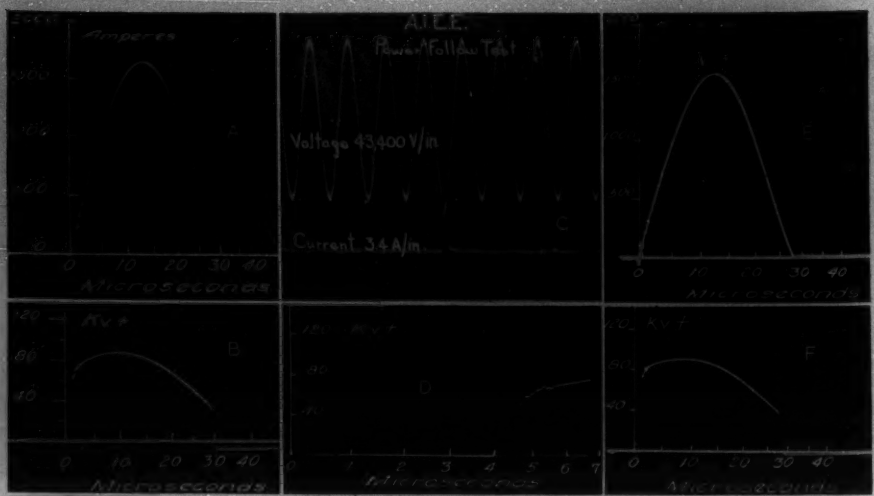

Fig. 2. Test records of the recommended A.I.E.E. standard impulse and operating cycle tests on a 25 kv station type arrester

A, B, and D. Ampere-time and volt-time curves of impulse test before operating duty test
C. Magnetic oscillogram taken during one of 30 operations with combined 750 ampere impulse and 24 kv power voltage
E and F. Impulse test records after operating duty test

a clear air gap with a 1.5 x 40 microsecond positive impulse wave, a value of 16 kv crest per inch of striking distance and a value of 12 kv crest for creepage over wood alone. This minimum flashover voltage is usually greater for negative waves and is always greater for shorter waves.

Now, a traveling wave of voltage e on a line of surge impedance Z is accompanied by a surge current of the value $i = e/Z$. The surge impedance of the average overhead line may be assumed to be of the order of 400 to 500 ohms. In order to limit the traveling wave voltage from line to ground at the end of a line, the protective device must discharge a current of from 1 to 2 times the traveling wave current as determined by the formula given in the caption of figure 1. In effect, the protective device reduces the surge voltage by drawing current through the line surge impedance. These general relationships may be applied to any protective device or system such as an air gap, resistor, capacitor, cable, deion protector, or a lightning arrester.

In table I are shown representative data for various voltage ratings, showing the currents in crest amperes that the arrester will be required to discharge in the most usual class of disturbance, i. e., a direct stroke at sufficient distance to result in a traveling wave from the origin of disturbance to the arrester. These currents are based upon limitation of the traveling wave voltages by the minimum flashover clearances from line to ground shown in the table. Under these conditions and for an arrester voltage ratio of 2.5, the current discharge on a long positive wave cannot exceed the values in the third column of the table. For a wood pole line, designed to secure maximum use of the wood for impulse insulation, the traveling wave voltages and corresponding currents may be greater.

In recognition of the fact that the function of a lightning arrester is to limit surge voltages by discharging current when subjected to a traveling wave, the proposed lightning arrester standards of the A.I.E.E.[8] include a representative impulse test to determine the performance of the device. This test may be summarized as follows:

The applied test impulse shall rise at 100 kv per microsecond per 11.5 kv of arrester rating. After the arrester begins discharging, the current shall rise to crest value in 10 microseconds and fall to half value in not less than an additional 10 microseconds. The specified crest value of current is 1,500 amperes for both line type and station type arresters.

Figure 2 shows records of a test made as required by the proposed A.I.E.E. impulse and operating duty cycle tests on a 25-kv station-type arrester. This

Table I—Approximate Maximum Surge Currents Through an Arrester at the End of a Line, Where the Traveling Wave Is Limited by Line-to-Ground Flashover

System Voltage, Kv	Minimum Surge Flashover Distance, Line-to-Ground, Inches	Crest Arrester Current, Amperes
2.3	12	800
13.8	20	1,200
24	24	1,350
69	36	1,700
115	42	1,750
138	52	2,170

laboratory impulse test is the equivalent of an operation in service by a traveling wave of the shape and magnitude shown in figure 3 and derived by equation 3, figure 1. On this test the arrester reduced the 850 kv, which otherwise would have appeared at the open end of the line, to 90 kv. It may be noted that the proposed A.I.E.E. tests for arresters are in close agreement with the current values shown in table I.

Direct Strokes

Turning now to the second and less usual class of disturbances, that in which a direct stroke or streamer thereof terminates on the line in the immediate vicinity of an arrester, limitations of line insulation are not an important factor in determining the value of current that must be discharged. In this case the maximum current is determined by the characteristics of the stroke or streamer itself, and the principal source of information concerning these characteristics is data from field measurements on, and operating records of, transmission lines in service. Such measurements as have been made in the field and published[7,8,21] showing the order of current values caused by direct strokes to transmission lines, indicate that they may reach a maximum of 100,000 amperes.

Other sources of data give an indication of the probable frequency of occurrence of surge currents above a certain minimum value. These are the records of lightning flashover on transmission lines with known insulation characteristics. A streamer terminating on a line transmits a voltage surge in the form of a traveling wave in both directions from the point of contact. Following the procedure previously set forth in this paper for determining the current accompanying a traveling wave, the flashover voltage of the line divided by half the surge impedance of the line, say 250 ohms, is a measure of the total current from the streamer into the 2 surges, one in either direction. Where protective devices of the gap type are applied to prevent all line-to-ground flashovers on a high voltage line, the devices must discharge substanially full surge current to ground either individually or in parallel. More often, probably the 2 devices nearest the stroke divide the current roughly between them.

In table II are listed certain overhead transmission lines with their published flashover records stated in terms of flashovers per hundred miles of lines per year. From such data as have been published, the author also has tabulated (1) the impulse flashover voltage of the insulation, and (2) the minimum current required to raise the line to flashover voltage on a positive impulse of the 1.5 x 40 microsecond wave shape, this wave being about the equivalent of the lowest lightning surge that will cause flashover in service. These lines have no overhead ground wires. The current values in this table are qualified somewhat by the facts that the lightning severity was not the same for all lines and that the tendency of a power arc to follow surge flashover varies with the type of insulation and with the power voltage.

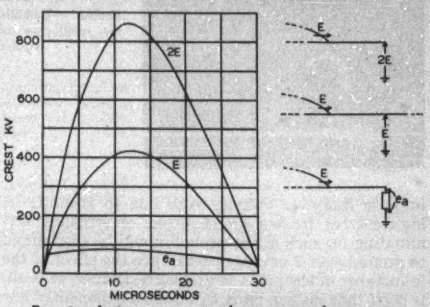

Fig. 3. Line surge equivalent to impulse test in figure 2. The test current determines the shape of the equivalent voltage surge as given in figure 1 (equation 3)

Taken with these reservations, however, the data in table II give an indication of the probable frequency of lightning disturbances involving impulse currents of 5,000 amperes or more. As they stand, these data indicate that exposed overhead transmission lines may be subjected to disturbances of major severity from 25 to 50 times per hundred miles of line per year, which is equivalent to one disturbance for every 20,000 to 10,000 feet of line per year, respectively. From these considerations of the possibilities involved in direct strokes of lightning, it appears that the proposed A.I.E.E. impulse test of 1,500 amperes is not representative of this service condition. The 16,000 ampere test illustrated in figure 4 is more nearly representative, and it appears that on very highly insulated lines short traveling waves may occur with currents up to 25,000 amperes.[20]

Direct Strokes on Distribution Circuits

Overhead lines operating at from 2.3 to 33 kv will have a range of from 100 to 500 kv crest in minimum

Table II—Flashover Records and Impulse Flashover Characteristics of Some Typical Overhead Transmission Lines

Reference No.	System Kv	Miles	Years	Flashovers or Outages per 100 Miles per Year	Surge Insulation, Distance, Inches	Approximate Minimum Impulse Flashover, Kv	Minimum Surge, Amperes to Cause Flashover
9	110	Average		25	84	1,350	5,400
10	66	38	1	16	84	1,350	5,400
11	220	40	2	59	70	1,100	4,400
12	132	21	6	40	64	1,000	4,000
12	132	40	6	50	47	750	3,000
13	110	75	4	19	40	650	2,600
14	140	226	2	19	50	800	3,200
10	66	38	1	240	24	390	1,550
15	33	1,045	1	45	18	290	1,150
16	60–100	738	1	26	34	550	2,200
16	30–60	4,277	1	30	12–30	200–500	800–2,000
17	100	213	3	29	33	390	1,550
18	30–60	2,375	1	35	12–30	200–500	800–2,000

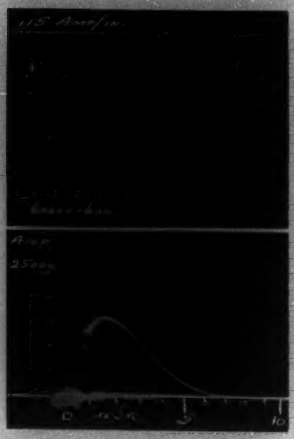

Fig. 4. Oscillograms of test on a 6,000 volt arrester connected to a 6,000 volt source while passing a 16,000 ampere test impulse

Top. Magnetic oscillogram showing power voltage across arrester and power follow current through arrester

Bottom. Cathode ray oscillogram of impulse

impulse flashover voltage from line to ground. A high current from a direct stroke or streamer terminating on such a line probably will be discharged to ground over 2 or more paths since the effect of the inductance of the paths or ground resistance, or both, is such that no one path will have a sufficiently low impedance to limit the line-to-ground voltage to the flashover value at adjacent points of low insulation. The flashover of additional paths to ground will limit the magnitude and duration of the current discharge through an arrester in the vicinity of a direct stroke to the line. Line-to-line flashover will distribute the total current among the arresters in a set.

General consideration of distribution line insulation leads to the conclusion that a set of 2,300 volt arresters may be expected to discharge half the current from streamers terminating on the line within 250 feet of them. Direct strokes or streamers to lines in exposed territory will occur more or less indiscriminately and the probability of a stroke to any single 500 foot section in a year is, as was derived previously in this paper, of the order of one in 20 to 40. Where lightning arresters or other protective devices are so arranged as to afford maximum protection to distribution transformers, i. e., 3 point protection, the arresters must discharge full impulse current. Past practice of using arresters separately grounded has resulted in transformer flashovers with high impulse currents, these flashovers in effect shunting current around the arresters.

Measurements on an urban distribution system have been reported recently by Halperin and McEachron[19] in which 24 current recorder years yielded only 1 current measurement of more than 300 amperes, this one current reaching a value of 1,500 amperes. It should be borne in mind that these data were obtained in sheltered urban territory where the probability of line disturbance is somewhat less than for a line through open country. Furthermore, records obtained on exposed transmission lines lead to the conclusion that a high current record need not necessarily have been expected during the period of time covered by these records.

H. W. Collins has published records[21] of surge currents measured in the common ground lead of 3 phase arrester installations on the Detroit Edison 24 kv system. Of the records obtained, about 4 per cent showed currents of more than 5,000 amperes; the highest was 34,000 amperes. About 1 in 12 arrester installations produced records of more than 5,000 amperes during one year.

Figure 4 shows a cathode ray oscillogram of a 16,000 ampere impulse passed through a 6,000 volt standard commercial arrester under laboratory conditions. The magnetic oscillogram of the same test records the power voltage across the arrester and the power follow current through the arrester. This 16,000 ampere impulse is of the order of magnitude of impulse currents that distribution arresters may be expected to encounter occasionally in operating service, but is by no means as severe as the *maximum* current that a protective device may be required to discharge in present day distribution service.

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Discussions

Of A.I.E.E. Papers—as Recommended for Publication by Technical Committees

ON this and the following 31 pages appear the discussion of a paper presented at the transmission and distribution session of the 1934 A.I.E.E. North Eastern District meeting, Worcester, Mass., May 16–18, and the discussions of papers presented at the 1934 A.I.E.E. Pacific Coast convention, Salt Lake City, Utah, September 3–7. All discussions on these papers received in complete and acceptable form at Institute headquarters, and subsequently reviewed and recommended for publication by A.I.E.E. technical committees, are included. Authors' closures, where they have been submitted, will be found at the end of the discussion on their respective papers.

Experimental Analysis of Double Unbalances

Discussion and author's closure of a paper by E. W. Kimbark presented for oral discussion at the transmission and distribution session of the North Eastern District meeting, Worcester, Mass., May 16, 1934, and published in this issue, p. 159–65.

H. W. Bibber (Ohio State University, Columbus): In commenting on Mr. Kimbark's paper, which I had the opportunity of reading in advance of the meeting, I should like to begin by commending him for the restraint he has shown in describing the general aspects of symmetrical component analysis. It seems as though everyone who digs into the subject deeply enough to master the principles involved feels moved to write an elementary exposition. I personally am no exception, and know the temptation to which he was subject.

Since the number of a-c calculating boards is so limited, it is fortunate that those having convenient access to them take the opportunity of trying out experimentally some of the methods that the rest of us may work out analytically. This brings out such interesting matters as the necessity for a phase converter if the "connection" method is to be employed, or the possible usefulness of the equivalent Π connection rather than the T which Miss Clarke developed in her 1931 A.I.E.E. paper on simultaneous faults. Thus the opportunity is provided for an extension of our knowledge such as Mr. Kimbark's paper represents.

From personal experience I know that the use of an induction motor running at or near its synchronous speed to serve as a phase converter has the disadvantages mentioned by Mr. Kimbark. I wonder if the possibility of using thyratron tubes with a suitable commutating circuit might not offer a chance for improvement, as it would be possible to secure much closer coupling because of the lower leakage reactance obtainable with transformers. Such a circuit would of course have to provide for energy storage, as the instantaneous power would be different in 2 circuits coupled so that the voltages are in the ratio 1:a or 1:a^2.

This paper indicates that further work by the author and others is in progress, which should make the a-c calculating board an even more versatile instrument. This is most encouraging and should lead to future developments of importance.

Edith Clarke (General Electric Co., Schenectady, N. Y.): Mr. Kimbark's paper (Fig. 8) shows a double unbalance consisting of a conductor shorted to ground and at the same time open, such as may occur when single pole switching is used or when a line is opened by fuses. When the circuit breakers at the 2 ends of the line do not open simultaneously there is a period, while the fault is still on the system, during which one end of the faulted conductor is open. If currents due to capacitance are neglected, and there are no circuits tapped off between the fault and the opening in the conductor, the opening may be assumed at the fault as in Fig. 8. System currents and voltages obtained under this assumption will be correct with the exception of the voltages along the conductors between the fault and the actual opening.

Mr. Kimbark has shown that this problem can be readily solved on the a-c calculating board by the "connection method." To solve it by the "equivalent circuit method," either mathematically or on the a-c calculating board, it is first necessary to determine the equivalent circuit to replace the double unbalance in the positive sequence system. This equivalent circuit is not given in the paper. Since an a-c calculating board is not always available and the problem is one of practical importance, the equivalent circuit will be given.

The 6 relations between the symmetrical components of currents and voltages at the points of unbalance, x and y of Fig. 8, are given by eqs 12 and 13 of the paper. The 4 equations pertaining to the negative and zero sequence currents and voltages at points x and y can be expressed in terms of C_0, D_0, S_0, C_2, D_2, and S_2, the impedances of the branches of the equivalent wyes which replace the zero and negative sequence systems between points x, y, and the zero potential planes for the system, subscripts

The Oklahoma City Oil Field

ONE of the items which will be of particular interest to those attending the A.I.E.E. South West District meeting, Oklahoma City, Okla., April 24–26, 1935, is the Oklahoma City oil field adjacent to the city. This general view of a portion of the oil field was taken in 1930 from a point just adjacent to the Oklahoma City business section, and shows a large number of wells in the process of drilling. The Oklahoma City field has 1,032 wells producing, with an average of one well for every 6 acres. This field has produced to date 240,000,000 barrels of oil; geologists report that an additional 125,000,000 barrels of oil will be produced within the next 5 years. Although the oil has flown almost entirely from its own natural gas pressure until within the last year, it is now necessary to use pumping on practically all wells. At the present time, the connected capacity in the field is 25,000 horsepower. This field has been the proving ground for developing the Reda pump.

0 and 2 indicating zero and negative sequence, respectively. Branch C is connected to point x, branch D to point y and branch S to the zero potential plane.

By eliminating negative and zero sequence currents and voltages from these 10 equations, 2 equations containing only the 2 positive sequence currents and the 2 positive sequence voltages at points x and y will remain. When these 2 equations are put in the form of eqs 16, it will be seen that $m = n$, and therefore the double unbalance can be replaced in the positive sequence system by an equivalent wye.

Let Z_x, Z_y, and Z_z be the branches of the equivalent wye between points x, y, and the zero potential plane for the positive sequence system, branch Z_x being connected at point x, the point of fault, branch Z_y at point y, the point of open circuit, and branch Z_z to the zero potential plane. Then

$$Z_x = -\frac{C_0 z_2 + C_2 z_0}{z_0 + z_2}$$

$$Z_y = \frac{C_0 z_2 + C_2 z_0}{z_0 + z_2} + \frac{z_0 z_2}{z_0 + z_2}$$

$$Z_z = -\frac{Z_x Z_y}{Z_x + Z_y} + Z_0 + Z_2$$

where

Z_0 and Z_2 are the zero and negative sequence impedances, respectively, viewed from the fault with no conductors open. z_0 and z_2 are the zero and negative sequence *series* impedances offered to zero and negative sequence *series* voltages, respectively, applied between points x and y with no faults on the system.

From the equivalent wyes with branches C_0, D_0, S_0, C_2, D_2, and S_2 representing the zero and negative sequence systems, the following relations may be obtained:

$$Z_0 = \frac{C_0 D_0}{C_0 + D_0} + S_0$$

$$Z_2 = \frac{C_2 D_2}{C_2 + D_2} + S_2$$

and

$$z_0 = C_0 + D_0$$

$$z_2 = C_2 + D_2$$

F. M. Starr (General Electric Co., Schenectady, N. Y.): Mr. Kimbark has made an interesting and valuable contribution to the existing literature on simultaneous faults and double unbalances in polyphase systems. His method of analysis on the a-c calculating board is novel and plausible. He has introduced the feature of coupling the phase-sequence networks through insulating transformers. As noted in the paper these transformers should be ideal ones, i. e., without resistance or reactance.

Coupling of this type may be introduced more accurately by using an equivalent linkage instead of an actual transformer. There are several such linkages but the most suitable one is shown in figure 1 of this discussion.

This linkage is composed of 6 simple impedance links which are already available on the calculating board. It may be given any resistance, reactance, and ratio characteristics which the particular system demands. In this case $L_1 = L_2 = M$, which corresponds to zero reactance and a ratio of unity. For derivation of this circuit, see "Equivalent Circuits—I," F. M. Starr. A.I.E.E. Trans., v. 51, June 1932, p. 287–98.

E. W. Kimbark (Massachusetts Institute of Technology, Cambridge): Neither the ideal transformer nor the phase converter has been perfected. Therefore the suggestion of Mr. Starr, concerning the use of an equivalent impedance linkage in place of an actual transformer, and that of Mr. Bibber, concerning a phase converter using thyratron tubes, are most welcome.

An ideal insulating transformer of unity ratio has several uses in connection with the calculating board in addition to those suggested in this paper; for example, in representing the mutual impedance between parallel transmission lines not bused at either end,[1] and in setting up electrical analogues of structures.[2] Research to determine how the ideal coupling may best be attained, whether by a linkage of inductive and capacitive reactors or by a transformer, using in either case the best magnetic materials, would seem worthwhile. If neither method gives sufficient precision for desired application, various methods of compensation can be resorted to. Mallock[3] has devised an automatic method of supplying exciting current; another possibility is to supply the exciting power mechanically, and the reactive volt-amperes by condensers, as has been done for the phase converter. Similar means might be used to compensate for the leakage impedance.

Perhaps it should be pointed out that the linkage presented by Mr. Starr is not "ideal" unless the reactors can be built with no resistance. At the same time the reactance values should be very high to reduce the exciting current to a negligible quantity. The equivalence between the linkage and the transformer holds only at a single frequency; as the calculating board is operated at a constant frequency, this is satisfactory, provided that the circuit is not too sensitive to small frequency fluctuations.

My paper did not go into much detail on the equivalent-circuit method, as the principal contribution was believed to lie in the extension of the connection method. Miss Clarke's discussion therefore serves to amplify that part by deriving the equivalent T or wye circuit for one type of combined series and shunt unbalance. The derivation of equivalent circuits for simultaneous faults is given in her own paper (reference No. 3 in the paper). It will be observed that the resulting algebraic expressions are rather complicated. The use of the connection method dispenses with a large amount of algebraic and arithmetical work.

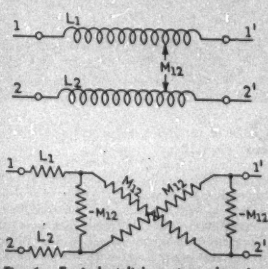

Fig. 1. Equivalent linkage to replace insulating transformer

References

1. Discussion by W. A. Lewis of F. M. Starr's Equivalent Circuits, A.I.E.E. Trans., v. 51, June 1932, p. 323.

2. Structural Analysis by Electric Circuit Analogies, V. Bush. *Jour. Franklin Inst.*, v. 217, March 1934, p. 289.

3. An Electrical Calculating Machine, R. R. M. Mallock. Royal Soc. *Proc.*, series A, v. 140, May 3, 1933, p. 457.

The Insulator String

Discussion and author's closure of a paper by R. W. Sorensen published in the August 1934 issue, pages 1221–4, and presented for oral discussion at the transmission session of the Pacific Coast convention, Salt Lake City, Utah, September 6, 1934.

G. M. Barrow (Westinghouse Elec. and Mfg. Co., Derry, Pa.): Sorensen's time load tests on suspension insulators supplement similar tests that were started some years ago and which are being continued by various insulator manufacturers. In general, the log of his tests checks similar results on tests with which I have been associated. According to the figures, the longest duration of any of the tests so far recorded was 140 days. No doubt the test will be continued as it is of interest to compare performance over a period of some years.

From the illustration in figure 1 of the paper it appears that the test set-up is in a laboratory. Such location and performance over a short period as reported offers a good comparison of the relative ability of the insulator designs to distribute sustained load stress. The dielectric failure of the insulator may be assumed to occur when the critical fatigue limit is reached. This limit is a product of maximum stress in the porcelain and time. No mention is made of the insulator being subjected to temperature changes. Differential expansion is an important factor in determining the resultant stress of load and thermal changes. The addition of thermal changes to the load test would provide a more complete comparison of performance. The performance of such combined tests is reviewed in my paper in Electrical Engineering, June 1934, pages 867–70.

The data compare the respective performance of the different insulators on the several loads. Supplementing the authors first conclusion the evaluation of each individual design can be determined by comparing its time load performance with its average A.I.E.E. combined mechanical and electrical strength and its ultimate strength. As an example, I have observed that a commercial suspension insulator with an average A.I.E.E. combined mechanical and electrical strength of 22,000 pounds suffered failures

in 60 per cent of the units in one week at a load of 10,000 pounds. Another design with an A.I.E.E. strength of 15,000 pounds has shown no failures in 2 years at a load of 11,500 pounds. Obviously, the latter insulator is superior in design.

In his second conclusion the author attributes the improvements in the last 15 years to the first half of this period. This may apply to some extent to manufacturing processes but the features of design that are responsible for the marked improvement in mechanical performance were developed, as indicated by literature of the Institute, during the latter part of this period. The only glass suspension insulator developed commercially during this period has a poor ratio of time load to quick time test values.

Conclusions 1 and 4 are in accordance with good engineering practice.

W. A. Hillebrand (University of California, Berkeley): The tests reported by Sorensen are valuable because they contribute to our knowledge of insulator performance under a known set of conditions, and information so difficult and expensive to obtain is doubly welcome. The careful and thorough manner in which the tests have been made leads to the hope that they will contribute to our understanding of the insulator problem.

However, it must be recognized that 90 per cent of suspension insulators are used where they can never during their lifetime be subjected to a load greater than 5,000 pounds, even on the most heavily loaded line. The standard 10 inch disk today is designed for 15,000 pounds mechanical and electrical strength, with a strong tendency to appraise competitive designs by their ability to pass high time-loading tests.

The justification for this course has been clearly stated by one engineer as follows: "Although it is not proposed to use insulators at higher working loads than formerly, nevertheless it is felt that the ability to support sustained, high loads without failure is proof of low specific stresses in the dielectric at the usual working loads and should result in a longer lived insulator." Such a line of reasoning stresses the loading test, places a premium upon the maximum values, and forces designers to use thicker and thicker parts because the elastic limit in the metal obviously may not be exceeded.

The use of heavier metal parts imposes higher thermal stresses upon the 90 per cent of insulators in suspension position, and suspension insulators fail. Therefore, in the writer's opinion, the results of time loading tests are useful, principally in connection with thermal tests in estimating the relative merits of different designs.

Referring now to specific parts of the paper, the values of figure 10 are presumably dry flashover at 50 cycles. Is this not so? Were corresponding data obtained with impulse voltages and at power frequency with insulators wet?

In the last paragraph on page 1224 it is stated that careful maintenance should permit the occurrence of not over 2 bad insulator units per string. A requirement as onerous as this would impose an unreasonable burden of inspection and testing and is probably impossible of fulfillment. The distribution of depreciated units among the various strings will, in general, be of a random nature according to the law of probability. This means that with a 13 unit string and 5 per cent of the total number of insulators bad, there would be a total of 650 bad insulators per 1,000 strings with a probable distribution as follows:

351 strings with 1 unit bad
110 strings with 2 units bad
21 strings with 3 units bad
4 strings with 4 units bad

If lightning is the principal hazard, the probability of a tower being struck which supports one of the strings with 3 or 4 bad is slight. However, if the hazard is due to a combination of the operating voltage, dirt, and moisture, a single string with more than the minimum permissible number of bad units is likely to fail.

G. M. Whistler (Westinghouse Elec. and Mfg. Co., Emeryville, Calif.): A review of Barrow's comments suggests certain amplifications within the $7^1/_2$ year period referred to by Sorensen, during which time little development has been made according to his claim. It should be emphasized that for the first year or 2 of this period it was very difficult for the majority of the insulator companies to meet successfully with any degree of consistency a 6,000 pound time load test for even 72 hours.

At the present time, as indicated by Barrow's and Hawley's papers, such tests can be met with a greater degree of success at loads increased from 75 to 100 per cent. This indicates very definite improvement in suspension insulator designs, particularly when it is considered that the head and cap dimensions for the present day 15,000 pound insulator are considerably smaller than in the former 9,000 or 11,000 pound insulator. Using dimensions similar to these former insulators, it is possible today by reason of improved design to meet strengths essentially in the high strength of 25,000 pound class. These improvements, as indicated by the papers referred to, were accomplished by design details which utilize the vastly greater compression strength of porcelain and subject the insulator to rise of tension and shear components.

R. W. Sorensen (California Institute of Technology, Pasadena): Barrow's deduction as to the tests being conducted in a laboratory and that, therefore, the insulators on which the tests were made were free from differential expansion due to temperature changes, is correct. In fact, the particular laboratory in which the tests were made is one that is very free from any sudden changes in temperature, humidity, or barometric pressure, and is, because of the absence of these changes, all the better suited as a laboratory for such tests as those under discussion.

We have considered similar tests made with temperature changes and continuously applied voltage, but so far for the purpose we had in mind have thought them of insufficient value to warrant the trouble and expense involved in their making. On the other hand, the insulators, as was mentioned in the paper, have not been wholly without the effect of stress changes because each unit as it failed was replaced by a new one, an operation which required the unloading of the string and a reloading thereof. Our experience on this test showed quite clearly that these changes in loading were a factor in shortening the life of many units as compared to what the life might have been with no fluctuations in load.

As I examine the tests I have reported, I am not at all inclined to agree with Barrow's inference that our tests show that "the only glass insulator developed commercially during this period has a poor ratio of time load to quick time test values," unless he includes in his statement that most of the porcelain insulators act the same way; because, as a matter of fact, in the paper by intention I have very carefully avoided any notation which would show the type or make of insulator to which the data given applies. But, he has brought up the subject, I think it only fair to state that the glass insulators we tested had a life expressed in pound days of load well above the average of the insulators covered by the report made in my paper.

I do not think any reply is needed for the comments of Hillebrand and Whistler, other than to say that none of the discussion given has changed my opinion that 13 units per string will be ample for most of the 230 kv transmission lines which will be used by the Metropolitan Water District to supply power from Boulder Dam to its pumping stations.

Field Tests on Conductor Vibration

Discussion of a paper by E. M. Wright and J. Mini, Jr., published in the July 1934 issue, pages 1123–7, and presented for oral discussion at the transmission session of the Pacific Coast convention, Salt Lake City, Utah, September 6, 1934.

A. E. Davison (Hydro-Electric Power Commission of Ontario, Toronto, Can.): The conclusions drawn and recorded in this paper are the result of experimental work and should receive more than ordinary attention because they appear to cut across a considerable number of thought and idea paths. These conclusions may even encounter some prejudice. For instance, it is a little difficult to reconcile the conclusion that "for the particular type of conductor and dampers tested, one damper installed on the conductor approximately 4.5 feet (1.37 meters) from the suspension clamp at each end of the same span will sufficiently limit vibration under all conditions and is better from a damping standpoint than an additional number," with the record found in *Electrical West*, April 1934, page 34, wherein photographs record the installing of absorbers 2 or more at a time under comparatively strenuous and difficult conditions. It may be that quite a different type of conductor damper is being recorded by the photographs referred to in the magazine, or it may be that when the work illustrated is finished only one absorber will be used at each end of the span, thereby conforming to that more economical practice pointed out in the paper.

Prejudice may also be encountered because of the industry's having introduced,

during several years past, a considerable number of trunnioned clamps, first used in Germany as far back as 1897 or thereabouts. For instance, conclusion number 4 states that "the tendency to either retard or aid the transmission of vibration waves from one span to the adjacent ones" is not noticeably different when using trunnion or nontrunnion types of clamps. It will be inferred from this conclusion that fatigue is similarly not affected. Alternately, a recent investigator in Europe (H. Maass, Elektrotechnik und Maschinenbau, Jan. 14, 1934) seems to have satisfied himself that there is an improvement in the life of the equipment when using trunnioned clamps for he says, according to translations, that cables suspended in the older types of clamps were ruptured after 3 million vibrations, artificially applied, whereas new types of clamps investigated similarly but using lighter material and rotating about an axis at right angles to the cable showed considerable improvement.

Certain questions arise regarding the interpretation of the data secured. For instance, is it good practice to assume that the undamped conductor can be taken as a basis for observation of the other 2 conductors? We think that the recorders as indicated in figure 1 of the paper may of themselves introduce a considerable suppression, or may break up certain of the wave systems or trains which are being generated in both the damped and undamped cables. Are we reasonably sure that this damping, if any, by the instruments themselves is having a similar or equal effect in the vibrations which are being investigated, first in undamped and second in damped spans?

Can it be correctly inferred from figure 4 of the paper, where 3 dampers and 2 dampers per span at one end are indicated, that 2 dampers are actually better than one in suppressing vibration? Some readers might not so interpret the charts.

Is it correct to infer from figure 5 that the distance from the tower at which recorders are set has some bearing on the resulting records? It apparently is not clear in the paper whether the damper experimented with was especially designed for the particular type of conductor or the standard commercial article picked at random and used on the particular cable.

G. W. Stickley (Aluminum Company of America, Massena, N. Y.) and **H. L. Anderson:** Certain tests described by the authors, studying damping effects of different numbers and spacings of Stockbridge dampers, are similar to some made at several field laboratories of the Aluminum Company of America, a preliminary report of which was made several years ago. (Vibration of Overhead Transmission Lines, R. A. Monroe and R. L. Templin. ELECTRICAL ENGINEERING, July 1932, pages 482–7, and August 1932, pages 562–8.) It is of interest to note that in such cases the results in general are in close agreement. In this connection there are several comments which can be made.

In their conclusions, the authors state that although the conclusions "apply only to the type of conductor, the particular location, span, and tension used, it is quite probable that the same general conditions would be found in other conductors, regardless of size, tension, and span." Referring to the first conclusion, this should not be interpreted as meaning that for all sizes of conductors the best location for the dampers is 4.5 feet from the suspension clamp, for this factor, like damper weight, naturally varies with cable diameter, as shown in figures 1 and 2 of this discussion.

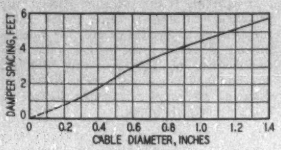

Fig. 1. Stockbridge damper spacing

Spacing of dampers is from center of suspension clamp, edge of insulator groove, or mouth of dead end

Similarly, referring to the second conclusion, the most prevalent frequencies will vary inversely with conductor diameter, and also may be different in different locations. At Massena, N. Y., 795,000 circular mil aluminum cable steel reinforced has been observed to vibrate with frequencies of from 4 to 40 cycles per second, the most prevalent being from 10 to 30 cycles per second.

The first conclusion also states that "one damper . . . at each end of the same span . . . is better from a damping standpoint than an additional number." With dampers of the design which we have found most adequate when used singly at each end of average length spans, our observations have shown no diminution in damping effect from the use of additional dampers. The amount of work to be done by dampers naturally increases with span length, and it would seem logical to vary either the damper weight, or the number of dampers, with the span length. The former is undesirable because, if the ratio of damper weight to unit weight

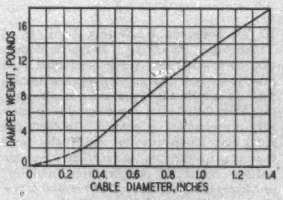

Fig. 2. Stockbridge damper weights

of the conductor becomes too great, a reflection point may be formed at the damper, with resulting decrease in damping efficiency. For this reason, and also for simplicity, our work has led to the development of one size of damper for each conductor diameter and the use of more than one damper at each end of the span where the span length is sufficiently great to require it. This led to observations for determining the limiting span length for the use of one damper at each end. For 795,000 circular mil aluminum cable steel reinforced we have chosen this limit conservatively at 1,000 feet. The limiting span length for 2 dampers at each end has not yet been definitely determined, but is at least 2,000 feet.

The results of the tests of the effect of trunnion versus nontrunnion clamps confirm our ideas regarding the relative merits of these 2 general types, our ideas formerly having been based partly on observations in endurance tests made on 120 foot spans in an indoor laboratory with mechanically vibrated test samples.

Figures 1 and 2 of this discussion are based on tests made at 3 locations, including 870 foot and 1,060 foot spans in an actual transmission line in New Jersey, and experimental spans from 400 to 1,225 feet long in Texas and New York. These tests to date cover a period of more than 30 months, and include approximately 8,500 24-hour vibration records from 7 different sizes of conductors from 0.25 to 1.40 inches in diameter. In addition, certain of the data shown have been confirmed in records from spans in actual transmission lines in other parts of the United States and in foreign countries.

Insulator Surface and Radio Effects

Discussion of a paper by W. A. Hillebrand and C. J. Miller, Jr., published in the August 1934 issue, pages 1213–20, and presented for oral discussion at the transmission session of the Pacific Coast convention, Salt Lake City, Utah, September 6, 1934.

W. A. Kates (Corning Glass Works, Corning, N. Y.): I note that the authors conclude from their tests with needle gaps in foggy atmosphere that the dielectric strength of air is a maximum under fog conditions, and I wonder whether this was also corroborated by sphere gap tests. I would expect sphere gap sparkover to be increased if the effect noted was an increase in strength of the air itself.

I would like to ask the authors if, in their experiments with liquid electrodes and the arrangement of figure 1, the effect of the glass adjacent to the liquid electrodes was the same as for the metal electrodes. Were glass strips fastened to the brass electrodes when the upper curve of figure 2 was taken? Also, would the lower curve of figure 2 be greatly changed if the glass surface were continuous across the space between the 2 liquid electrodes, as it would be, of course, on the top skirt of a pin type insulator supporting 2 charged drops?

Figure 3 of the paper shows a simplified representation of the circuit made up of the different parts of an insulator. It seems to the writer, however, that this circuit is not quite complete and that the inclusion of the additional elements in the diagram leads to conclusions differing from those of the author. Successive portions of the dielectric of an insulator are quite conveniently represented by the capacitances C_1, C_2, and C_3. Also, air gaps are in parallel with all of the capacitances, and each

capacitance is shunted by the surface resistance of the insulator. Let us for purposes of discussion represent these by R_1, R_3, and R_5. Assume further that C_1 and R_1 represent the capacitance and surface resistance, respectively, between the tie wire and a portion of the surface 1 centimeter away, "air line" distance. The sum of R_4 and R_5 will then be much greater than R_1. This is true so long as a reasonably uniform surface resistance per square inch obtains. If, now, R_1, R_3, and R_4 are all decreased, there should be less tendency to break down the gap G because there will be a lower voltage between the tie wire and the point on the adjacent insulator surface. This is especially true in the case of the common pin type insulator where R_3 and R_5 probably do not decrease in value in direct proportion to the decrease of R_1.

The foregoing predicts less corona on a pin type insulator, for example, when the surface adjacent to the tie wire is conducting. This is confirmed by our experience in the design of corona-free insulators. The elimination of corona at the tie and line wires presents very little difficulty; it is the termination of the surface coating which is the problem, as this coating must be terminated under such conditions of electrostatic field as result in no edge discharge.

Our experience as outlined confirms the authors' discussion concerning figure 7. I would interpret it as at variance with their conclusions from figure 3, however.

The experimental apparatus of figure 4 and the use of wash water from insulators as a surface coating is quite ingenious. However, there is one important difference between conditions in this apparatus and those of a pin type insulator. In the test apparatus, the electrostatic field at the dielectric surface is generally parallel to this surface, even though there is a bottom plate of conducting material. To the contrary, in a pin type insulator, the field is generally perpendicular to the top skirt. This difference is fundamental and would result in different edge effects of the dielectric adjacent to the electrodes and hence different relative test results as well as absolute ones.

G. M. Barrow (Westinghouse Elec. and Mfg. Co., Derry, Pa.): The authors' investigation and determination of the surface contamination on insulators exposed to salt, fog, and dust, and their exposition on wet arcover and initiation of an arc on an insulator, are of interest. The results of the radio interference measurements in table III indicate that such coating on insulators becomes conducting under conditions of high relative humidity or fog to a degree sufficient to cause disturbance. Perhaps the statement at the end of the section on radio influence "that a pin type insulator should exhibit corona at the tie wire at a much lower voltage when its surface is coated with a conducting film than when it is not coated" should be qualified. A conducting coating in contact with the conductor or tie wire reduces the potential gradient over those areas. This is a form of treatment that improves the radio interference characteristics of a pin type insulator as reviewed in Gilchrest's paper, ELECTRICAL ENGINEERING, June 1934, pages 899–903.

Referring to the authors' mention of the diminishing intensity of interference at distances from the transmission line, and the absence of any interference in receiving sets in nearby residences, it is of interest to note that, if the receiving set is beyond the field of influence of the line itself, in some cases disturbance may be conveyed to the receiver on the service taps by carrier current effect.

As the authors suggest, one remedy for the conditions they investigated is to keep the insulators clean of contamination which is both expensive and difficult. It is doubtful if the low capacity type of insulator to which they refer would offer any improvement as the causes of interference are surface conditions which would develop with any type of design.

F. W. Maxstadt (California Institute of Technology, Pasadena): It is stated in the fourth paragraph of the paper and again under the heading "Initiation of an Arc" that between 30 and 60 milliamperes are required for a preliminary arc "to be maintained until the gap between conductor and ground is bridged." Since this is an extremely important observation it would be helpful to know whether the value was measured by means of an ammeter in series with the insulator just prior to arcover or calculated from measured surface resistance or obtained in some other way.

If such a value applies over a wide range of insulator shapes and sizes and is determinable without high voltage equipment but instead may be calculated from megger readings, a new means of predicting impending insulator trouble is available.

In order to check this observation, I have prepared glass rods 2 inches in length but of diameters varying from $^1/_4$ to 2 inches. One after another these rods were placed between parallel plates and sprayed with a mixture of magnesium chloride and table salt (about 150 milligrams of each dissolved in 75 cubic centimeters of distilled water), tested for wet and dry resistance, and flashed over. In each case the flashover voltage was about 8,500 wet and 21,000 dry (effective value). Strangely enough, the wet surface d-c resistance was about 300,000 ohms measured at 550 volts for each rod in spite of the ratio of 8 to 1 in extreme diameters. Taking into account the series protective resistance of 50,000 ohms, an initial current of about 25 milliamperes should flow.

When, however, a 50 milliampere meter was placed in series with the test sample and the voltage raised to near the flashover value, very erratic currents were observed, some swinging the meter off scale and some making it swing to 30 or 40 milliamperes. Even these flashes did not cause complete arcover and their peak currents must have been well over 60 millamperes in order to swing the meter needle up so high on impulses of very short duration. In these tests the only difference between the behavior of the 2 inch and the $^1/_4$ inch diameter rods was in the rapidity with which the latter dried out as compared to the larger rod. Only a matter of 5 or 10 seconds was required to dry the coating completely and reduce the leakage current to a minute value. Since a spark probably forms in only one narrow channel at a time, the diameter of the test piece should have nothing to do with the initial current required to cause complete arcover. That initial current, however, is well over 60 milliamperes and can probably be measured only with the cathode ray oscillograph. Insulator surface resistance as measured with a few hundred or even 1,000 volts has no direct relation to the current in question since the gaps that afford spark paths

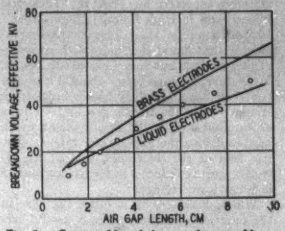

Fig. 3. Curves of breakdown voltages of brass and liquid electrodes

o = Needle gap

are high resistance paths in the resistance test and are short-circuited by sparks in the arcover condition.

When these samples were wet the initial glow, which formed on the surface as the voltage was raised, occurred at about 1,200 volts maximum or 600 volts per inch. It was barely visible at a distance of 2 feet in a very dark room and covered only a small fraction of the insulation surface. The value of 400 volts per inch given in the paper probably depends more upon size of insulator and total voltage than upon any calculated gradient.

In connection with the laboratory test specimen the statement is made that "the purpose of the annular ring was to provide a definite path uniform in all directions for leakage currents." It must not be supposed that the current density or voltage gradient will be in any sense uniform since a radial field is decidedly nonuniform. It would have been interesting to test in the laboratory some of the insulators actually used on the power line. The voltage of initial radio influence in terms of humidity and other tests such as those made on the artificial specimen might have yielded valuable information.

On page 1215, referring to the discrepancy in capacitance between the laboratory specimen and the commercial pin insulator, the authors state that the former was about twice that of the latter "so that corona for clean surfaces should occur at a lower voltage than for an insulator." I see no reason for a relation between capacitance of an insulator and its initial corona voltage unless the electrode area enters into the relation.

In table I the surface resistance as measured between electrodes in the laboratory test specimen when "clean" may have no meaning because of the uncertain area of contact between an approximately flat piece of brass and an approximately less flat piece of glass. When contaminated with wet conducting material the value is no doubt reliable.

In table II the last 2 lines, for clean glass surface, show diminishing radio effect for increasing relative humidity, whereas for contaminated surfaces the trend is in the opposite direction. This is not explained. Also it would have been considerably more convincing to have figure 7 actually completed to show the falling off of radio effect above 90 per cent humidity as predicted.

I offer figure 3 of this discussion with the addition of values of the average needle gap voltages as given by Peek in "Dielectric Phenomena in High Voltage Engineering," 1929 edition page 117. This comparison indicates that liquid electrodes with no intervening medium but air act like needle points. To be sure, for gaps below about 3 centimeters they have a slightly higher breakdown strength than the needle gap and for gaps above that length the liquid seems to be scattered into the gap by the intense electric field at the electrodes, so that the effective gap is reduced in length and hence in breakdown voltage.

When, however, as is often the case in the practical insulator, there is a solid surface extending between liquid electrodes, the voltages indicated in figure 2 should be reduced by 50 per cent or more. Figure 3 of the paper "Insulator Arcover in Air," F. W. Maxstadt, ELECTRICAL ENGINEERING, July 1934, page 1062, will show the effect of the presence of insulation surfaces between electrodes when the field is uniform. Approximately the same ratio may be expected for non-uniform fields.

In table III it would be interesting to know whether the 100 per cent humidity points are for fog, dew, or rain.

The authors suggest that the effect of sand and clay particles which stick to an insulator surface is to provide points for electrical discharge to take place. Experiments by Schwaiger (See "Theory of Dielectrics," A. Schwaiger, translation by R. W. Sorensen, John Wiley, 1930) on the arcover voltages of many substances in uniform fields indicate that roughness of an insulator surface has no effect upon the arcover voltage. Since in the commercial insulator no attempt is made to polish the electrodes or smooth down minute points, it would seem unlikely that particles of sand and clay on either insulator or electrodes would have an influence on its electrical behavior.

Hillebrand and Miller have brought out some very important observations. If radio effects cease at a distance of no more than 300 feet from a disturbing power line the great bulk of radio listeners have nothing to fear from such sources. Perhaps slow voltage branch lines can be completely isolated so as to transmit none of the radiations.

Since commercial insulators as used on power lines seem to be comparatively free from radio influence when dry or when clean and moist, according to the tests reported, and are still satisfactory when dirty and moist but operated at lower voltage, there are 2 not unreasonable remedies for power line radio influence. The first is to keep the insulators clean. The second is to provide additional insulation so as to reduce the voltage per unit to the range of quiet operation.

Radio listeners in metropolitan areas have nearby powerful broadcast stations to which to listen. These same areas are comparatively free from radio influences because of the pressure brought to bear upon the offenders. The combination is favorable to the listener. Conversely, the farther one goes from a metropolitan area the less likely he is to get satisfactory radio reception. There are 2 important factors working against him. First he must use a much more sensitive receiver to reach out for his favorite programs, because of greater distance to the broadcast station. Second, he is likely to have a great deal more local radio influence because of indifferent maintenance of the electrical transmission and distribution equipment in his neighborhood. If the disturbances from a high voltage transmission line extend only 300 feet, it should be commercially feasible to limit them to that area and prevent their extension over other circuits which can be made quiet in themselves.

Wide-Band Open-Wire Program System

H. S. Hamilton, April 1934 issue, pages 550–62.

Line Filter for Program System

A. W. Clement, April 1934 issue, pages 562–6.

Discussion of papers presented for oral discussion at the communication session of the Pacific Coast convention, Salt Lake City, Utah, September 3, 1934.

D. I. Cone (The Pacific Tel. and Tel. Co., San Francisco, Calif.): In assessing the value of the work reported by Hamilton and Clement it is important to bear in mind the greatly extended width of the transmission band of frequencies necessary for program transmission as compared with that for commercial messages. The field tryout and application of the wide band open wire program system involve the organization of apparatus, installation, and testing procedure over thousands of miles of line and in dozens of offices in such a manner as not to interfere with the commercial service being continuously rendered over the same pole lines and apparatus and even over the very wire circuits used for the experiments with the new facilities.

That the experiments were carried out and the new facilities placed in readiness for service with practically no interference of any kind with commercial working schedules is a tribute to the work of the authors and of their many associates in the numerous offices and companies whose plant and operations were involved.

The result is a system that meets highly exacting requirements of fidelity, that requires minimum effort to maintain it in satisfactory operating adjustment, and that takes its place in the open wire lines surrounded by numerous other communication channels over the distances necessary in transcontinental program service.

Joint Use of Poles With 6,900 Volt Lines

Discussion of a paper by W. R. Bullard and D. H. Keyes published in the December 1933 issue, pages 890–8, and presented for oral discussion at the management and protective devices session of the Pacific Coast convention, Salt Lake City, Utah, September 4, 1934.

W. G. Rubel (Mountain States Tel. and Tel. Co.): The "Principles and Practices for the Joint Use of Wood Poles by Supply and Communication Companies" were formulated by the joint general committee of the National Electric Light Association and the Bell System in 1926. Since that time a large amount of research work has been done with a view to increasing the safety in situations where joint use at the higher distribution voltages appears to be the best over-all engineering solution. These studies have included investigations of a number of cases of actual contact between supply wires and telephone plant. The information now available shows conclusively that under unfavorable conditions the results of such contacts may be serious. However, coördinative measures have been developed such that under favorable conditions their application will reduce the hazards involved in joint use at these higher voltages so that they are comparable with those involved in many existing situations of joint use with the ordinary distribution voltages. This paper describes a situation involving favorable conditions. Prompt deënergization of the power system following a contact is one of the most important considerations. Other favorable conditions include limited fault current, the presence of telephone cable or paired wire rather than open wire, and low resistance protector grounds at telephone subscribers' stations.

Although excellent progress has been made in the study of the problem of higher voltage joint use, no general solution has been found and it is therefore necessary to adhere to the practice of entering into such joint use only in those cases where specific study shows it to be the best over-all engineering solution. Field engineers of the operating companies of the Bell System, appreciating the desirability and advantages of joint use distribution, would welcome a solution of the problem which would permit a more general application of joint use than has heretofore been thought feasible in situations involving voltages of over 5 kv. With the progress already made and the coöperative studies now under way by the joint committee, there is every indication that such a solution will shortly be reached.

While the construction of separate non-conflicting power and telephone lines to avoid joint use with the higher distribution voltages will in many cases reduce the probability of contacts, this is not always true where numerous drop and service wire crossings result. Furthermore, the construction of separate lines in built-up areas is often not satisfactory from the public's standpoint and the economies and other advantages generally associated with joint use are, of course, sacrificed by such construction. In view of these facts, any proposal of a

power company to use circuits of over 5 kv for house-to-house primary distribution in a particular urban area directly affects the telephone company operating in that locality, whether or not the power and telephone circuits are to be carried on joint poles. Any decision as to the use of such distribution voltages in built-up communities should, therefore, be based not only on a joint consideration of power system economies and advantages, but also upon a joint consideration of changes in the degree of safety to telephone plant and equipment which may be involved.

In rural areas where both power and telephone distribution is relatively much less dense, it is often practicable and more economical to maintain separate pole lines on opposite sides of the road. Where the telephone circuits are made up of open wire, and water pipe grounds are not available at subscribers' premises, both the hazard and induction problems involved are much more difficult than in urban areas where the telephone circuits are carried in cable and there are water pipe grounds at subscribers' stations. In rural areas, however, important economies could sometimes be effected through joint use if the hazards and induction difficulties could be taken care of at a reasonable cost, and it is therefore important that each situation of this kind where joint use is proposed be carefully studied.

The degree of hazard in any situation involving possible contact between power wires and telephone plant cannot be measured solely by the voltage of the power circuit. A number of factors must be taken into account, among the more important of which are:

1. The maximum voltage to ground which can reach the subscribers' stations or the central office as the result of a contact.
2. The maximum current that can flow from the point of contact to ground *via* the telephone plant.
3. Whether cable or open wire telephone circuits are involved.
4. The length of time that a power wire may remain energized and in contact with the telephone plant.
5. The resistance of telephone station protector grounds, cable sheath grounds, and central office grounds.
6. The probable frequency with which contacts may be expected to occur.

Even with the greater strength of construction, better clearances, and higher insulation employed with the higher voltages, accidental breaks are liable to occur in both the telephone and power conductors which may result in direct contact between the 2 classes of circuits. Safety is a relative matter, and there is no known method of constructing pole lines carrying both open wire power circuits and telephone plant that may be said to be entirely free of hazard. Therefore, the selection of coordinative measures to be applied in any given case of joint use is largely a matter of judgment, and the ones selected will normally be those whose costs are not out of proportion to their benefits from a safety standpoint.

P. P. Ashworth (Utah Power and Light Co.): This paper is of utmost importance and value because it indicates that a step has been made in the right direction; that is, toward the elimination of an arbitrary voltage limitation for joint use in favor of procedures based upon sound economic and engineering analyses of the specific situation involved. I commend this method of approach to the problem of joint use.

It was no surprise to me that the 6,900 volt system was proved more economical than the 2,300 volt. In fact, to those of us in the West, who are accustomed to the use of higher distribution voltages, the economic answer would have been quite obvious from the beginning.

I am not sure that I would have stopped at 6,900 volts delta, unless some unusual obstacles prevented, but probably would have gone to 11,500 volts wye so as to get the outstanding advantages of the wye system over the delta. An 11,500 volt wye system, with the neutral wire bonded to the telephone cable messenger and grounded at frequent intervals, would, in my opinion, be a safer and better scheme than the 6,900 volt delta system selected. With the wye system the special grounding bank would have been unnecessary.

In our approach to the joint use problem I believe we should, at the outset, separate the cases into 2 distinct classes, and build up construction specifications with the particular class in mind. One class would involve power and open telephone circuits, and the other power wires with lead sheath telephone cables. The conditions and hazards are quite different in the 2 classes of joint use, and the specifications should take account of this fact. Personally, I cannot see that, with proper relaying of the power circuit and protective grounding, the voltage, or even the grade of construction, has much to do with the hazards to a sheathed telephone cable on jointly used poles, whereas these factors are all-important when open wire circuits are involved.

In every case the design features should be clearly set forth at the outset, as was done by the authors in the study described in the paper.

It may seem, at first thought, that a major application of higher voltage joint use will be on rural lines. However, modern rural line practice dictates the use of long spans of 250 feet and more. The extra costs, etc., of providing and maintaining high-grade construction for joint use on such lines will, in most cases, justify building separate pole lines.

R. F. Penman (Electric Bond and Share Co., New York, N. Y.): Joint construction at the lower distribution voltages has been and now is so well established that we cannot question the continuation of this practice or the benefits to both the power and communication companies using it. Many separate power and communication leads now in the same alleys, streets, or highways will be combined on joint poles when their condition warrants reconstruction and simplification.

Many of the power utilities have found it an economic necessity also to establish and use a higher distribution voltage such as 6.9 kv, 11 kv, 13.8 kv, or higher. Joint construction at these voltages would appear to offer comparable advantages to those already realized with joint construction at the lower distribution voltages if the personal and property hazard be not increased.

Many companies have already entered into extensive joint use with their higher voltage distribution lines. Replies to a recent questionnaire distributed by the Edison Electric Institute showed that 54 per cent of the companies answering reported that they had some joint use at voltages above 5 kv, varying in extent from a few poles to over 300 miles, and including a total of over 1,000 separate cases.

Even though this relatively extensive joint use at the higher distribution voltages has been entered into we all appreciate that the problem is far from solved as both utilities must coördinate their facilities not only for the maximum economy but with careful attention to the reduction in hazards to customers operating personnel, and the utility plants.

Studies of the mutual problems of the power and communication utilities have been undertaken coöperatively by the E.E.I.-Bell System joint subcommittee on development and research. The representatives of these 2 pole-using utilities on this subcommittee have made notable progress in determining the basic factors covering the proper methods to employ in the proper coördination of the 2 plants. It appears to me that this is the only practical method of attack in dealing with mutual problems of this nature.

One of the questions raised was whether there was economic justification for the power companies to have or to increase their distribution voltages above 5 kv. The Staten Island situation was selected as a specific case for study and the paper by Bullard and Keyes has given the results of this study very clearly.

It is indeed interesting to find that the change from 2,300 to 6,900 volts reduces the distribution investment by $571,000 and reduces the losses by 24,000,000 kilowatt hours over a period of 20 years. The study clearly justifies the conclusion drawn, namely, "The adoption of the higher voltage in the power system appears, therefore, to provide the best engineering solution in this case and joint use of facilities apparently may be entered into in all instances in Staten Island where the 2 services should preferably be placed on the same poles."

The decision in favor of joint construction in the Staten Island area not only recognizes the advantages from an economic standpoint but also clearly illustrates the splendid attitude of coöperation which now exists between the power and communication engineers.

Some may be inclined to criticize this paper on the ground that it covers almost an ideal case for higher voltage joint use as the average spans are short, grounding conditions are good, and the telephone circuits are largely in cable. However, this thorough treatment of a relatively simple specific case appears to me to be the logical first step in treating a very complex and involved general problem for which we hope and expect a satisfactory solution will be found through continued coöperative effort and study.

A similar study has been made of the joint use situation at Grand Rapids, Mich., primarily from the standpoints of hazard and protection instead of economics. In this case the voltage was somewhat higher, being 7,200 volts, the average span lengths were about 35 per cent longer, and more

open wire was used on the telephone facilities. The same general conclusion, that joint construction was the best engineering solution, was arrived at.

Additional studies are now under way, involving higher voltages and other conditions, and even though it is too early to predict the outcome of these studies it appears that a satisfactory general solution involving joint construction will be found as the answer.

Study of these specific cases will in time clarify the fundemental requirements that both utilities must meet before general joint construction at the higher voltage can be freely employed. Even at the present time we can agree that the power utilities should provide speedy disconnection of their circuits when contacts occur. Of course this also implies adequate grounding of the communication facilities and protective devices.

In this area the operating companies distribution voltages are largely 4-kv 4-wire and 11-kv 4-wire. The connection of new loads to 4 kv circuits in time makes it necessary either to construct additional 4-kv feeders or to change the voltage on existing 4 kv circuits to 11 kv. Sometimes the additional 4 kv circuit proves to be the more economical solution. In other cases raising the circuit voltage is by far the cheaper procedure.

In view of this, when we enter joint construction with 4 kv distribution lines we should know that ultimately we can stay in joint construction if the load conditions increase to such an extent that the 11 kv circuit is necessary. Using joint construction at 4 kv and later building separate lines if the voltage needs be increased to 11 kv is certainly not a satisfactory answer.

The paper under discussion illustrates this point very definitely. If joint construction at 6,900 volts had not been successfully worked out in this case then the choice would have been between 2,300 volts with joint construction or 6,900 volts with separate lines. The 2,300 volt system with joint construction would probably have proved to be the more economical, even though the paper doesn't discuss this possibility, and in this event the $571,000 of potential saving in investment and a 24,000,000 kilowatt-hour reduction in losses would have been lost.

I believe the 2 utilities, led by the joint subcommittee, will find a satisfactory general solution to this problem and in time establish the proper bases under which higher voltage joint construction can be safely and advantageously employed.

W. R. Bullard (Electric Bond and Share Co., New York, N. Y.) and **D. H. Keyes** (Bell Tel. Labs., Inc., New York, N. Y.): In the discussion by Ashworth several interesting points are raised which warrant further consideration. The question of the utilization of the 11,000 volt grounded wye system instead of the 6,900 volt delta received considerable discussion in the early stages of this study. The decision to use the 6,900 volt delta system was made by the engineers of the operating power company. They preferred this system because by so doing they could utilize a large amount of existing equipment.

The bonding of the telephone cable and the neutral of the distribution system introduces a series of new problems involving not only the protection features, but also questions of noise on the telephone circuits and electrolysis of underground cable sheath. Various phases of this problem are now under investigation and it is expected that it will be necessary to complete a comprehensive investigation of the entire subject before mutual agreement can be reached as to whether or not such a practice would be satisfactory.

In discussing the advantages of utilizing a grounded wye connection, Ashworth points out that this would make unnecessary the grounding bank. As brought out in Rubel's discussion, the amount of current which flows into the telephone plant when in contact with power conductors is one of the factors which enter the problem of relative safety. The grounding bank introduces current limitation which generally is not obtained when the system is operated wye grounded. The methods to be employed for equivalent safety for a wye grounded system are being studied.

The committee is actively engaged in studying all of the factors which enter into the problem of safety for the different kinds of plant involved and has been continuously confronted with the necessity for a different treatment of cases which involve open wire as compared with those which involve cable only.

The Expulsion Oil Circuit Breaker

Discussion and author's closure of a paper by A. C. Schwager published in the July 1934 issue, pages 1108–15, and presented for oral discussion at the management and protective devices session of the Pacific Coast Convention, Salt Lake City, Utah, September 4, 1934.

D. C. Prince (General Electric Co., Philadelphia, Pa.): The general drift toward explosion chambers of one sort or another is a fine tribute to the foresight of such pioneers of the oil circuit breaker industry as E. W. Rice, Jr., E. M. Hewlett, and J. D. Hilliard. These pioneers were so prolific that it is difficult for any present-day engineer to produce a design which does not bear a strong resemblance to some vision of one of them. It is no discredit to Schwager that this is so in his case.

Figure 1 is a reproduction from a Hewlett patent application which was filed in 1910. This patent shows an explosion chamber with stationary segmental contact at one end into which the contact rod slides. The explosion chamber has 2 vents, as in Schwager's case. This stationary contact is located just outside the chamber through which the moving contact passes. In operation the moving contact is withdrawn into the explosion chamber setting up a blast through the vent adjacent to the fixed contact in a manner very closely resembling that described by the present paper. If Schwager's theory is accepted at its face value, the Hewlett design would be even better since it is not necessary to expel a block of oil before an active gas blast can take place.

Although Schwager's conception of the theory of operation of the explosion chamber differs from my own theory, the important fact is whether the design does or does not operate efficiently under practical conditions rather than whether it operates on one theory or another. However, it should be recognized that, as between 2 theories, some sort of critical test must be set up which would be expected to work differently depending upon which theory of operation actually represented what has taken place. For instance, in the tests at the Philo plant of the Ohio Power Company, Zanesville ("Circuit Breaker Field Tests," R. M. Spurck and H. E. Strang. A.I.E.E. TRANS., June 1931, pages 513–21, and *Electrical World*, Jan. 31, 1931), 2 forms of explosion chamber were compared, all other things being the same. In the first form a conventional explosion chamber was employed having a throat and hollow contact through which the oil in the chamber would be expelled. In the second form, an intermediate contact was placed in the explosion chamber allowing pressure to be generated so as to force solid oil out through the explosion chamber throat and contact. The tests were conducted with the same system set-ups and currents of the same order of magnitude. In 28 tests the plain explosion chamber showed an average arc duration of 8.6 cycles as compared with 3.5 for the oil blast in 40 tests under the same conditions. It is felt that this type of comparison is required if any valid conclusions are being drawn concerning the active element in interrupting the arc.

Schwager conclusively determines that the explosion chamber is very much superior to the open arcing between plain contacts as an arc interrupting means. His tests throw no light on whether the active agent is a gas blast or a more or less fortuitous oil blast. Various other conclusions drawn by him do not seem to be very well established. I do not feel that he has recognized the full achievement of the prior art in reducing arc energy when he states that 0.5 kilowatt-second per thousand kilovoltamperes is generally considered the best value obtainable. In the paper "The Oil-Blast Circuit Breaker," D. C. Prince and W. F. Skeats, A.I.E.E. TRANS., June 1931, pages 506–12, a record of 23 tests was given with values as low as 0.06 and an average of 0.18 kilowatt second per thousand kilovoltamperes. Such values are bettered in the performance of the high voltage impulse circuit breaker.

Noticeable oil deterioration would hardly be expected on the tests recorded. In Philo tests, Spurck and Strang recorded a series of 40 tests under conditions very much more severe than Schwager's in which the dielectric strength dropped only from 30 to 28 kv.

All of the interrupting tests reported by Schwager were single phase to ground tests with maximum recovery voltage of 65 kv. In an article "To Interrupt High Voltage in Three Cycles," D. C. Prince and E. W. Boehne, *Electrical World*, June 2, 1934, it was explained why it is that the first phase to clear a 3 phase fault has to clear a recovery voltage of 86.6 per cent of line to line voltage. For this reason it should have been necessary for Schwager's breaker to clear a 95 kv fault in order to demonstrate its ability to successfully interrupt a

110 kv circuit. These values are the rms 50 or 60 cycle components. A high frequency oscillation is superimposed on these values and may reach a considerably higher crest. The breaker under test may have been able to clear such a voltage, but it is felt that such evidence should be presented before a claim to that effect is made.

Most of the papers presented on oil circuit breakers for the past several years have referred to recovery voltage rate as one of the factors determining the difficulty in clearing a short circuit. It is generally considered not only in this country but abroad that the arc length and distress of the circuit breaker vary between wide limits as a function of this voltage recovery rate. In general, the recovery rate at the substation on a high voltage transmission line is quite low and the circuit breaker duty correspondingly light, while at the generator bus it may be high and the duty severe. Specific recognition of this fact was made in connection with the Philo tests which were deliberately carried out adjacent to the high power steam generating station for this very reason. It would be interesting to know what the effect upon Schwager's breaker would have been had high recovery rates been present. In the absence of such information, his comparisons of arc lengths with those reported in other tests are entirely meaningless. The Philo tests showed a difference of nearly $2^1/_2$ to 1 between the average arc duration as between 270 volts per microsecond and 2,400 volts per microsecond for the plain explosion chamber. With the oil blast contacts the ratio is less than 1.6 to 1. We see from this that the sensitivity of various forms of interrupting means to rate of recovery voltage rises may be quite different. High rates of rise may occur quite unexpectedly in the field and it is therefore a source of considerable assurance to an operator to know that his circuit breaker is not a "fair weather" circuit breaker capable of interrupting only the easier faults which may be thrown upon it, but that it will handle the most severe faults within its nominal rating. Such assurance cannot be given without more complete information than that provided in Schwager's paper.

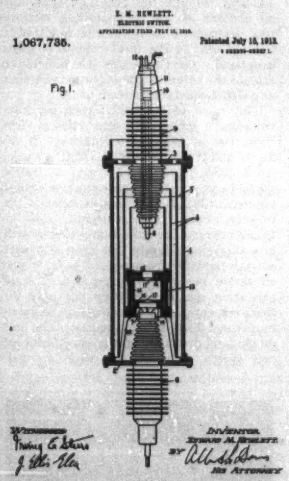

Fig. 1. Reproduction from a patent application filed in 1910, showing explosion chamber in an oil switch

The question of the efficiency of various numbers of breaks in series has been a moot one for a number of years. Information is available ("Engineering Features of Oil Blast Action," D. C. Prince, *General Electric Review*, August, 1933) to prove that in the case of the high voltage impulse circuit breaker a number of breaks in series have an additive effect. However, that circuit breaker is particularly designed to provide a favorable distribution of potential among the different breaks. This condition is not generally met in the tank type breakers. Where it is not met, the effect of added breaks may be very slight or even negligible.

Figure 9 of the paper compares the arcing time of 3 and 6 explosion chambers. The times are in the ratio of 2 to 1.6 or a reduction of only 20 per cent in arcing by doubling the number of breaks. From table II and accompanying text it appears that the arcing time should be a half cycle or less, at least at 12 kv. Where 6 breaks provide a cumulative action, this short arcing time should be maintained to 6 times 12, or 72 kv. Obviously nothing of the kind has occurred, since the tests at 65 kv show over 3 times this much arcing, even with six chambers.

Recently a circuit breaker was equipped first with 2 and then with 4 explosion chambers of the very latest and most effective type and submitted to tests under precisely similar conditions. In order to eliminate the possible variations of individual tests, 3 tests were made with each arrangement. These tests were made at 220 kv and a recovery voltage rate of approximately 4,000 volts per microsecond. The average arcing time and length of arc with 2 explosion chambers were found to be 2.8 cycles and 7.9 inches per break, and with the 4 explosion chambers, 2.4 cycles and 7.3 inches per break. The 4 chambers thus show a gain of 14.3 per cent in arcing time and 7.6 per cent in arc length inches per break. The total average arc length was 15.8 inches for the 2 break design as against 29.2 inches for the 4 break design. Average arcing time of the 2 break breaker was 1.7 cycles at 132 kv. The arcing time of the 4 break circuit breaker at 220 kv would have been less than this, had the 4 breaks been dividing the voltage. The decrease in arcing time seems to be too small to justify the added complication of the extra parts required and increased oil deterioration due to increased arc length, and proves rather conclusively that the performance of the multibreak design cannot be found by multiplying the performance of the single break by the number of breaks unless there is some concrete evidence that such an operation is justified.

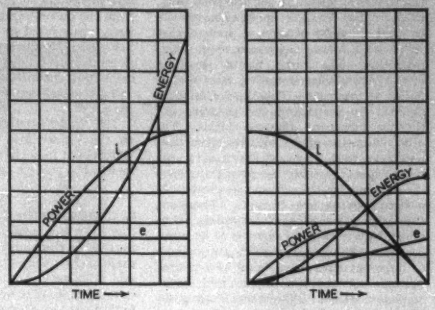

Fig. 2. Comparison of energy liberated in arc as computed under different assumptions

Curves on the left are drawn assuming current increasing from zero and arc voltage constant; those on the right are drawn assuming current decreasing to zero and arc voltage increasing

Incidentally, the 1.7 cycles average arcing time at 132 kv mentioned above was obtained with approximately 3,000 volts per microsecond recovery voltage rate, and compares with the average 1.7 cycles given by Schwager for his interrupting tests at only 65 kv and low voltage recovery rate.

It was fairly conclusively shown that the multibreak explosion chamber did not accomplish any useful purpose and certainly the conclusion cannot be safely drawn that where 3 explosion chambers will interrupt 65 kv, 6 would interrupt 220 kv or higher as claimed by Schwager. It seems probable that the 65 kv was actually interrupted by one explosion chamber of the 3. With 6 the performance would be substantially the same. This is not saying that 65 kv represented the limit of safe operation of the explosion chambers tested by Schwager. However, his data seem rather inadequate to support any prediction of the operation of a considerably higher voltage breaker.

It is probable that the designs discussed in this paper are capable of interrupting more voltage than that employed in the tests. The limit of recovery voltage rate was probably not reached and certainly not exceeded.

R. C. Van Sickle (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): In addition to presenting interesting developments in arc rupturing devices and demonstrating their superiority to plain breaks, this paper shows clearly the need for the

short circuit testing of circuit breakers. The organization with which the writer is connected has been designing and testing arc rupturing devices for a number of years and has found that even though a new arc rupturing device is designed with great care, some modifications will be indicated by the results of tests. It has also been found essential that the entire range of currents be covered by tests because in such devices there are 2 limitations which require consideration. The longer arcing times on low currents, when excessive, may lead to failure to interrupt. This type of failure is avoided by restricting the passages and thereby increasing the gas blasts. The other limitation occurs with heavy currents and is due to the pressures developed within the devices. Opening the passages relieves the pressure, but this affects unfavorably the performance at low currents. Therefore, the design is necessarily a compromise determined by the range of currents to be interrupted. The currents which are difficult to interrupt have been found in 2 ranges, between 300 and 500 amperes and at the maximum values. Since these characteristics have been found for a number of arc rupturing devices, including some similar to those described in this paper, it is probable that the characteristics hold for the expulsion breaker also. Consequently there is some question about the advisability of extrapolating the good results obtained between 960 and 3,600 amperes over the range from 100 to 10,000 amperes.

It is not clear just how much significance it was intended should be attached to the theoretical calculations of the oil piston motion. It is stated that because of the various assumptions which were necessary the results should be taken qualitatively rather than quantitatively. However, the first design had a calculated value of $\frac{V_0}{AH^3} = 0.36$ which was a reasonable tolerance over the calculated minimum 0.17. When the volume of gas generated was found to be less than the calculated amount and the resulting constant only 0.13, the device was not expected to operate in a quarter of a cycle. The next device had a constant of 173, probably indicating that the details were determined by other considerations.

The volume of gas generated being less than half of the calculated volume may possibly be explained by a review of the assumptions used in the calculations. The arc voltage was assumed to be constant during the first half cycle and it may have varied linearly starting at zero. The expression $E_t \cong E_0 \frac{(\omega t)^2}{4}$ for $o < \omega t < \frac{\pi}{2}$ is used for the energy, but it is based on constant arc voltage and is applicable for a quarter of a cycle just after a current zero instead of a quarter of a cycle just before a current zero. If the voltage is assumed to vary linearly from zero and the current to decrease sinusoidally from a peak to zero, the energy liberated, or the gas generated, is less than half of that calculated using the formulas in the paper. This is shown graphically in figure 2 of this discussion. On the left are the curves for the assumed conditions of constant arc voltage during a half cycle and the corresponding current, power, and energy curves. On the right are the curves with the suggested modifications. The arc voltage is shown for only a quarter cycle but its average for a half cycle is the same as the voltage used in the other set of curves. The current is shown for the quarter cycle preceeding the first current zero after contact separation. The power and energy curves are obtained graphically from the current and voltage curves. The energy calculated in this way is less than half of that obtained with the other assumptions and this ratio is about the same as the ratio of experimentally measured gas volume to calculated gas volume given in the paper.

The results obtained with these devices on the 110-kv field tests are very satisfactory and indicate a very good beginning for a line of modern circuit breakers.

A. C. Schwager (Pacific Electric Mfg. Corp., San Francisco, Calif.): It is realized that in a paper combining the descriptions of 3 major items, namely, theory, construction, and field tests, of a new oil circuit breaker development, it is necessary, due to space limitations, to omit from discussion many features which in a longer paper would be well worth mentioning. I therefore greatly appreciate the opportunity given me by Prince and Van Sickle to discuss in detail some of the items which due to their secondary importance had to be omitted.

First of all I thoroughly agree with Prince in the credit which he gives the early pioneers. One cannot help but admire their accomplishments, for 30 years ago they gave us fundamental designs which with practically no important alterations determined the general trend in circuit breaker design until a few years ago. Hewlett, as early as 1904, has shown that a blast of oil directed at high velocity across the arc shows excellent rupturing ability. Even before the oil circuit breaker was invented. Elihu Thompson in 1892 showed that arc interruption can also be accomplished by subjecting the arc to a high velocity gas blast. Although his design was later abandoned, it has during the last few years been reapplied abroad. Switches based on the air blast principle show remarkable performance, since they can interrupt short circuits up to 220 kv in a half cycle. It is easily seen why I have chosen for a starting point the ingenious method of arc interruption first proposed by him. The disadvantage of these air blast switches is, of course, the necessity for a ready supply of arc-extinguishing gas. However, if the Rice and Hewlett design, which makes use of the energy liberated in the arc to extinguish it, is combined with the Elihu Thompson gas blast principle, an expulsion type of arc interrupter is obtained which has all the remarkable features of the air blast switch. Although both the Hewlett and Thompson principles were previously used independently, it is believed that the expulsion circuit breaker makes use for the first time of a combination of these 2 principles and can therefore be expected to have quite different and improved characteristics when compared to the original Hewlett type switch.

In a comparison between the Hewlett switch and the expulsion oil circuit breaker, Prince states: "the Hewlett design would be even better since it is not necessary to expel a block of oil." The accumulation of a large quantity of gas during the time required for the removal of the oil piston is one of the fundamental features of the expulsion oil circuit breaker. Only in this manner can most economical use be made of the gases generated during the arcing period for the extinction of the arc. In the Hewlett switch the gases can escape immediately upon contact separation, a violent stream being directed throughout the arc during the entire cycle. This gas stream is of no purpose while the current flows at or close to its maximum value, since interruption at that instant is neither possible nor desirable. Due to the steady escape of gases during the entire half cycle, the gas stream at the moment of current zero will be many times weaker than one which is initiated near current zero after a period of accumulation of arc gases. Therefore, in an expulsion breaker the gas blast at the instant of the first current zero will be sufficient for interruption, whereas in the Hewlett switch interruption due to the weaker extinguishing action will not occur at such an early moment. The question as to whether the active agent is a gas blast or a more or less fortuitous oil blast has been carefully investigated by means of cinematographic studies of interruptions by expulsion contacts installed in a glass tank. By measuring the small volume of oil within the expulsion chamber (less than 1 cubic inch) and the large volume of gas escaping through the expulsion tube, the oil content of the extinguishing mixture was determined to be in the order of a few per cent of the total volume of gases generated. For this reason it is difficult to explain the action of the expulsion chamber on a well defined solid stream of oil.

The value of 0.5 watt second per kilovoltampere interrupted was chosen from "The Use of Oil in Arc Rupture," B. P. Baker and H. M. Wilcox, A.I.E.E. TRANS., April 1930, pages 431–41, and of course applied to kilovoltampere values which approach the full rupturing capacity of the breaker. For smaller currents, such as Prince refers to, our values agree closely with his, averaging slightly less than 0.2 watt seconds per kilovoltampere. The expulsion oil circuit breaker, however, is capable of producing such a low ratio not only for small currents, but for currents up to maximum rated interrupting capacity. The best method of determining the superiority of one switch over another with approxi-

Fig. 3. Oscillogram of recovery voltage

mately equal arcing times is by a comparison of the arc voltages on oscillograms. Since I have not been able to find published data of arc voltages as small as that shown in figure 11 of my paper for currents in the order of 10,000 amperes, I believe that it is safe to assume 0.5 watt second per kilovoltamperes a fair value of the status of the previous art.

The writer is, of course, familiar with the excellent paper "Circuit Breaker Recovery Voltages," R. H. Park and W. F. Skeats, A.I.E.E. TRANS., March 1931, pages 204–38, on circuit breaker recovery voltages. The recovery values listed in table IV of the paper refer to the voltages appearing a few cycles after interruption and not to the first recovery voltage wave. Since the recovery voltages (60-cycle rms values) in the single phase ground tests reached values as high as 1.5 times line to ground voltage, most of these tests are actually an indication of the performance of the breaker at 110 kv. A recovery voltage of approximately 84 kv is shown in the oscillogram, figure 3 of this discussion corresponding to test number 2, table IV; the theoretical value on the basis of Prince's calculations amounts only to 60.5 kv. Since on the larger part of these single phase tests, performed on a practical high voltage system, the first half cycle of the recovery voltage was greatly in excess of the voltage before the short circuit, extreme caution has to be used in attempting to predict performance on the basis of theoretical calculations alone.

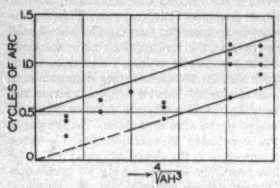

Fig. 4. Relation between arcing time and oil piston dimensions

Being associated with the manufacture of multiple break switches, I have been doubtful as to the claims of manufacturers of this type that the performance could accurately be determined from that of a single contact, until this statement was sufficiently proven. In my opinion, the tests by Sporn and St. Clair ("Tests on High and Low Voltage Oil Circuit Breakers," A.I.E.E. TRANS., volume 46, 1927, pages 289–311) on a high voltage multiple break switch have given ample proof of the correctness of this theory. The multiple break switch tested by them gave excellent service, each contact apparently contributed equally to the interruption. In conjunction with our plain 6-break switch tests shown in figure 9 we have performed 2-break tests under identical conditions and obtained arcing times varying from 20 to 25 cycles. The superiority of the multiple break principle, therefore, seems to be sufficiently established by tests.

Prince states that on the high voltage impulse breaker favorable use can be made of multiple break. To influence recovery voltage distribution use is made of electrostatic shielding. Such electrostatic shielding could, of course, most easily be applied to our 6 expulsion contacts, if it were necessary. There is unfortunately a fundamental error involved in assuming that the electrostatic capacitance alone determines the distribution of the recovery voltages appearing across the various contacts. Tests by Kopliowitch (Schweizerischer Elektrotechnischer Verein *Bulletin*, 1932, figure 10) show that the most radical attempt to influence the voltage distribution across a breaker is futile. Apparently the space charges surrounding the remainder of the arc path are so predominant that the effect of the electrostatic field disappears entirely. If the recovery voltage were a function of the electrostatic field alone, then it should be the same for various rupturing devices tested under identical circuit conditions. It has been shown, however ("Arc Extinction Phenomena in High Voltage Circuit Breakers," R. C. Van Sickle and W. E. Berkey, A.I.E.E. TRANS., Sept 1933, pages 850–7) that space charges within the breaker can modify the rate of rise of recovery voltage in a ratio of 1 to 10. R. M. Spurk and W. F. Skeats ("Interrupting Capacity Tests on Circuit Breakers," A.I.E.E. TRANS., Sept. 1933, pages 832–40) have also found that the recovery voltage distribution is equal across the contacts under conditions which are certainly present in the expulsion breaker.

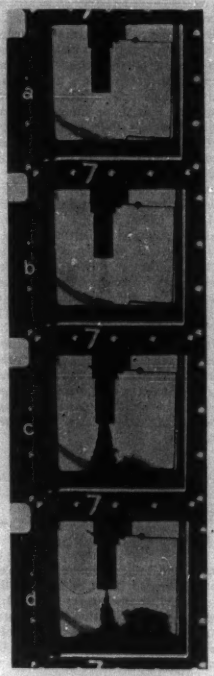

Fig. 5. Camera record of expulsion oil circuit breaker interrupting 175 amperes at 12 kv

With such available test data and theoretical considerations it can safely be stated that equal voltage distribution exists in a multiple break expulsion oil circuit breaker. The fact that only a slight difference in arcing time exists between our 3- and 6-break tests has no direct relation to the number of breaks. If a single chamber is designed to initiate a gas blast say in one cycle, then it will not be possible to reduce this time by the use of multiple breaks, since each chamber requires at least one cycle for the establishment of its gas blast. The same explanation applies for the 220 kv test performed by Prince on 2- and 4-explosion chambers.

The lack of space available prevented a more thorough description of the test set-up and there is just cause under these circumstances to call the breaker a "fair weather" breaker. However, care was taken to obtain the most severe conditions of recovery voltage rise. Two synchronous condensers with a total capacity of 50,000 kva located at the Newark substation were connected in all cases and in tests 1 and 6, table IV, represented the only power source. The combination of these 2 condensers, an 11 to 110 kv transformer, the high side of one phase grounded directly through the test breaker, and a single 4-mile open line for measuring voltages allows an accurate calculation of the rate of rise of recovery voltage, giving a value slightly in excess of 1,000 volts per microsecond. With equal voltage distribution theoretically assured, the tests on 3 expulsion contacts with this set-up show that a 6 break expulsion breaker will interrupt a 110-kv 3-phase short circuit with 2,000 volts per microsecond rise in less than 2 cycles. Therefore, the assumption of performance under the most severe system conditions is amply justified.

Van Sickle points to the difficulty encountered with some arc rupturing devices when rupturing currents in the range between 300 and 500 amperes and suspects that similar performance might have to be expected with expulsion oil circuit breakers. Although test number 5, table IV, partially disproved this assumption, additional 12 kv tests on a single expulsion chamber were performed to investigate its performance in this critical range. The results are given in table I of this discussion, showing a uniform arcing time.

Table I

Amperes Interrupted at 12 Kv	Arcing Time, Cycles	Amperes Interrupted at 12 Kv	Arcing Time, Cycles
200	1.0	980	0.7
220	1.0	1910	1.0
380	1.0	3600	1.0
600	1.0	3710	0.9

The importance of such small arcing times in the low current range is an outstanding feature of this device. Whereas a breaker with a highly increased arcing time within this range can cause oil carbonization due to a few normal switching operations, equally or more severe than that due to a heavy short circuit, the expulsion breaker is free of this disadvantage.

In the limited space available only 2 contacts were investigated to demonstrate the influence of the dimensions of the oil piston upon the arcing time and I thoroughly agree with Van Sickle that they alone cannot conclusively prove the theory outlined. Additional tests in which the dimensions of the oil piston were more gradually varied have been performed and will be discussed in the following.

In the paper it was assumed that the arc energy and correspondingly the gas volume increase in quadratic relation with time. The assumption of constant arc voltage and contact separation at current zero led analytically to this relation in the simplest manner. As brought out by Van Sickle and confirmed by our tests, the arc voltage in an actual circuit breaker whose contacts move at constant speed increases linearly, in fact almost proportionately with time. The gas generation for contact separation at current zero as well as current maximum can be approximated by a quadratic law, the rate for separation at current maximum being approximately twice that for separation at current zero. The value $V_i \cong V_0 \frac{(\omega t)^2}{4}$ used in equation 3 represents approximately the average of these 2 conditions. Writing equation 9 in a more general form results in:

$$\omega t_0 = \text{const} \sqrt[4]{\frac{AH^2}{V_0}} \qquad (9a)$$

where t_0 represents the time required for the initiation of a gas blast. Interruption of the current takes place at its next current zero and depending upon the instant of contact separation will result in an arcing time lying in a range between t_0 and $t_0 + \frac{\pi}{\omega}$

From equation 9a it can be seen that for the 2 extreme cases with a ratio of 2:1 in the rate of gas generation, the respective times t_0 will differ less than 20 per cent. With the average rate of gas generation used in equation 3 of the paper, the values ωt_0 for any particular contact separation are likely to be within 10 per cent of the calculated value. A different rate of gas generation, instead of being brought about by a different instant in contact separation, can be produced by a change in current. It can be expected that currents producing arc energies not varying in excess of 2:1 will have the same negligible influence upon t_0.

Several expulsion chambers with various values of $\sqrt[4]{AH^2}$ were built and tested at 12 kv, interrupting currents from 1,000 to 3,500 amps. Figure 4 of this discussion shows the relation between arcing time and $\sqrt[4]{AH^2}$. All test points lie in a zone of a width of $^1/_2$ cycle, the lower boundary line of the zone of which the arcing time is identical to the expulsion time establishing the approximately proportional relation predicted between ωt_0 and $\sqrt[4]{AH^2}$. The expected small influence of a variation in V_0 due to instant of contact separation and current value is well confirmed.

The fourth root relation between ωt_0 and V_0 allows a theoretical interpretation of the uniform performance of the expulsion contact over the entire current range. Assume the expulsion time for maximum current to be $^1/_2$ cycle, the expulsion time will be less than 1 cycle as long as arc energy and gas generation are not reduced to less than $^1/_{16}$th of the original value. Since such a large reduction between maximum current and currents in the order of 300 to 500 amperes is not experienced in the expulsion breaker, performance can be expected to take place with a variation in arcing time not exceeding $^1/_2$ cycle, a conclusion which is experimentally proved in table I.

In an endeavor to verify all phases of the interruption in an expulsion chamber, such as oil expulsion, gas blast, and interruption, we employed a method which also enabled us to estimate oil velocities. An expulsion chamber was mounted in a glass tank, the opening of the expulsion tube being directed toward the bottom of the tank, and the movable contact withdrawing in an upward direction. Figure 5 of this discussion shows an interruption of 175 amperes at 12 kv. Frame *a* shows the lower end of the expulsion tube preceding contact separation; in frame *b* the arc is established and the oil piston which is clearly visible has almost completely left the tube. In frame *c* the high velocity gas blast is established and the current is interrupted as can be verified from the following frame *d*. These pictures were taken at the relatively slow speed of 64 per second, but they prove the correctness of the expulsion theory developed and besides allow a calculation of the oil velocity. The average velocity in the case shown exceeds 60 feet per second. If higher camera speeds were employed, it would not be difficult to measure instantaneous oil velocities with a fair degree of accuracy.

Distance Relay Action During Oscillations

Discussion and authors' closure of a paper by E. H. Bancker and E. M. Hunter published in the July 1934 issue, pages 1073–80, and presented for oral discussion at the management and protective devices session of the Pacific Coast convention, Salt Lake City, Utah, September 4, 1934.

W. A. Lewis (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper is the first analytical study of the action of distance relays during oscillations, although the action of these relays under fault conditions with various connections has been previously analyzed. (Fundamental Basis for Distance Relaying, W. A. Lewis and L. S. Tippett. ELECTRICAL ENGINEERING, July 1931, page 420–1.) In the paper it is assumed that the oscillation takes place only after the fault is cleared, or, in other words, that the fault and the oscillation are not present simultaneously. Unfortunately, this state of affairs is realized all too seldom. Normal switching and relaying on a well designed system are arranged so that the system will remain stable for a severe fault in the worse fault locations and with maximum load. Since these combinations occur infrequently, most faults do not occur under the most severe conditions, and a severe swing seldom results unless a fault is not cleared in the anticipated time. The failure to clear may be due to the absence of suitable relays to clear rapidly the particular fault encountered, the temporary removal of equipment from service, or to some defect in the equipment or control power. As an example, the cases cited in the discussion by Gerrell (ELECTRICAL ENGINEERING, Sept. 1934, page 1320.) may be pointed out, in which the faults causing interruptions were at such locations that the high speed relays had no opportunity to clear the fault. In such cases we have to content with the fault and the oscillation simultaneously, and relays which may operate correctly for either condition alone may trip undesirably when the 2 conditions occur simultaneously. The analysis of this case is much more difficult but is fully as important as the case analyzed by the authors. If one line fails to clear in the anticipated time it is very important that other lines should not trip incorrectly if it is possible for synchronism to be maintained.

The device which is most particularly affected by presence of a fault during an oscillation is the starting element of the reactance relay. As shown by the curves in the paper, when there is no fault the power factor near the electrical center, where the voltage is low, is such that the relay torque is low and a large current is required for operation of the starting element. When the fault is also present, the voltage is further reduced and the addition of fault current reduces the power factor, so that the starting elements will operate at a much smaller total current. This is to be expected, since the starting element should operate in the line sections near the fault whenever a fault occurs. However, under such conditions the starting element is of no value in preventing tripping during the resulting oscillation, and reliance must be placed in the ohm unit alone. In the paper the conclusion is reached that reactance relays close to the electrical center will have less tendency to trip during an oscillation than impedance relays in the same location. However, it is the starting element which prevents tripping, and if the fault is present simultaneously this conclusion cannot be maintained.

To bring out the details, a simple example has been investigated, as shown in figure 1 of this discussion. The system is the same as that considered by the authors except that a fault has been added with impedance in series. As far as the effects on relays external to the faulted section are concerned, this is equivalent to a fault between bussing points on the tie line, or to a fault at some location in the receiving-end system which is not immediately associated with the tie. If the fault should be a 3 phase fault, it is easily conceivable that it will produce a severe oscillation if not cleared rapidly, and yet this location may readily be one which is not protected by high speed relays. The location of the fault branch has arbitrarily been taken as 20 per cent of the distance toward the receiver from the electrical center of the system without fault, and the impedance in series with the fault has been taken equal to the impedance between the center and the point of fault application. The relay station considered has been taken as 5 per cent toward the sending end from the center. The current required to operate the various relay elements for several settings as a function of the displacement angle is given in the

figure. The curve notation is the same as given in the paper, page 1079. It will be noted that curve *C*, which shows the current required to operate the starring element of the *GCX* relay on the 12*A* tap, is now very small for any angular position, and less than that required to operate the distance element, except for the 8 ohm setting, which is seldom, if ever, used. The dashed curves *K*, *M*, *O*, and *P* show the current required to operate the impedance relay when set on the 2, 4, 6, and 8 ohm taps, respectively. The solid curves *E*, *G*, *I*, and *J* show the current required to operate the ohm unit of the reactance relay when set on corresponding taps. It will be noted that in the region from 90 to 130 degrees, as covered by the paper, figures 8 to 12, inclusive, about 20 per cent more current is required to operate the impedance relay, and in consequence there is less danger of incorrect tripping. The relay location is within the zone which is more favorable to the reactance relay when there is no fault, but this same location becomes unfavorable to the reactance relay when the fault is present.

In connection with the discussion by Bancker and Hunter (ELECTRICAL ENGINEERING, Sept. 1934, page 1322). I assume that the equations give the current for unit voltage and that they should be multiplied by 115 to give the current for full voltage. At least this appears to check the values given in the figures. It is probable that greater approach to actual conditions will be obtained by the use of a higher figure, since this voltage is supposed to be proportional to the internal voltages of the machines, but there is some doubt as to what value should be used, and the use of 115 provides a factor of safety.

E. H. Bancker (General Electric Co., Schenectady, N. Y.): To consider the problems raised in Lewis' discussion would require a study of at least 27 different sets of conditions. Fortunately many of these may be grouped and others may be disposed of briefly.

The 3 original conditions which may exist are:

1. Fault originally beyond the back-up zone.
2. Fault in the back-up zone.
3. Fault in the intermediate zone.

The 3 types of relays under discussion are:

1. The *GAX* reactance distance relay.
2. The *GCX* reactance distance relay.
3. The 3 step impedance relay.

The progress of the swing following the start of the fault may lower the ohmic indication to the various types of relays to:

1. The back-up zone.
2. The intermediate zone.
3. The instantaneous zone.

If the fault originally lay beyond the back-up zone and the action of the system oscillation was to lower the ohms to a value which caused the starting unit or back-up impedance element to operate, it should be remembered that the indicated ohms must stay within this setting long enough for the back-up time to expire before tripping will occur. While this is possible, it indicates a lack of adequate relaying elsewhere on the system, since the fault must persist for the total duration of back-up time plus whatever time it took for the swing to bring the initial indication from outside of the back-up zone to within it. As ordinarily set, this would mean that the fault duration was anywhere from 2 to 6 seconds and indicates that the relaying of lines immediately adjacent to a section subject to oscillations should be coördinated to avoid false tripping. Another possible remedy would be the use of a lower ohmic setting for the back-up element. The requirements of this element are that it must operate surely for any and all faults within the section protected by the relay. If it is possible to utilize a lower ohmic setting for the back-up element of the impedance relay, it is equally possible to go to a higher current setting for the reactance relay starting unit since the requirements for the 2 elements are the same.

A fault originally beyond the back-up zone which initiates a swing, bringing the indicated ohms down to the intermediate zone, is even less likely to occur within the allotted time than the case just considered. In order to reach intermediate zone, the back-up zone must first be traversed and intermediate reached before the expiration of intermediate time or none of the 3 types of relays would trip. In other words, if intermediate ohms are indicated after intermediate time has expired, the relay does not trip until back-up time is reached.

It is obviously still more improbable that the ohmic indication for a fault which was initially outside of the back-up zone will ever become as low as the instantaneous distance so that this case is probably of no practical importance.

Coming now to those faults which start as though in the back-up zone, if they continue to indicate this same distance for the duration of back-up time, all the types of relays will, and should, trip. Any such condition as this is probably an improper application of relays because the fault should not persist for this length of time or selectivity cannot be secured. The other possible causes are that some breaker and relay failed to clear in its allotted time and back-up action was required, which again is correct action for the relays.

The third alternative is the possibility that the fault did clear, but that the swing had progressed enough to keep the starting element and back-up impedance elements from resetting. In this last case the action can be studied from the curves of the paper, since it involves a swing without any fault and in this case reactance relays near the center are less susceptible than impedance relays, while the reverse is true at the more remote points.

The *GAX* relay cannot operate in intermediate time once it has indicated back-up distance and hence, should the swing change an initial fault within the back-up zone to one indicating in the intermediate zone, the relay will not trip until back-up time, and, as before, a fault persisting this length of time indicates that something is wrong elsewhere on the system.

Similarly, if a fault swung down to the instantaneous zone, the *GAX* relay might be prevented from tripping merely by the change of one internal lead. In the standard relay, instantaneous tripping is not prohibited after having indicated back-up distance, but if desired could be provided by opening the instantaneous contact with the transfer relay that opens the intermediate time contact. This case, however, is a rather infrequent one since it would require a large change while the fault exists. It is much more likely to occur if the fault should clear but leave the starting unit picked up since the ohm unit would then probably indicate very low ohms and trip immediately.

With the *GCX* type of relay, an oscillation must progress fast enough to bring the ohms from an initial value in the back-up zone, down to the intermediate zone, before the expiration of intermediate time after

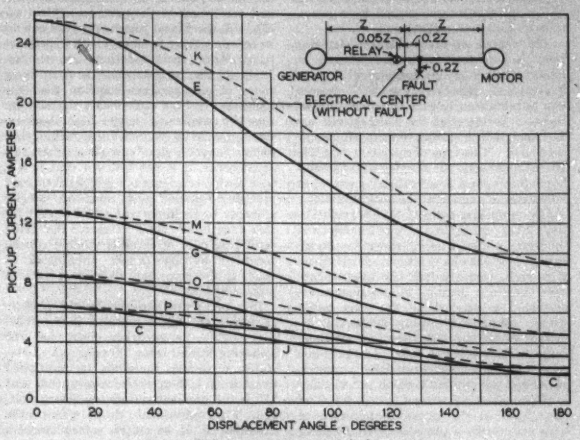

Fig. 1. Relay characteristics with fault on system

the start of the fault, or the relay cannot trip because of the passing contact used for intermediate time. The likelihood of an oscillation producing such a major change in ohms in such a short time is somewhat remote. The statements made with reference to the *GCX* also are applicable to the impedance relay, which as Lewis states has a somewhat lesser chance because of the higher indicated ohms caused by a simultaneous fault and oscillation.

The chance of an oscillation changing from back-up to instantaneous ohms is so remote that it is not considered of great importance. However, the *GCX* cannot trip instantaneously even when this occurs, because shortly after the starting unit has first operated, the instantaneous trip circuit is opened. This type of relay can only trip immediately after the starting unit contacts have closed, for a few tenths of a second at intermediate time, or at the back-up time.

The remaining cases of faults which initially start within the intermediate zone and then stay there or swing down to the instantaneous zone have no great significance. If a fault occurs within the intermediate zone and stays there for intermediate time, it should be tripped by the relay under study. Should the swing bring the indicated ohms into the instantaneous zone, it is a fairly conclusive indication that some other relay has failed to perform as anticipated because any fault which was initially in the intermediate zone of some relay must have been in the instantaneous zone of some other relay if the relays were properly applied. Hence, correct relay and breaker action would prevent the possibility of a simultaneous fault and swing of this nature. This case is also very unlikely to occur since the chance of a swing reducing the ohms from intermediate to instantaneous within intermediate time, when the relay would trip anyway, is very remote.

From these considerations it becomes evident that while the starting units of reactance relays near the electrical center are not as immune to a simultaneous fault and oscillation as they are to a plain oscillation, there is no reason why they cannot be set to compare favorably with impedance relays since their functions are similar. It should also be noted that the most likely cause of misoperation requires that the indication be for a fault within the back-up zone for something longer than back-up time. While it is entirely possible that swings may be slow enough so that this could occur, it is not believed that it is a very likely occurrence nor is it believed good practice to permit faults upon any circuits adjacent to an important tie to persist for this length of time. Hence, the most disturbing case of possible trouble can be corrected by the proper application of relays in the immediate vicinity of sections prone to oscillate.

In a previous discussion by the authors (ELECTRICAL ENGINEERING, Sept. 1934, page 1322) the equation given for the operating current is for 100 volts. As Lewis states, it should, therefore, be multiplied by at least 1.15 upon the assumption that 115 is the nominal system secondary voltage. The additional drop within the machines is, as he states, somewhat of a safety factor because the actual internal voltage of the machines is higher than the nominal rated voltage.

Lightning Investigation on a 220 Kv System

Edgar Bell, Aug. 1934 issue, p. 1188–94.

Theory and Tests of the Counterpoise

L. V. Bewley, Aug. 1934 issue, p. 1163–72.

Counterpoise Tests at Trafford

C. L. Fortescue and F. D. Fielder, July 1934 issue, p. 1116–23.

Lightning Investigation on Transmission Lines—IV

W. W. Lewis and C. M. Foust, Aug. 1934 issue, p. 1180–6.

Lightning Performance of 132 Kv Lines

Philip Sporn and I. W. Gross, August 1934 issue, p. 1195–1200.

Discussions of papers presented for oral discussion at the session on lightning at the Pacific Coast convention, Salt Lake City, Utah, September 5, 1934.

P. L. Bellaschi (Westinghouse Elec. & Mfg. Co., Sharon, Pa.): The field investigations during the past 3 lightning seasons have enhanced materially our previous knowledge of lightning stroke phenomena. The mechanism of the lightning stroke formation has been studied most effectively by means of the "rapid" camera.[1] In the laboratory lightning stroke currents have been produced for the first time[2] and from first hand studies of lightning currents in the laboratory during these past $1^1/_2$ years, valuable data on lightning phenomena have been obtained. New and improved methods[2,3,4] for determining lightning currents have been applied in the field. From these improvements a more accurate determination of lightning currents has been possible lately than was possible before.

More remains to be done, however. Direct measurements of the lightning stroke potential and current with the cathode ray oscillograph are obviously very desirable. Such measurements could be accomplished by intercepting the lightning stroke before it strikes earth with a conductor elevated above ground, either with a kite or a balloon or other means. While these investigations appear to be of a scientific nature, they would undoubtedly establish more solidly the fundamental principles of lightning protection and they would, therefore, contribute beneficially to the engineering technique of protection.

The papers the writer wishes to discuss deal in particular with lightning as it affects the design and operation of transmission lines. Whether a transmission line is lightning proof or to what extent it is vulnerable to outages from lightning depends so much on a knowledge of the lightning stroke phenomena that it is of fundamental importance to compare the data on lightning presented in these papers with any other corresponding data obtained from similar and other sources. To limit this discussion to reasonable length I shall confine this critique to Lewis and Foust's paper which in a good measure reports and correlates the data obtained on the systems investigated by Bell and Sporn and Gross.

The importance of the lightning stroke as a source of disturbance on lines, as well as at substations, becomes more apparent from actual numerical figures on the frequency of occurrence. In comparing data from various sources it is well agreed that account must be taken of the line construction, topography of country in which each line runs, isoceraunic level or storms per year, and the lightning severity during the various seasons. This discussion does not intend to compare the various data to the last detail but rather its purpose is to emphasize once more the real importance of direct strokes in so far as these affect the continuity of service of overhead lines and may subject line and station apparatus to damage and even destruction.

Referring to the data on the 220-kv Wallenpaupack-Siegfried line, the 37.5 miles of the line with no ground wire protection gave 266 flashovers of towers in the 6-year period from 1928 to 1933. In this period the average lightning severity was 90. This transmission line lies in a territory where the isoceraunic level is approximately 35. On this line, then, lightning strikes on the average once per year per 0.85 mile of line.

Lightning investigations on a 60-mile telephone wood-pole line in Texas indicate that 35 poles were damaged during 1930. The average isoceraunic level in this case is approximately 40. On this particular line lightning strikes on the average once per year per 1.72 miles of line.

A survey made in 1927–28, by one company, on 811 miles of wood-pole lines, reveals the following interesting data.[5] The system consists of 66- and 33-kv pin type lines without overhead ground wires but with pole ground wires on 20 per cent of the poles. A detailed report was made of each pole which showed any sign of damage, regardless of its severity. Since 20 per cent of the poles were grounded the length of the exposed circuit is 650 miles. The total structures or poles involved numbered 213. This system covers a territory where the isoceraunic level is 80. On the average lightning strikes this system approximately once per year per 3 miles of line.

Two years field experience on a number of distribution transformers located throughout the country in exposed territory indi-

cates that each year approximately 0.5 per cent of such transformers are subjected to direct strokes of lightning.[8]

Without any attempt at correlating in detail all these data, it is apparent that the frequency of occurrence of direct strokes on high voltage, medium voltage, and distribution voltage systems is sufficiently great in all cases to warrant a consideration of the protection required or the relative risk incurred from direct strokes to lines, substations, and distribution transformers.

Measured values of lightning stroke currents in tower legs have apparently suffered a marked scaling down during the past 2 years. A comparison of the currents measured 2 years ago with the present data (tables I and II of this paper and table IV in a previous paper[7]) shows clearly that the earlier values must have been substantially too high, due possibly to the inductive lead effects vitiating the earlier measurements. The present measurements have been made with the crest ammeter magnetic link. A comparison is made in the following between the most recent tower currents reported by the authors and the data on lightning currents that have been obtained during the past 2 years and more by the writer.

Field experiences with direct strokes to distribution lines, radio antennas, wood pole ground wire, and other elevated objects constitutes the sources from which the data on lightning currents have been obtained by the writer. The lightning current in the path of a direct stroke may be determined in a number of ways. It may be determined from the physical effects produced when these effects are in turn evaluated in the laboratory by similar effects produced by artificial lightning stroke currents.[9] Analysis of the physical effects recorded will often enable predicting the lightning stroke current on the basis of fundamental considerations.

Experience with a large number of direct strokes of lightning to a wood pole line with pole ground wires in a territory subject to severe lightning indicates that no case has been recorded where the segment of No. 10 copper wire (which is used at the top of the pole) has been actually fused. Data have also been obtained by the writer with a direct stroke through a No. 10 copper wire of a radio antenna. Similar observations on radio antennas and direct experiments with lightning rods[9] indicate that the current in a direct stroke can be expected to fuse copper wires of No. 14 size and smaller, but that larger conductors will ordinarily conduct the current successfully to ground.

Field investigations with the cathode-ray oscillograph show a duration of the waves, produced on lines by lightning, of from 15 to 100 microseconds where time is measured from the start to the half crest value on the tail. Measurements of the light intensity of the stroke by Dr. B. F. J. Schonland indicate that the duration of the discharge is on the average 40 to 50 microseconds. However, his measurement also brings out that the wave form is characterized with a sustained peak on the crest that endures a fractional part of the duration. More remains to be known of the wave form and duration of the lightning stroke current but a duration of 40 to 50 microseconds on the basis of an equivalent exponential wave form seems reasonable.

Another consideration pertains to the repetitive nature of the stroke. A limited number of strokes consist of a single discharge, a greater number of 2 or more discharges, and again a limited number of a great number of discharges. It is an important fact that the first discharge is the most intense and severe while the successive discharges appear markedly reduced in intensity.[1] Considering the extensive experiences on the fusion of copper conductors produced by lightning, a reasonable number could have been produced by a single discharge or by a heavy single discharge followed by a markedly weak discharge.

Equations of the surge current required to produce fusion of various common conductors have been established[3] experimentally and analytically by the writer.

Let

$i = I_{(max)} \, e^{\frac{-0.693}{T} t}$ be the surge current discharge where

t = time in microseconds

$I_{(max)}$ = crest value of current in amperes

T = duration of current discharge from crest to half crest value

Then the current for a single lightning discharge that would produce fusion of a copper conductor is given by the following expression

$$I_{(max)} = 320{,}000 \frac{A}{\sqrt{T}} \qquad (1)$$

where A = cross-sectional area of conductor in square millimeters.

From equation 1 it is evident that a single lightning stroke discharge of 40 microsecond duration in order to fuse a No. 14 copper wire (1.63 millimeter diameter) must attain a current in the order of 100,000 amperes.

Field experience has also revealed valuable information on direct and nearly direct strokes of lightning at distribution transformers provided with deion gap protection.[8] The plugs or electrodes of the deion gaps discharging these heavy lightning currents were marked on the faces with a "surface figure" or "surface fusion." The "surface figures" when compared with similar figures obtained on deion gaps tested with known lightning currents in the laboratory were found to indicate that 0.5 per cent of the gaps discharged lightning stroke currents of approximately 20,000 amperes and greater. In 0.30 per cent of the cases lightning currents of 40,000 to 60,000 amperes and more were recorded. In one case recorded in 1934 where the lightning stroke hit right at the transformer, from all the evidence available properly correlated, a current of at least 100,000 amperes was discharged.

As additional evidence, it is well known that with direct or nearly direct strokes of lightning at distribution transformer installations, fuse cutouts and similar apparatus have been completely destroyed and shattered. Similar effects have been produced in the laboratory with heavy surge current tests.

One very interesting method for determining the lightning current consists in evaluating the crushing effect of a lightning stroke discharging through 2 conductors in parallel, an instance of which has been observed in the field. An analytical study of crushing effects would reveal very interesting data, but the analysis is unfortunately too lengthy to be reproduced adequately in this discussion. It is sufficient to say that a correlation of the crushing effect with a similar result obtained in the laboratory indicates that currents from 40,000 to 100,000 and possibly somewhat more at the worst may be expected in the field due to direct strokes.

The data in tables I and II reported by the authors indicate maximum tower currents of from 50,000 to 63,000 amperes. The total current discharged by the lightning stroke would accordingly be somewhat greater than this. Close to 50 per cent of the currents recorded are of 20,000 amperes or greater. Practically all the currents are of negative polarity; this fact establishes more firmly previous data indicating the prevailing frequency of the negative polarity strokes.

The method used to measure the tower currents in tables I and II is based on the magnetization of links of magnetic materials and their ability to retain the magnetization produced. The authors are no doubt aware that this method of measurement was perhaps the first one used in the very early days of lightning investigation some 30 years ago, when an attempt was made to estimate the maximum lightning stroke current discharged to earth.[6] With the modern refinements and facilities for calibrating these magnetic links, dependable data on lightning stroke currents should be forthcoming in the years to come. Other methods for determining the lightning stroke currents will no doubt continue to contribute an equal amount of valuable data. In the absence of direct cathode ray oscillograms of the lightning stroke current, it will be only through a correlation of all these data that dependable values of the magnitude and duration of the lightning stroke currents can be established.

The data in figures 1 to 4 give specific information on traveling waves appearing at a point on the Wallenpaupack-Siegfried line and at the Wallenpaupack substation. From these data it is reasonable to expect that "at the end of the line the waves may reflect and increase in voltage."

From the standpoint of stresses imposed on the 220-kv station apparatus only reflected waves greater than 400 kv need be considered. This substation was then subjected, in the course of about one year, to 10 surges in excess of 400 kv. Five of these surges are of positive polarity and average about 600 kv; the other 5 are negative and average about 800 kv. The negative surges are on the whole of higher voltage than the positive. The highest surge is a negative surge reaching a value of 1,270 kv in 3.3 microseconds, where it was chopped, presumably by the "spillway" gap at the substation. The duration of the front of 9 of these surges is from 3 to 10 microseconds, the tenth surge having a 38 microsecond front. The duration of the tail of 9 surges, measured from zero to half crest value, is 15 to 40 microseconds. One surge indicates a duration of about 70 microseconds.

These field data on traveling waves confirm once more the adequacy of the $1^1/_2 \times$ 40-microsecond wave used to test apparatus in the laboratory, as it simulates traveling waves as they appear on lines and at apparatus in actual service.

The data in figures 1 to 4 also show that 80 per cent of the traveling waves are of positive polarity, the bulk of which are from

100 to 500 kv. Since it is definitely established that direct strokes are predominantly of negative polarity, these data apparently indicate that the bulk of the positive waves originate from the induced effect of lightning. A consideration of the amplitude of the positive waves shows that while induced voltages may be practically inconsequential on 220-kv lines, they may assume a certain importance on medium voltage and particularly on low voltage lines.

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3. Lightning Currents Measured, H. W. Collens. *Electrical World*, May 12, 1934.

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5. Damage to Wood Pole and Cross Arms Caused by Lightning. *Edison Electric Bulletin*, Feb. 1934.

6. Discussion by J. K. Hodnette, Electrical Engineering, April 1934, p. 616.

7. Lightning Investigation on Transmission Lines—III, W. W. Lewis and C. M. Foust. A.I.E.E. Trans., June 1933, p. 475–81.

8. "Code for the Protection Against Lightning." Handbook of the Bureau of Standards, p. 63.

J. H. Hagenguth (General Electric Co., Pittsfield, Mass.): The results of tests described by Bewley and Fortescue and Fielder are in general very similar. The voltage induced on the line wire when the ground wire alone was connected is 23 per cent in one case and 24 per cent in the other. This of course is to be expected, since the spacing of the 2 lines is approximately the same in both cases, also the height above the earth's surface. Also, the induction on the line wire when both the ground wire and the counterpoise were connected in both tests is of the order of from 27 to 32 per cent. The impedance of the buried counterpoise was found to be a function of time. This was also found in previous tests made in Michigan. The data presented by Bewley undoubtedly shows the presence of multivelocity waves and therefore the proof of the existence of separate ground levels for current and voltage images. He experiences, however, the difficulty of determining the proper depths of these ground levels, similarly as Fortescue and Fielder. This discussion is an attempt to clear up some of these difficulties and reduce the problem of the counterpoise to a practical basis. The considerations following are based on the same tests described by Bewley.

Current Plane and Importance of Induction From Counterpoise

The induction on the line wire from a wave traveling on the counterpoise was found to be approximately 9 per cent by Bewley. It was stated by Fortescue and Fielder that they expect a greater percentage for greater depths of current plane. Since Bewley's calculation showed such good agreement with test results, his simplified equations (appendix *B*) were used to calculate the induced voltages on the line wire for various depths of current planes. In table I of this discussion h_3 is depth of current plane below a counterpoise spaced 1 foot above ground and h_3 is depth of plane below the line wire. The depth of voltage plane was assumed to be constant at H_3 = 2 feet below the insulated counterpoise. The ratio of induced voltage on the line

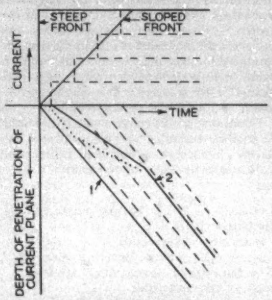


Fig. 1. Velocity of propagation of depth of current plane as affected by front of current wave

1. Steep front
2. Sloped front

wire to the applied voltage on the counterpoise is e_3/e_2.

Now it can be seen that the coupling factor e_3/e_2 increases very slowly as h_3 is increased and a value of 19.2 per cent is obtained at h_3 = 1,000 feet, i. e., the current image would be $2h_3$ = 2,000 feet below the counterpoise. But, as will be explained later, it takes about 6 microseconds before such a low depth is reached at the test location. It appears from this table in connection with the other data obtained during the tests that the voltage induced will hardly ever exceed 13 per cent (current image 400 feet below counterpoise) and usually will be less than 10 per cent, especially when the height of conductor above the earth's surface is increased above values given in the table. The induction from the ground wire on the line wire was found to be approximately 24 per cent in both papers. This induction, calculated on the basis of the usual electrostatic theory of multiconductor systems, will have about the same magnitude and it will increase considerably as the height of the conductor above the surface of the earth is increased. It can now be stated that the induction from the counterpoise is less than 50 per cent of the induction from the ground wire for low height of conductors and less than 25 per cent for very great conductor height.

In addition it should be noted from Bewley's figure 4, part I, that the voltage induced from the ground wire is 24 per cent, and from figure 11, part II, the voltage induced from the counterpoise alone is 9.8 per cent. However, when both ground wire and counterpoise are excited (figure 11, part III) the induced voltage is only 27.5 per cent. Thus the additional coupling contributed by the counterpoise was only 3.5 per cent. This is due to the reaction between counterpoise and ground wire when both are carrying currents and shows that the benefit from voltages induced from the counterpoise is indeed small.

There is, however, another and more important function of the counterpoise: that of reducing tower top voltages. If we assume a surge impedance of a ground wire as 500 ohms, the tower footing resistance as 400 ohms, and a counterpoise impedance of 100 ohms (ground wire and counterpoise 2-way) then the effective impedance Z_s of the ground installation is 37.7 ohms.

The surge impedance Z of the lightning stroke has been variously estimated to be between 200 and 400 ohms. The voltage of the tower top e_1 then would be

$$e_1 = E\,\frac{2Z_s}{Z_s + Z}$$

where E is initial lightning discharge. Using the 2 outside limits for values of the surge impedance of the lightning stroke, we get table II of voltages $(e_1 - e_3)$ across the line insulators, where e_3 is voltage induced on line wire.

From this table 2 principle conclusions can be drawn:

1. The reduction of voltage caused by reflection phenomena between counterpoise impedance and surge impedance of the lightning stroke is the most important, and next in importance is the induction on the line wire from the wave on the ground wire. The contribution of the counterpoise as far as induction is concerned is negligible.

2. A change in the value of the lightning stroke surge impedance produces changes in insulator voltages to a considerable degree. The small reduction obtained by induction from the counterpoise can therefore be neglected for all practical purposes.

The problem then resolves into calculation of electrostatic induction from the ground wire and the reduction of tower top voltage due to the impedance effect of the ground installation.

Table I—Induced Voltage and Surge Impedance for Various Depths of Current Plane

h_3	2	8	20	60	120	200	500	1,000
h_4	31	37	49	89	149	229	529	1,029
e_3/e_2	0.007	0.0314	0.0564	0.0948	0.121	0.139	0.171	0.192
Z_3	547	552	561	577	591	604	627	644
h (Test)		0.24	0.41	0.86	2.4			
Z_4	357	397	419	447	465	475	496	511
h (Test)		0.5	0.6	1.03	1.46			
m_1	1	0.992	0.977	0.947	0.924	0.905	0.874	0.851
m_2	1	0.9	0.85	0.8	0.77	0.751	0.723	0.70

During the Pittsfield tests it was found that the surge impedance of an overhead line and of an insulated counterpoise varied with time when an impulse was applied.

In table I are listed the surge impedances of line wire (Z_3) and of insulated counterpoise (Z_4) for different current plane levels. The variation of surge impedances with time found by test is within the range of the values shown in the table and the approxi-

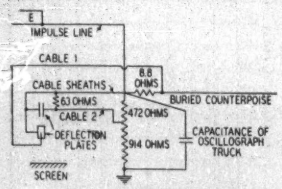
mate times of their occurrence are given in the rows i_3 and i_4, respectively.

The conclusion from this is that apparently the current plane starts close to the surface of the earth and then departs from it at a rate of approximately 140 feet per microsecond at the test location. The contention that the current plane starts close to the surface of the earth can also be arrived at by the following considerations:

1. A wave traveling on an overhead wire with approximately the velocity of light enters a counterpoise at that velocity. The velocity in the counterpoise cannot change abruptly from this value. This means that the voltage and current planes must be close together.

2. At the front of the wave, where the current just begins to enter the ground, the "center of gravity of the currents" must be close to the earth's surface, since it takes a definite time for the current to travel into the soil.

The approximate path of the ground plane is shown in figure 1, curve 1, of this discussion for a wave with rectangular front and in curve 2 for a sloped front (by law of superposition). From the tests the line of



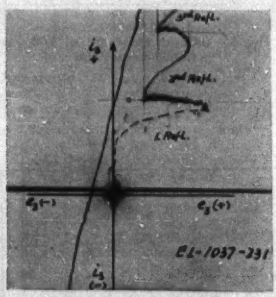


Fig. 2. Method for simultaneous recording of voltage and current in counterpoise and (bottom) oscillogram

penetration actually appears to be straight after the first half microsecond. Up to that time it appears to follow an exponential curve.

The line of penetration (from table 1, i_3 and i_4) is different for the line wire than for the insulated counterpoise, because the wave front in the 2 tests was different, i. e., steeper for the wave on the overhead wire. After the fronts are over the 2 lines are practically parallel. For a rectangular front, the line of penetration would start at zero and parallel to the tail values of the other 2 lines. The rate of penetration will depend upon the resistivity of the soil, the rate being higher for higher resistivity.

Table II—Voltages Across Line Insulators From Stroke to the Tower

Surge Impedance of Stroke	200 Ohms	400 Ohms
Voltage from reflection only	$e_1 = 0.32E$ $e_2 = 0E$ $e_1 - e_2 = 0.32E$	$e_1 = 0.17E$ $e_2 = 0E$ $e_1 - e_2 = 0.17E$
Voltage including 40 per cent induced from ground wire	$e_1 = 0.32E$ $e_2 = 0.13E$ $e_1 - e_2 = 0.19E$	$e_1 = 0.17E$ $e_2 = 0.07E$ $e_1 - e_2 = 0.10E$
Voltage including 40 per cent and 10 per cent induced from ground wire and counterpoise, respectively	$e_1 = 0.32E$ $e_2 = 0.16E$ $e_1 - e_2 = 0.16E$	$e_1 = 0.17E$ $e_2 = 0.09E$ $e_1 - e_2 = 0.08E$
Voltage without counterpoise ($Z_s = 154$ ohms) using 40 per cent for induced voltage from ground wire	$e_1 = 0.87E$ $e_2 = 0.35E$ $e_1 - e_2 = 0.52E$	$e_1 = 0.56E$ $e_2 = 0.22E$ $e_1 - e_2 = 0.34E$

The depth of penetration for uniform resistivity will depend on the length of the traveling wave or, in other words, on the slope of the tail of the traveling wave. This will explain the difference in induced voltage obtained as shown by part II, figures 11 and 12 of Bewley's paper. The difference between the 2 tests was the traveling wave voltage E and the length of the wave t. In figure 11E = 47 kv and $t \rightarrow \infty$, while in figure 12E = 300 kv and t = 7 micro-

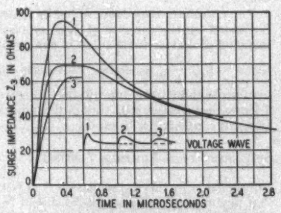


Fig. 3. Variation of surge impedance of 925-foot buried counterpoise for successively applied waves as calculated from oscillogram of Fig. 2

Curve 1 for 1 reflection from impulse generator
Curve 2 for 2 reflections from impulse generator
Curve 3 for 3 reflections from impulse generator

seconds. (Values for traveling waves given here refer to the wave before it reaches the junction between transmission line and counterpoise, while values given in figures 11 and 12 of the paper show voltage after the waves reached the junction.) The difference of 3 per cent in induction can therefore be explained this way since it requires a change in current plane depths of only 10 to 20 feet.

Impedance of Buried Counterpoise

The impedance of a buried counterpoise has been shown to be a function of time. Both papers neglect, however, to show the value of impedance at the front of the waves. This is due to the fact that it is extremely difficult to superimpose 2 oscillograms, taken successively, and find simultaneous values of voltage and current, where fronts of less than 1 microsecond are involved. The only method known to the writer for successfully measuring the fronts is the simultaneous application of current and voltage waves entering the counterpoise on the 2 pairs of deflection plates. This was done in the case of the buried counterpoise and the oscillogram of figure 2 of this discussion was obtained. An analysis of this oscillogram gives the variation of impedance with time as shown in figure 3 for 3 successive reflections from the impulse generator. The values of the second and third reflections are only approximate since the true wave shape was not known and the value of voltage and current of the previous wave at the time when the reflected wave arrives was chosen as zero line. However, the point was to show the similarity of the 3 curves.

The question now is how to arrive at this impedance curve for a counterpoise at any given location. This problem is fairly simple and can be arrived at in the following manner:

The 2 outside values of the impedance function are the surge impedance (initial) and the leakage resistance (final) of the counterpoise. The surge impedance of a buried counterpoise following the reasoning developed in this discussion is a function of time at any point starting with a low value, rising rapidly at first and then slowly as the current plane penetrates into the soil. Simultaneously with the progress of the wave along the counterpoise the leakage

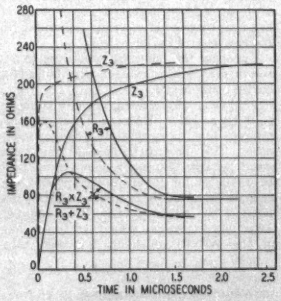


Fig. 4. Calculated transient impedance of 200-foot buried counterpoise

Solid curves for sloped wave front (about 0.4 microsecond)
Dotted curves for rectangular wave front
Z_3 = surge impedance
R_3 = leakage resistance
$\frac{R_3 \cdot Z_3}{R_3 + Z_3}$ = approximate transient impedance

resistance decreases until it reaches its lowest value for steady state conditions (by the process of a great number of small negative reflections). These 2 functions are plotted in figure 4 for a 200-foot counterpoise at the test location. It is an interesting point for speculation that the 2 impedances in parallel give a function approximately equal to that shown in figure 6 of Bewley's paper for

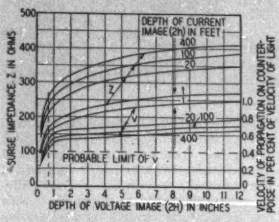


Fig. 5. Relation between surge impedance and velocity of propagation of buried 1/4-inch steel wire counterpoise for different levels of voltage and current images

the tail and figure 3 of this discussion for the front. This sort of procedure is probably permissible as long as the front of the wave has not reached the end of the counterpoise. The dotted curves on figure 4 are plotted for a wave with rectangular front.

The difference in the 2 examples is due to the difference in initial velocity of penetration of current plane into the soil.

Figure 5 of this discussion has been prepared to suggest possible limits for the surge impedance of a buried counterpoise as functions of the depths of voltage and current images. The upper limit of average velocity of propagation can be taken as $v_2 = 0.4$ of the velocity of light. Now, considering the curves of figure 5, it may be seen that for $v_2 = 0.4$ and $2h_3 = 400$ the surge impedance is approximately 250 ohms. For average soil conditions a value of 200 ohms is more likely. As shown in figure 4 the surge impedance proper is not a constant but rises more or less rapidly depending on the steepness of the wave front.

I propose the following procedure to arrive at the effective value of impedance of a buried counterpoise:

Find value of d-c resistance of a counterpoise by actually burying 200 feet of counterpoise and measuring its leakage resistance. This procedure appears to have merit because this much counterpoise will be available for tower protection and the expense involved is not lost, since at the point of test protection usually is required. Assuming an average velocity of 40 per cent of the velocity of light, it would take $\frac{400}{0.4 \times 985} \cong 1$ microsecond to reduce the impedance of the counterpoise to its leakage resistance, and we assume a surge impedance of 200 ohms. Suppose the leakage resistance by test is 80 ohms. Plotting these 2 points on figure 6 the approximate impedance function for an infinitely steep wave is obtained. To obtain values of maximum impedance when the wave fronts are sloped, straight lines are drawn cutting the line of initial surge impedance at the desired time (i. e., 200 ohms, 5 microseconds, and 200 ohms, 1 microsecond) where these lines cross the line of impedance maximum impedance for that wave front is obtained. Comparing the result with figure 4 it is seen that the values so obtained are pessimistic for the steep wave fronts and in special cases this can be taken care of by actual calculations as in figure 4.

It was found by tests in Pittsfield that the voltage at the entrance of the counterpoise was not subjected to reflections from the end of the counterpoise (see figure 6 of Bewley's paper) when its length was 200 feet. The conductance at the test location was rather low, approximately 0.065 mho per 1,000 feet. Therefore, the only purpose of lengthening the counterpoise would be to decrease its leakage resistance. This can, however, be better obtained by installing a number of 200-foot counterpoises, because the leakage resistance of 4 200-foot counterpoises of approximately 20 ohms is obtained in approximately 1 microsecond, while the same value of leakage resistance with 1 800-foot counterpoise is obtained in approximately 5.5 microseconds. Furthermore, the additional advantage of reducing the initial surge impedance proportional to the number of counterpoises installed is obtained.

The maximum impedance found by figure 6 divided by the number of counterpoises installed should be substituted in the equation $e = E\,\frac{2Z_s}{Z_s + Z}$ as shown previously to obtain maximum tower top voltages. Figure 7 shows the variation with time of the factors affecting counterpoise behavior.

Suggestions for Further Testing

As regards further investigation it is felt that new information and checks should be obtained about the impedance of the counterpoise under different soil conditions, rather than such elaborate tests as recommended by Fortescue and Fielder. The reflection phenomena are well understood and theory has been checked by experiments to prove that reflections can be calculated accurately once the impedances at the junction points are known.

To test the impedance of the counterpoise accurately a measuring circuit such as shown in figure 2 should be used. The impulse generator should be discharged directly into the counterpoise to eliminate complications. For instance, one source of error is repeated reflections.

Fortescue and Fielder show impedance curves for the guy ground and for the counterpoise. The resistance of the guy ground varies from 240 to 50 ohms, while the meggered resistance was found to be 150 ohms. I believe that the values found are not the true values on account of the repeated reflections on the 185 feet of line between the

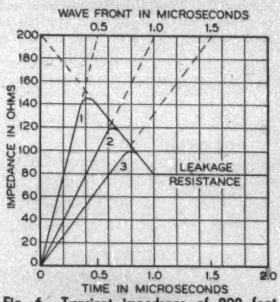


Fig. 6. Transient impedance of 200 foot buried counterpoise

1. Front of applied wave 0.5 microsecond
2. Front of applied wave 1.0 microseconds
3. Front of applied wave 1.5 microseconds

e_2/e_3 = coupling factor
Z_1 = surge impedance of line wire
Z_3 = surge impedance of counterpoise
v_1 = velocity of propagation on line wire
v_3 = velocity of propagation on counterpoise
h_3 = depth of current plane
L_{22} = self-inductance of line wire
L_{33} = self-inductance of counterpoise
L_{23} = mutual inductance
R_3 = leakage resistance of counterpoise
$\frac{R_3 \cdot Z_3}{R_3 + Z_3}$ = effective impedance of counterpoise
P_{32} = constant = $18 \times 10^{11} \times 8.45$
P_{31} = constant = $18 \times 10^{11} \times 1.39$

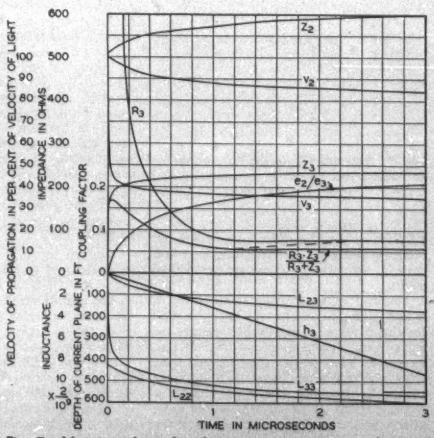


Fig. 7. Variation of coupling factor, surge impedances, velocity of propagation, and depth of current plane with time when rectangular wave is applied on buried counterpoise

impulse generator and the counterpoise or guy ground, respectively. When repeated reflections are applied to the terminal of a variable impedance, such as a counterpoise, the impedance can be found by current and voltage measurements only so long as a reflection from the other end of the line has not returned. To illustrate this point figure 8 has been prepared. This is a replot of figure 2 of this discussion. At time $t = 6.5$ microseconds, when the reflection from the impulse generator returns, the impedance found by dividing e by i will result in the dotted curve marked "apparent Z," while the impedance without the reflection would have decreased as shown by the solid curve. The difference between apparent and actual impedance will be less than that shown when the length of line is shorter, as in Fortescue and Fielder's figures 5 and 6, but to offset this a greater number of reflections will appear. In figure 5 curve A of the paper at least 3 distinct reflection points can be seen at 0.375, 0.75, and 1.125 microseconds (0.375 microsecond is the time for the wave to travel twice the length of the line). The surge impedance values found for guy wire and counterpoise are therefore distinctly too high at the wave front. In figure 6 of the paper it was shown that the counterpoise impedance reduces to approximately 4 ohms in 5.5 microseconds. The value of the leakage resistance as measured by megger was 6 ohms. The minimum leakage resistance is reached, however, only after the wave reaches the end of the counterpoise and returns. This means in this case that the wave travels at a velocity of $\frac{3{,}730}{5.5} = 680$ feet per microsecond, or 69 per cent of the velocity of light. This velocity would be much greater than those obtained by other investigators. However, the reason for this apparent discrepancy in velocity again is the repeated reflections, together with the fact that the inductance of the short piece of the line forms an oscillatory circuit with the impulse generator. A record of a similar behavior can be seen on figure 2 of this discussion, where the beam crosses the i axis well above the zero point, that is the apparent impedance equals zero. Thus the impedances of the guy ground and the counterpoise are too low at 5.5 microseconds.

It therefore appears necessary to avoid connections between generator and counterpoise which give rise to reflections. It is further necessary to have a wave with a very steep front since the impedance varies considerably as the wave front changes (see figure 4 of this discussion).

The contention that the current plane varies with time, as outlined above, and its velocity of penetration into the earth can best be checked by making a test with a long (several thousand feet) insulated counterpoise laid on the surface of the earth. This will eliminate the leakage resistance effect, and show the greatest variation of surge impedance with time. Tests should be made at different locations. Data available to power companies with regard to leakage resistance of installed counterpoises should be collected, so that a picture of how the conductance varies in different localities can be formed.

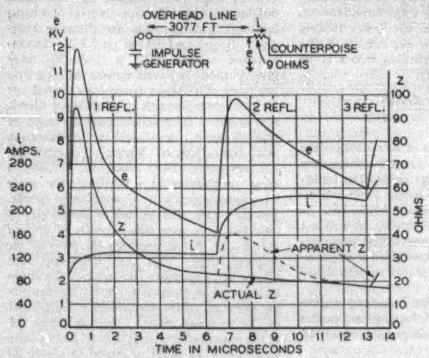


Fig. 8. Errors in surge impedance measurement of counterpoise caused by repeated reflections

S. K. Waldorf (Johns Hopkins University, Baltimore, Md.): The papers of Fortescue and Fielder and of Bewley are comparable in several respects, as they are both based on studies of counterpoises under laboratory conditions. The experimental results of the studies agree very well with each other as may be expected from the soil resistivities of both test localities being very nearly the same.

As Fortescue and Fielder have pointed out, with soil of low resistivity such as they and Bewley encountered in their tests, leakage is the dominating effect in the behavior of the counterpoise. Very frequently soils of much higher resistivity are found in actual installations of counterpoises on transmission lines, often being 25 times as great. Thus, these studies yielding the characteristics of counterpoises buried in soils of moderate resistivity do not establish their effectiveness in soils of high resistivity, as the source of their indicated effectiveness may or may not reside for the most part in the reduction of tower footing resistance which they cause. Fortescue and Fielder state that the question of the usefulness of the counterpoise is still an open one as applied to soils of high resistivity. Bewley's conclusions to his paper lead one to believe that the problem is much nearer to solution.

Bewley states in conclusion 7 of his paper that counterpoises longer than 200 to 300 feet do not appear justifiable. As the experiments indicate that the action of a counterpoise on a surge is as much due to diffusion as any other factor, it seems that in soils of high resistivity, greater lengths than those prescribed are necessary to cause sufficient attenuation for the prevention of an appreciable reflection to the tower. This view is strengthened by the analysis of the lightning oscillogram obtained at Cherry Valley in 1930, given in the paper by Lewis and Foust. That oscillogram indicated a wave front of at least 5 microseconds, and perhaps 10 microseconds, on an actual lightning stroke. In the event of a lightning stroke of this character striking a tower equipped with counterpoises and situated in soil of high resistivity, aside from any coupling effects which may exist, protection due to the counterpoises would rest primarily in the diffusion effect. This would be due to any reflection present returning to the tower long before the wave crest of the stroke had arrived at the tower. Lewis and Foust point out that under such circumstances the effectiveness of counterpoises is measured solely in terms of low leakage resistance. This view neglects any protective effect of coupling that may act under the given conditions, as its presence in appreciable degree has not yet been demonstrated. The lack of conclusive information on the subject has been due to the low soil resistances at the test locations used thus far for counterpoise tests. In any case, to reduce the current density and voltage gradient at the tower footing, a multiplicity of counterpoises in parallel would be more effective than a lesser number of longer length, having the same leakage resistance for the group in both instances.

The installation of a number of counterpoises in parallel introduces the problem of their effective distribution along the right-of-way of a transmission line. They usually cannot be laid in the desirable radial configuration when they are individually more than a few hundred feet long. To confine them within the necessary limits, they must be buried parallel to each other and to the overhead conductors, divided with equal numbers on opposite sides of the tower to which they are connected. It is important to know the practical minimum distance that can be used between parallel counterpoises without the individual counterpoises losing effectiveness due to the proximity of the others in the group. This problem, together with the related one of counterpoise length and number, still requires solution for soils of high resistivity.

Figures 5 and 6 of Bewley's paper show that the transient impedance of a counterpoise falls to its leakage resistance within a few microseconds where the latter is less than the initial surge impedance. A number of leakage resistances have been met on the Safe Harbor-Perryville line of the Pennsylvania Water and Power Co., which are appreciably larger than 150 ohms; the initial surge impedance of a counterpoise found both by Bewley and by Fortescue and Fielder. It would be interesting to see if a surge test of a counterpoise of this type

would show a transient impedance increasing with time instead of decreasing.

The lightning experience summarized by Sporn and Gross, Lewis and Foust, and Bell shows additional evidence that overhead ground wires are essential for protection, and that 2 ground wires are superior to one. The single tripout on the 220-kv line of the Pennsylvania Water and Power Co. listed in table VII of Lewis and Foust's paper occurred on a tower having a tower footing resistance of 25 ohms. The ground resistance of the tower footing alone in this case was 111 ohms and was reduced to 25 ohms by the use of auxiliary grounding consisting of 8 radial wires, each 50 feet long, buried about one foot in the ground, and terminating in salt treated ground rods, each one inch in diameter by 8 feet long. This is in line with the results of Bell's studies indicating that a tower of a 220-kv line is immune to lightning strokes only if its footing resistance is less than 13 ohms.

Observations being made this summer by means of surge crest ammeter links on the 220-kv line, referred to above, are in agreement with the experience cited by Bell and by Lewis and Foust that flashover does not occur unless the product of the tower footing resistance and crest surge current is greater than the maximum permissible surge voltage across the line insulators. These observations, extending over a $2^1/_2$ month period thus far, have involved measurements of lightning currents with 255 links collected from 150 towers and showed surge currents in the line towers ranging from a trace to 45,000 amperes. The maximum value of the product of tower footing resistance and crest surge current has been 1,220 kv. The maximum permissible surge voltage across the insulators on this line is approximately 2,000 kv. It is estimated from these records that the line has been subjected to 66 direct hits by lightning strokes during the observation period without a single insulator flashover or line tripout.

The experience of Sporn and Gross that low tower footing resistance reduces line flashovers, but does not eliminate them, is contrary to that of the other authors. This discrepancy probably is due to the fact that the American Gas and Electric Co.'s experience has been with lines having only single overhead ground wires which do not provide full shielding against direct strokes to the line conductors. Low tower footing resistance is of no help to prevent flashovers due to direct hits on line conductors.

In his description of the counterpoise installed at High Knob, Bell reports that tower footing resistances which formerly varied from 50 to 150 ohms were thus reduced to about 1 to 1.5 ohms. Evidently the former high values are ground leakage resistances as usually measured, whereas the final values are not. It will be of interest to inquire of the author how those latter low values were obtained.

L. V. Bewley (General Electric Co., Pittsfield, Mass.): Lewis and Foust state on page 1184 of their paper that assumptions made in my 1930 paper "Critique on Ground Wire Theory" in regard to the magnitude of lightning voltages and the steepness of the wave fronts are not substantiated by the data presented in their paper. Apparently they placed a wrong interpretation on my "assumptions" (which were not assumptions at all, but estimates calculated from the field data at that time available), and as I shall show, the information contained in the present Lewis and Foust paper substantiates those estimates very well indeed. Specifically, I stated that the maximum lightning voltage was of the order of 10,000 to 20,000 kv (this being the potential of the free traveling wave in the stroke, that is, the incident wave), and in subsequent papers and articles I have shown curves and data based on assumed lightning voltages (the incident wave) of 5,000 to 20,000 kv so as to give the designer a choice in selecting the protective level to which he wished to design. In terms of the surge impedance Z_{11} of the ground wires, the surge impedance Z_0 of the lightning stroke, the tower footing resistance R, and the tower current i, the incident wave of the lightning stroke is (as given in my 1930 paper),

$$e_0 = \left[\frac{(Z_{11} + 2Z_0)R + Z_{11}Z_0}{2Z_{11}}\right] i$$

In 1930 I used a value of $Z_0 = 200$ for the surge impedance of the stroke. Since then I have calculated a set of curves (The Lightning Stroke, *General Electric Review*, Dec. 1933) for this function which I believe to be more exact, and I found that $Z_0 = 400$ is a better average value to use. The surge impedance of a single ground wire is approximately $Z_{11} = 500$, and for 2 in parallel $Z_{11} = 300$.

Table I of the Lewis and Foust paper gives the tower currents and footing resistances for a line having a double ground wire. In this case we have

$$e_0 = \left[\frac{(300 + 2 \times 400)R + 300 \times 400}{2 \times 300}\right] i$$
$$= (1.83 + 200)i$$

and over the section with no ground wire
$e_0 = (0.5R + 200)i$
Applying this to their table I we find that

Item No.	e_0	Item No.	e_0
2	4,950	11	8,250
3	5,000	19	5,770
5	5,470	22	8,900
6	4,800	24	6,940
10	4,470	27	6,300

The other records were between 1,000 and 3,000 kv. Thus out of 32 cases we find 2 of the order of 8,500 kv, 2 of the order of 6,500 kv and 6 of the order of 5,000 kv.

Table II of the Lewis and Foust paper applies to a line having a single ground wire. In this case

$$e_0 = \left[\frac{(500 + 2 \times 400)R + 500 \times 400}{2 \times 500}\right] i$$
$$= (1.3R + 200)i$$

Applying this to their table II we find that

Item No.	e_0	Item No.	e_0
1	7,100	26	4,680
3	9,930	28	4,430
18	13,700	29	4,050
10	13,400		

The other records gave from 1,560 to 3,460 kv. Thus out of 23 records we find 2 of the order of 13,500 kv, 1 of the order of 10,000 kv, 1 of the order of 7,000 kv, and 3 of the order of 4,500 kv.

Now it is highly improbable that the most severe possible lightning stroke is included in these records, and consequently it would appear that 20,000 kv (as compared with a maximum of 13,700 calculated from their table II) is not an extravagant estimate for the upper limit of lightning voltages.

With regard to wave fronts the question is not so easily settled. In calculations I have usually taken the steepest wave front of high voltage surges to be one microsecond. Lewis and Foust show fronts in their figure 1 of from 1 to 80 microseconds, with the bulk of them between 3 and 10 microseconds. This line is 65 miles long, of which 37.5 miles are without ground wires, and the oscillograms were taken at one end. Therefore, on an average, the recorded waves must have traveled at least for 19 miles. But we know from impulse tests on transmission lines that the time to crest of a surge increases greatly with the distance traveled. Brune and Eaton (A.I.E.E. Transactions, v. 50, 1931, p. 1132–38) have given cathode ray oscillograms showing that the front of a 700-kv surge may flatten out 10 to 20 microseconds in 14 miles of travel, and about 5 microseconds in one-tenth of that distance. As shown in "Attenuation and Distortion of Waves" (Electrical Engineering, Dec. 1933, p. 876–84) a surge propagates as a multivelocity wave whose components travel at different speeds. *But the fastest wave travels at the velocity of light and is a wave which carries no ground current, so that it preserves the front of the original surge.* This very important fact allows us to estimate the front of the surge at its point of inception, merely by measuring the front of the fast velocity component of the recorded wave. Thus in figure 3*A* of the paper referred to, the total front of the surge after 14 miles of travel is about 20 microseconds, but the clearly defined fast wave component shows a front practically equal to that of the surge at its starting point. Now, of course, if the wave has not traveled far enough for the multivelocity components to disengage to the extent that they are clearly defined on the oscillogram, an estimate of the original front cannot be made by this method. Thus in the figure 3*A* referred to, the multivelocity components cannot be clearly distinguished over the first 1.4 miles of travel. Also, in the case of equal waves on all 3 conductors there will be no fast component. Nevertheless, many of the oscillograms taken on the lines of the Pennsylvania Power and Light Co. distinctly show the multivelocity components, and I suggest that they be reexamined in the light of multivelocity theory. It is unlikely that all lightning wave fronts are as short as one microsecond, or even that any large percentage of them are that short, but there seems to be little doubt that fronts of that order of steepness occur in association with high magnitudes, and therefore if we wish to anticipate the worst conditions we must not ignore these short fronts.

I can sympathize with the wish of Lewis and Foust to solve the lightning problem "merely as a problem of limiting the tower potentials on an ordinary resistance basis, rather than on the basis of dealing with a complexity of traveling wave reflections and couplings." But data now available do not indicate that it is proper to confine the effect of the counterpoise to one of resistance only, or to neglect the reflections from adjacent towers. In the first place it is the reflections from adjacent towers

(where ground wires are used) which fix the shape and duration of the tower voltage as much as does the shape of the lightning wave itself. On a 1,000-foot span and with low footing resistances the insulator flashover can be estimated on the basis of a 5 to 10 microsecond wave. Reflections up and down the tower are of importance for very low footing resistance, high towers, and steep waves. As far as coupling is concerned, it reduces the voltage across the insulators by about 30 per cent. It is interesting to consider a 1.5 × 40-microsecond lightning wave of 10,000 kv impinging on a tower with a 10-unit insulator string, 30 ohms footing resistance, 1,000-foot spans, and a ground wire with 30 per cent coupling.

	Neglecting Reflections and Coupling	Including Reflections and Coupling
Maximum voltage across insulators	1,260 kv	885 kv
Duration	40 μsec	8 μsec
Insulator flashover value	860 kv	1,000 kv

These results show that reflections and coupling are helpful. Incidentally, the conception of a main stroke going up from ground to cloud after an ionized path is created by the initial downward dart, does not essentially alter the picture from a traveling wave point of view (The Lightning Stroke, L. V. Bewley, *General Electric Review*, Dec. 1933).

Lewis and Foust remark on the critical footing resistance of 12 ohms which seems to give immunity to the Wallenpaupak-Siegfried line; Bell, in considering the effects of tower footing resistance, states on page 1193, "it would be very helpful if the secret of why tower footing resistance affects the operation of transmission lines could be made clear"; while Sporn and Gross say, "the magnitude of tower footing resistance required to make a line practically lightning proof has been much discussed, but rarely stated with any assurance; 10 ohms and 5 ohms have been mentioned as possibilities." In an article "How to Design Ground Wires for Direct Stroke Protection" (*Electrical World*, Mar. 17, 1934) there is given a table and formula for computing the tower footing resistance, and it is suggested that the footing resistance be taken as

$$R = \frac{\text{Permissible kv across insulators from table}}{150}$$

Now the Wallenpaupak-Siegfried line has 16-unit insulator strings and 1,000-foot spans. The table gives 1,830 kv for the permissible voltage across the insulators. Therefore, the tower footing resistance should be 12 ohms or less.

The Glenlyn-Roanoke line has 10 insulator units, and I will assume 750-foot spans. The table gives 1,240 kv as the permissible insulator voltage, and therefore the tower footing resistance should be 8.3 ohms or less. Figure 4 of the Sporn and Gross paper indicates that, if their ground wire clearance were adequate, they would get immunity at about 8 ohms. There is no mystery about the effect of tower footing resistance. But footing resistance alone cannot serve as a universal panacea of protection—the length of the span and the ground wire clearance are equal partners with it. Zero footing resistance will not prevent outages if the ground wire clearance is inadequate.

There is, I think, some very conclusive evidence in the Sporn and Gross paper suggesting that they have gone far enough in the matter of reducing the tower footing resistances, and that further benefit will be obtained by *increasing the heights of their ground wires*. According to table VIII of their paper most of the outages occur on the top conductor (vertical configuration), in spite of the fact that the coupling is much closer and therefore the voltage across the insulators less for the top conductor. This means 1 of 2 things: (1) either the ground wires are not high enough to provide sufficient shielding effect, or (2) the ground wires are not high enough to prevent flashovers from occurring out on the span (where tower footing resistance is out of the picture). In either case the remedy is the same—increase the ground wire clearance. On lower and medium voltage circuits, insulator flashover following a steep front stroke to a tower is possible even for zero footing resistance.

Fortescue and Fielder have obtained results from their field tests on a buried counterpoise which agree very well with the results found in tests at Pittsfield and in Michigan. There are, I think, a few improvements which could advantageously be made in their testing technique: (1) place the surge generator far enough away so that reflection from it will not interfere with the events occurring at the test point; (2) use a shorter counterpoise so that the transition from the initial surge impedance to the final leakage resistance is more clearly defined; (3) make tests also on an insulated counterpoise so that the zero plane for current images can be definitely located and the multivelocity components identified; (4) measure velocities by reflections and by the method due to E. J. Wade described in my paper; (5) measure the impedance by the method described in J. H. Hagenguth's discussion and therefrom obtain data on the "front of the wave phenomena."

Fortescue and Fielder apparently adhere to the idea of a "common true ground plane" for both current and voltage images, and proceed to calculate its location by ignoring the fact that this concept is incompatible with the reduced velocities. In the closing discussion to my own paper on the subject I will show calculations based on multivelocity theory (an offspring of taking the current and voltage images at independent depths) which are in detailed quantitative agreement with our oscillograms and establish the validity of the multivelocity theory. The authors state that the coupling was increased by raising the counterpoise 6 feet above ground. This is not substantiated by a comparison of their transcribed oscillograms.

C. L. Fortescue (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The data from Bell's comprehensive and clear report are of particular interest because of the admirable way in which they have been classified. They present the facts very clearly and the facts completely confirm the general reliability of the theory of ground wire protection against direct strokes which has been developed since the winter of 1929.

In view of the large amount of published data it is hard to see why the author, under the caption "Tower Footing Resistance," page 1193, says, "It would be very helpful if the secret of how much and why footing resistance affects the operation of transmission lines could be made clear." In the case of the effects of tower footing the results are as clear as day. If a line is designed for a certain level of protection it will have a definite number of outages per hundred miles per year which will vary with the number of lightning storms that occur per year. The only factor which may mask the results is imperfect shielding. Imperfect shielding results in a condition in which not all strokes terminate on the ground wires but a percentage terminate on the conductors, so that an imperfectly shielded line has partly the characteristics of an unprotected line and partly those of a protected line. This is well illustrated by reports of lines in the Great Lakes district where 132 kv lines of identical construction over the same territory, but of which some are provided with 2 overhead ground wires and some with only one, show for those protected with 2 ground wires an average of 1.7 outages per hundred miles per year and for the others an average of 5 outages per hundred miles per year. The difference between the 2 is due almost entirely to the imperfect shielding afforded by one ground wire as usually installed in the past. This also accounts for the fact that on many so-called protected lines flashovers take place when the tower footing resistance is low. This is due not to any fault in the theory but to the fact that the lightning stroke which caused the flashover did not terminate on the ground wire but on the line. I have estimated the shielding factor for a 132 kv line with one ground wire as usually installed to be about 70 per cent.

Mr. Bell's figures 2 and 3, pages 1193 and 1194, show quite clearly that with a protected line insulated with 16 standard 10-inch $5^3/_4$-inch spaced insulators no flashovers take place with tower footings below 12 ohms. The value for tower footing resistance which has been set by the writer and his colleagues for a line that is practically lightning proof for the last 5 years is 10 ohms and below. Of course, the effect of higher footing resistances may be offset by using more insulation and *vice versa*, but this requires larger tower structures and is generally much more costly than reducing the tower footing resistance to 10 ohms or less. Inadequate shielding or inadequate insulation cannot be compensated by low footing resistance.

The theory of the protective effect of counterpoises is yet in the development stage, but no doubt it will finally be brought to a satisfactory solution. In the meantime many more counterpoises are being installed in various parts of the country and this will increase the amount of data available for determining the effect of counterpoises. It is gratifying to note that the $2^1/_4$ mile line over High Knob provided with a single parallel counterpoise still has a perfect record.

Among the 220 kv lines that have been designed according to the theory discussed

above, is the Philadelphia portion of the Roseland-Plymouth Meeting connection which has a perfect record up to date, according to my information. The Safe Harbor line has had one outage since it went into operation in January 1933. This line passes through a difficult terrain where great trouble had been experienced in keeping down the tower footing resistance.

It is interesting to note, in the paper by Sporn and Gross, a decided improvement in performance resulting from the installation of counterpoises. Their data on the performance of 132 kv lines protected by 2 overhead ground wires of conventional design is at variance with all other statistical data that I am familiar with. In the Great Lakes district where careful statistical records have been kept for years the reduction for 2 ground wires as compared with 1 is 66 per cent whereas Sporn and Gross indicate only 20 per cent. It seems to the writer that this discrepancy is statistical data needs some explanation. Certainly none can cavil at the performance of the Windsor-Canton line which seems to be consistent except for the year 1926.

W. A. Hillebrand (University of California, Berkeley): Mr. Sporn's problem is the improvement of transmission line reliability, for which the starting point must be the careful compilation of records such as those reported upon in the paper by Mr. Gross and himself.

In the solution of this problem insulation plays an important rôle, for which reason it is significant that, in going from the 132-kv circuits reported by Sporn and Gross to the 220 kv circuits of which the records are given by Lewis and Foust, an increase in insulator length from 10 to approximately 18 units or about an 80 per cent increase in impulse flashover voltage resulted in a decrease in tripouts per 100 circuit miles per year from the order of 11 to about 2.5, or over 75 per cent.

In view of the exceptional reliability and freedom from outage of some highly insulated wood lines, the unfavorable record of the 60.3 circuit miles of such construction reported by Sporn prompts inquiry as to structural details of the line in question. Are crossarms steel or wood? Are the poles protected by grounding wire against lightning? Are guys insulated?

Do the records of 2-circuit lines indicate the relative frequency with which lightning will cause both circuits to flash over? In their discussion of 2-circuit outages Messrs. Sporn and Gross infer that in most cases the second circuit tripped out because operated in parallel at the time of the fault. Is this believed to be generally the case?

Records presented in both papers of maximum value of tower current due to a lightning stroke and of stroke polarities are confirmed by the most comprehensive field investigations of lightning yet reported upon. The investigation covers the records obtained in Germany during the summer of 1933 from 10,000 surge crest ammeters of the type referred to by Messrs. Lewis and Foust, which were installed on transmission lines of various voltages. One 60 kilometer, 100-kv line had every tower and the ground wire at every tower equipped with the magnetic recording links. The data were published in the *Elektrotechnische Zeitschrift* for May 24 and 31 of this year, which arrived in this country after the papers under discussion had been submitted for publication (Die Messung von Bligzstromstärken an Blitzableitern und Freileitungsmasten, von Dr.-Ing. H. Grünewald. May 24, 1934, page 505, and May 31, 1934, page 536).

Lighting Performance of 132 Kv Lines

Discussion and authors' closure of a paper by Philip Sporn and I. W. Gross published in the August 1934 issue, pages 1188–94, and presented for oral discussion at the lightning session of the Pacific Coast convention, Salt Lake City, Utah, September 5, 1934.

W. H. Burleson and **M. M. Kenneally** (both of Ohio Brass Co., Mansfield): The paper by Sporn and Gross is of unusual interest in that it includes an elaborate tabulation of operating and design statistics regarding the 132 kv system of the American Gas and Electric Company. This information is contained in table III, pages 1196–7 of the August 1934 issue of ELECTRICAL ENGINEERING. The industry as a whole, and the Institute in particular, can be greatly benefited by such contributions. We of the manufacturing group welcome such information and hope that the authors will continue their past performance of publishing interesting operating information. We believe that an exchange of information of this kind is of great importance to operating, designing, and development engineers. Too frequently investigations and design are predicated on assumptions which if data is collected and made public, can be far more accurate and reassuring than assumptions made purely upon the perception or skill of the individual engineer.

The utility of such tabular information as contributed by Sporn and Gross can well be illustrated by an additional analysis that we have made predicated upon the operating and design information contained in the paper. Since the early 1920's designing and operating engineers have attempted to evaluate the expected rate on arc protecting and shielding devices in connection with high voltage transmission lines. Information upon which to base such study has been highly local in color and limited as to mileage or years of experience. The method of collecting data on the individual properties made difficult the comparison of operating results. We believe that the 31 lines studied by the authors, in a system extending from Chicago to eastern Virginia, crossing the states of Illinois, Michigan, Ohio, West Virginia, and Virginia, are sufficient at least to attempt to evaluate the return that may be expected from investment in arc protecting and shielding devices of at least 3 designs. Many engineers have expressed the belief that on lines so constructed the expected lightning outages do not exceed 10 per 100 right-of-way miles per annum, and by employing modern high speed relaying and breaker operation, little or no serious damage to conductors and insulators from power arcs will be experienced. Such engineers, therefore, have raised the question of how much can be expended for arc protection on such lines.

We have taken the liberty of taking operating and physical data from the data submitted by the authors in table III, and regrouping the lines so as to include in a single tabulation:

1. Lines having arc protection consisting of a ring at the lower end of the string and a horn at the upper end of the string.

2. Lines having arc protection consisting of rings at the lower and upper ends of the string.

3. Lines having no arc protection devices. In order to afford additional measure of the value of arc protection devices, we are assuming that if these lines had been equipped with arc protection consisting of rings at the top and bottom of the string, all damage indicated in the authors' table would have been avoided, or 100 per cent efficiency is assumed in the arc protecting devices.

While the mileage and number of lines that were available for this comparison are not as extensive as in other groups, the amount of damage occurring on such lines is much more positive than from the lines equipped with rather elaborate arc protecting devices.

In table I we have summarized this information. While the assumptions as to the probable damage resulting from power arcs are subject to some question, we believe the evaluation of such damage will on the average be sufficient. For instance, conductor damage may vary from very casual repairs of from $2.00 to $3.00 to smooth rough spots on the conductor to the replacement of 2 or 3 spans of conductor in inaccessible locations. The latter may cost several hundred dollars. However, it is assumed that all repairs can be made on prearranged interruptions and work performed under favorable conditions.

It will be noted by the estimate submitted that individual lines have earned a fair return on the investment whereas other individual lines and the total of any of the groups indicate an exceedingly small return on the invested capital.

From a study of the above data it would appear that the following conclusions may be drawn:

1. Where the expected outages resulting from insulator flashovers exceed 10 per hundred miles of line per year some form of arc protection may be highly desirable.

2. The amount of money that may be expended for arc protection may be warranted as the expected number of insulator flashovers increases.

3. Where the voltage distribution on the string is sufficient to produce corona on the units of maximum stress, a part of the investment expended for arc protection may properly be charged to insulator shielding.

4. Where the size of the conductor and/or the combination of size and expected current in the arc are sufficient to produce burndown of conductor or insulator string, the return from investment in arc protecting devices will be much greater and therefore a larger initial investment is warranted.

5. Each transmission project can well be individually considered in determining the advisability of arc protection.

6. Careful consideration should be given in determining whether or not to spend available funds in reducing the number of expected flashovers by

(*a*) Lowering the tower footing resistance

(*b*) Improving the type, kind, and placement o overhead ground wires

(*c*) Lowering the height of the conductor above ground

(*d*) Reducing the span length

(*e*) Using expulsion gaps to prevent the flow of power current

(*f*) Improving the relay protection

(g) Increasing the speed of breaker operation
(h) Maintenance of breakers and relay system.

This is only representative and illustrative of the use to which that information as contributed by the authors can be put by both operating engineers and manufacturing engineers interested in and charged with the production of materials to be used on modern high voltage transmission lines.

Philip Sporn and **I. W. Gross** (both of the American Gas and Electric Co., New York, N. Y.): It has been pointed out by Bewley, Waldorf, and Fortescue that the reason why flashovers have occurred at the typical towers on our 132-kv system, where the tower footing ground resistance is low, is due to a lightning stroke contacting the line wires; that is, due to the incomplete shielding provided by one ground wire as used. This seems a very plausible explanation on the basis of the direct stroke theory and traveling wave phenomena on the line. We have considered this point in our analysis, but fail to find conclusive proof that flashing over of towers with low footing resistance is due to this cause. For example, if the lightning stroke contacted the line in midspan and produced a flashover there, or between that point and the tower, it would be expected, in a few cases at least, that evidence of burning of the line wires due either to the lightning current or the subsequent power arc would be found. In only one case that we recall in the past few years has such an occurrence been reported. As practically all our 132-kv lines receive a tower climbing inspection once each year and the line conductors between towers are very carefully inspected at this time, it would be expected that if such flashovers did take place some evidence of this would be observed. We are therefore rather reluctant to accept this explanation as the reason why towers of low footing resistance have flashed over. While we are thoroughly sympathetic with the theory of lightning discharges to a transmission line and the consequent voltages built up, we are, nevertheless, inclined to place considerable reliance in the record of line performance as obtained.

In reference to Mr. Hillebrand's comments on wood pole lines, the single line on which we reported has steel crossarms, has no ground wire, but does have a down conductor tying the steel crossarm to a coiled wire at the base of the wood pole structure. During the past 2 years, this line has been operated with this ground wire having a gap of about 8 feet between the lower crossarm and the ground. There are a number of all-metal guy wires on this line; guy insulators are not used. It was not intended in presenting and discussing the performance of this line to indicate that it was typical of present trends in wood pole construction, and we do not believe that too much weight should be placed on a direct comparison of relative performance of this wood pole line and the steel tower lines on our system.

Regarding the matter of 2-circuit outages referred to by Mr. Hillebrand, we believe these do indicate the relative frequency with which lightning causes both circuits to flash over. In other words, the load on the system in all cases is such that if one of the 2-circuit lines trips out from any cause, the other line will carry the load without tripping from overload. It is therefore apparent that when 2-circuit interruptions occur during lightning storms, these are due to practically simultaneous lightning faults on both circuits. While, of course, it is not known that some of these 2-circuit outages are not due to lightning faulting one circuit and the power arc spreading into the second circuit before the faulted circuit is interrupted, it is believed that this type of occurrence is extremely rare in the case of our 132-kv lines.

The discussion of Kenneally and Burleson on the economics of grading ring and shield protection is a typical example of how easy it is to prepare a set of figures that may be totally misleading. Thus, the data as presented in the summary are formidable enough, but so many errors of assumption were made in the preparation of them that no extended discussion of the results presented is warranted. As typical of some of the many errors, the discussers assume that conductor damage may vary from casual repairs of $2.00 to $3.00 for minor burns up to several hundred dollars, but no repair, no matter how minor (that is, one that involves as a minimum the burning of a single strand) can be made properly without lowering the conductor and this on a long span transmission line is quite an elaborate procedure, and will mean, in general, from a half a day to a day's work of a line gang. The sums involved in that, therefore, would be in the order of from $40.00 to $50.00, and not from $2.00 to $3.00.

Table I—Summary of Economic Analysis of Arc Protection, American Gas & Electric Company's 132 Kv System

	Total Ring and Ring Protected Lines	Total Ring and Horn Protected Lines	Total Protected Lines	Total Lines Without Arc Protection	Total A. G. and E 132 Kv System
Physical Data					
Length of Line, Right of Way Miles	587.2	671.9	1,259.1	160.9	1,420
Voltage Rating of Construction, Kv	132	132	132	132	132
Minimum Operating Voltage, Kv	33	132	33	132	33
Maximum Operating Voltage, Kv	132	132	132	132	132
Operating Data					
Lightning Tripouts, 1932 (No.)	58	87	145	10	155
Lightning Tripouts, 1933 (No.)	71	96	167	13	180
Lightning Tripouts, 1932 and 1933 (No.)	129	183	312	23	335
Insulator Damage, 1932 (No. Cases)	19	38	57	14	71
Insulator Damage, 1933 (No. Cases)	11	24	35	9	44
Insulator Damage, 1932 and 1933 (No. Cases)	30	62	92	23	115
Conductor Damage, 1932 (No Cases)	14	32	46	14	60
Conductor Damage, 1933 (No. Cases)	11	19	30	5	35
Conductor Damage, 1932 and 1933 (No. Cases)	25	51	76	19	95
Ring Damage, 1932 (No Cases)	82	99	181	..	181
Ring Damage, 1933 (No. Cases)	41	69	110	..	110
Ring Damage, 1932 and 1933 (No. Cases)	123	168	291	..	291
Total Damage, 1932 and 1933 (No. Cases)	134	223	357	28	385
Economics of Arc Protection*					
Effectiveness as Insulator Protection (Per Cent)	77	72	74	100*	74
Effectiveness as Conductor Protection (Per Cent)	80	74	78	100*	78
Arc Protection Devices Installed (No.)	14,215	14,567	28,782	4,823*	28,782
Installed Cost[1] (Est. Dollars/Set)	7	5	..	7*	..
Total Investment (Dollars)	99,454	72,835	172,289	32,961*	172,289
Carrying Charges on Arc Protection[2] (Dollars/-Annum)	14,910	10,926	25,836	4,944*	25,836
Cost of Protection 1932 and 1933 (Dollars)	27,154	20,072	47,226	9,592*	47,226
Max. Protection to Insulators[3] (No. Cases)	104	161	265	23*	265
Max. Protection to Conductors[4] (No Cases)	108	172	280	19*	280
Value of Insulators Protected (Dollars)	2,122	3,210	5,332	468*	5,332
Estimated Cost of Insulator Damage Avoided by Protection[5] (Dollars)	1,872	2,880	4,752	414*	4,752
Estimated Cost of Conductor Damage Avoided by Protection[6] (Dollars)	5,400	8,600	14,000	950*	14,000
Estimated Total Cost of Damage Avoided by Protection (Dollars)	7,272	11,480	18,752	1,362*	18,752
Ratio of Estimated Cost of Protection to Probable Damage Without Protection[8]	3.8:1	1.75:1	2.5:1	7 1*	2.5:1

* For comparison, lines without arc protection have been assumed equipped with ring and ring protection. The estimated damage assumes 100 per cent protection of both the insulator and the conductor. These items have not been included in the system total column.

1. Installed cost of ring and ring—$7.00 per set in place. Installed cost of ring and horn—$5.00 per set in place. No allowances made for extra cost yoke string protection.
2. Annual carrying charges, including interest, depreciation, and taxes, assumed 15 per cent.
3. Number of cases rings protected insulators.
4. Number of cases rings protected conductor.
5. Value of insulators protected at $2.00 per unit.
6. Assumes all cases protected (3) would have incurred a damage of 3 units and rings not been used. Damaged units valued at $2.00 per Unit, plus $4.00 per Unit labor charge; Total $6.00 per Unit.
7. Assumes all cases protected (4) would have incurred damage if rings had not been used. Average conductor damage estimated $50.00 per Case.
8. Ratio of carrying charges on protection to maximum expected damage had protection not been used.

Again the authors state that it is assumed that all repairs can be made on prearranged interruptions and that work will be performed under favorable conditions, but it must be recalled that many of the lines in question are single circuit, which means there is no such thing as a favorable time for interrupting the service of the line. In fact, to get one of the lines out of service frequently may mean preparations lasting days to get old or uneconomic plants properly manned and on the line, and even then the service would be subjected to a considerable hazard. The fact of the matter is that conductor burning is one of the few things that cannot be tolerated in the operation of an important line, if the entire investment (not alone the investment in a very minor item like a ring assembly) is not to be nullified by its unreliability.

The discussers again are in error in assuming a cost of $6.00 to change an insulator on a smashed insulator string. For work carried out in quantity, the figure might be reasonable, but for sporadic and spasmodic repairs the actual cost is more likely to be 4 or 5 times that. Again, in figuring cost of investment, the authors assume a necessary return of 15 per cent. This would be excellent if it could be obtained, but it isn't obtainable today to utilities in general on the entire plant investment, and there is no reason why such a cost figure has to be assumed in carrying insulator protective equipment.

Another item of expense the discussers failed to consider is the more frequent line inspection required on a line not equipped with arcing protection, if any attempt is to be made to keep the line conductors and insulators in a condition even approximately that existing on the protected line.

The above are only some of the many errors of omission and commission that render valueless the elaborate tabulation presented.

The remaining conclusions of the discussers, such as that the amount of money that is warranted for arcing protection increases as the expected number of flashovers increases, or that each transmission project should be discussed individually, are of course too axiomatic to need any further comment.

Theory and Tests of the Counterpoise

Discussion and author's closure of a paper by L. V. Bewley published in the August 1934 issue, page 1163–72, and presented for oral discussion at the lightning session of the Pacific Coast convention, Salt Lake City, Utah, September 5, 1934.

C. L. Fortescue (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper is particularly interesting to me because it reports a series of tests similar to those made at Trafford by Mr. Fielder and myself, and similar troubles and disappointments were encountered on account of the low resistivity of the soil on the site of the test. In addition to these troubles, however, in making our tests we had the elements to contend with because our tests were made during the months of January, February, and March, and the winter in Pittsburgh was unusually severe.

In general the tests reported in this paper lead to the same conclusion as those reported in our paper. Neither set of tests will enable the engineer contemplating a future transmission line or considering improving an existing line to determine whether it is more economical to use counterpoises or to reduce the tower footing resistances by other means, such as driven grounds. In other words, to obtain a logical answer he will be compelled to make some kind of comparative tests, for which he probably is not properly equipped, or else use his judgment based on the experience of those who have used counterpoises (of which there is very little statistical data at the present time) and wait for years to have his judgment confirmed or contradicted.

How much better it would be if similar tests to these could be made jointly by all interested utilities to determine the behavior of counterpoises in representative locations. I feel sure that the problem could be solved satisfactorily by half a dozen such tests carried out on sites having different soil conditions. The state of California offers exceptional opportunities as it presents a great variety of soil conditions. Transmission lines are no doubt available and in process of construction where such tests could be made covering a large variety of soil conditions at very little expense. The first tests on system stability were made in California and, as a result, the solution of an important problem of system design was achieved. The lightning problem is just as important from the system design standpoint as the stability problem, indeed it is an important element in the general problem of system stability as lightning proof lines will enable transmission lines to be loaded close to their static stability rating. For long transmission distances it is hard to contemplate a line over some portion of which counterpoises will not be needed.

Bewley brings in his artificial lightning surge over a short length of line (3,077 feet), a method which is to be highly recommended. For a section of experimental line which does not extend in 2 directions from the point of attachment of the surging line the effect should be equivalent to a surge impedance of the lightning channel of about 250 ohms. At Trafford we would have liked to do the same but space limitation prohibited it. The method of obtaining the velocity of propagation in the buried counterpoises is extremely interesting and the results obtained are about what would be expected. There never has been any doubt in my mind that the velocity of propagation of the main surge in the counterpoise is relatively slow as compared to that in the line and our tests indicate that the velocity in the line is considerably less than the speed of light. The effect of both leakance and the high dielectric constant of the earth is to slow up the velocity of propagation.

On one point I do not agree with the author. In figure 11, part II, he shows the same surge potential for e_1 and e_3, although e_1 applies to the overhead line and e_3 to the buried counterpoise. Again in figure 12 he shows similar results. The 2 surges in question are so much alike that one is forced to the conclusion that they are identical and the assumption has been made that e_1 and e_3 have the same value. Repeated tests have been made by us which demonstrate that such an assumption is not valid. In our tests at Trafford we found differences of potential due to the down drop lead from line to counterpoise of appreciable magnitude. In fact, in making measurements of surge impedance of grounds and counterpoise we found it necessary to place our measuring terminal right at the counterpoise because even a short length of line (about 70) between the counterpoise gave incorrect results.

L. V. Bewley (General Electric Co., Pittsfield, Mass.): Hagenguth's thorough analysis of our test data has resulted, I think, in 2 outstanding contributions to our knowledge of counterpoise behavior; first with respect to front of the wave phenomena, and second with respect to the simplification of counterpoise calculations. I will discuss these 2 aspects of the problem briefly.

Front of the Wave Phenomena

In this and 2 previous papers ("Attenuation and Distortion of Waves," L. V. Bewley, Electrical Engineering, December 1933, page 876–84. "The Counterpoise," L. V. Bewley, *General Electric Review*, February 1934) it was shown that the earth current must penetrate at a rapid rate immediately following the passage of the wave front, and then at a more gradual rate. After the "readjustment transient" at the wave front the effective current depth may be considered as constant as far as induction on the conductors is concerned, because the inductance coefficients change very little with an increase of current depth. From this consideration of the character of the earth current transient, several important effects could easily be explained in a qualitative way, but Hagenguth, from his careful and detailed study, has obtained actual quantitative data on the subject. In our original tests separate oscillograms of voltage and current were taken, and from them the surge impedance computed as a function of time by taking the instantaneous ratios of e/i. In the case of the overhead wires and the insulated counterpoise the impedance function as thus computed appeared to start at a high initial value, quickly fall to a minimum value, and then slowly increase. The explanation for this behavior was given in figure 13 of my paper. However, in the case of the buried counterpoise it was not at all clear whether the impedance started at a high value, fell to a minimum, and then slowly increased; or started at a low value, rose abruptly in a short interval, and then continued slowly to rise. Either interpretation could be arrived at by a very slight mismatching of the fronts of the voltage and current waves. Hagenguth therefore suggested that oscillograms be taken with voltage and current, respectively, on the 2 plates of the oscillograph. When this was done there was no doubt that the impedance of the buried counterpoise starts at a very low value and then rapidly rises to its path of relatively slow increase.

This is not inconsistent with the explanation for the insulated counterpoise given in figure 13 of my paper. In the case of the insulated counterpoise 1 foot above the surface of the earth, the earth current could get no closer than within 1 foot of the counterpoise, and therefore the minimum inductance was comparatively large, so that the change of capacitance exerted a dominating effect at the wave front. With the buried counterpoise the earth current is initially very close to the conductor, the inductance is practically nil, and consequently the surge impedance starts at nearly zero. The great influence of the initial inductance on the shape of the impedance curve is illustrated in figure 1 of this discussion.

The penetration of the current into the earth changes the inductance, and in consequence changes the surge impedance, velocity of propagation, and coupling. It appears permissible to ignore the change of capacitance in the case of the buried counterpoise. We may then summarize the effect of the current penetration in table I of this discussion.

From these considerations it is easy to visualize the flattening of the wave front, lengthening of the wave tail, decreased coupling of a short wave, etc. Hagenguth in his discussion has given curves and tables for the effect of the current penetration. He has also suggested that the reduced coupling in figure 12 of the paper, as compared with that in figure 11, is no doubt due to the smaller depth of current penetration associated with the shorter wave of the higher voltage surge to which figure 12 applies. It appears, therefore, that in regard to the front of the wave phenomena, we know a great deal more in a quantitative way than heretofore.

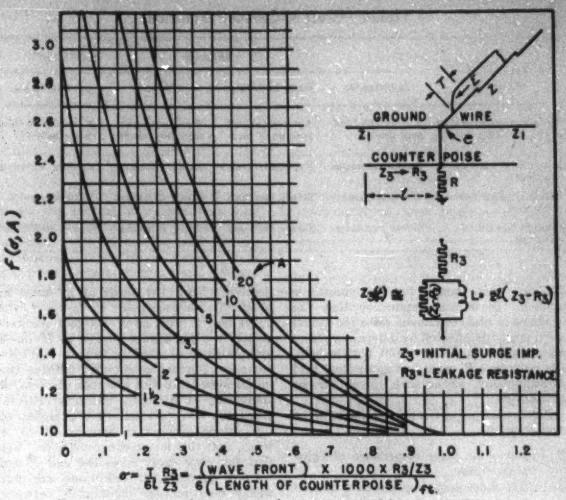


Fig. 2. Lightning voltage at top of tower permitted by a counterpoise

$$e = \frac{2E}{1 + Z/r'}\left[1 + A\left(\frac{1-\sigma}{A\sigma - 1}\right)e^{-3t/T}\left(\frac{A-1}{A\sigma-1}\right)e^{-A\sigma 3t/T}\right]$$

$$e_{max.} = \frac{2E}{1 + Z/r'} \cdot f(\sigma, A)$$

$$A = (1 + Z/r')/(1 + Z/r)$$

$$1/r = (N/Z_3 + 1/R + 2/Z_1)$$

$$1/r' = (N/R_3 + 1/R + 2/Z_1)$$

T = Front of incident lightning wave
N = Number of counterpoise wires

Simplified Counterpoise Calculations

From our own theory and tests, as well as tests made in Michigan in 1930 and tests by Fortescue and Fielder, 3 facts stand out rather clearly:

1. The additional coupling effect on the line wires due to a counterpoise is rather small in comparison with that of the ground wire. We found not more than 4 per cent while Fortescue and Fielder show from 4 to 8 per cent, and theory suggests that it will not exceed 10 per cent.

2. The initial surge impedance obtained by extrapolating the impedance curve to zero time appears to be of the order of from 100 to 250 ohms, with an average value of 150 ohms. The Michigan tests gave 220 ohms, the Pittsfield tests from 120 to 160 ohms, and the Trafford tests 150 ohms.

3. The impedance falls in a roughly exponential fashion from its initial surge impedance value to its final leakage resistance (which may be somewhat less than the measured d-c resistance). The time of transition requires approximately one complete reflection on the counterpoise, and since the velocity on the counterpoise is close to $^1/_3$ the velocity of light, this means that the transition requires $t = \frac{6}{1{,}000}$ (length of counterpoise in feet).

Hagenguth suggests in his discussion that the additional coupling due to the counterpoise be ignored entirely and that simplified calculations be based on regarding the counterpoise as an impedance varying from an initial value Z_3 to a final value R_3 in time $t = 6l$. He has calculated the impedance curve by considering half that portion of R_3 uncovered by the advancing wave front to be in parallel with the instantaneous Z_3.

In this connection I propose an equivalent circuit for the counterpoise consisting of its leakage resistance R_3 in series with $(Z_3 - R_3)$ shunted by an inductance L such that the time constant of the circuit is essentially the same as that of the actual counterpoise. On this basis a complete set of estimating curves may be obtained as shown in figure 2 of this discussion, so that for any assumed or measured values of the voltage of the lightning surge, the surge impedances of the stroke, ground wire, and counterpoise (initial), and the tower footing and counterpoise resistances, the corresponding voltage on the ground wire may be readily found. These curves are computed from the equivalent circuit of the counterpoise, choosing L so that the time constant of the equivalent circuit matches that of the actual transient im-

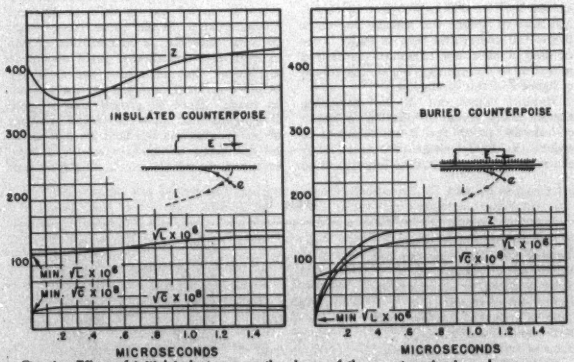


Fig. 1. Effect of initial inductance on the shape of the counterpoise impedance curve

Table I—Effect of Current Penetration

Penetration of Current	Effect on			
	Inductance	Surge Impedance	Velocity	Coupling
Initially close to surface of counterpoise	A minimum, and very small	A minimum, and practically zero	High, and practically the velocity of light	A minimum and very small
Initial downward displacement	Rapidly increases	Rapidly increases	Rapidly decreases	Rapidly increases
Relatively slow downward trend	Slowly increases	Slowly increases	Slowly decreases	Little change
Returns upward to wave tail	Slowly decreases	Slowly decreases	Slowly increases	Slowly decreases

pedance where a unit function current is applied. It is not imperative that the exact value of Z_3 be known, since the results are not greatly affected by a departure from an average value of $Z_3 = 150$, but the leakage resistance R_3 must be known from field measurements, either with direct current or a bridge.

As an example of the application of these curves, take:

Z = 400 ohms surge impedance of lightning stroke
Z_1 = 500 ohms surge impedance of ground wire
Z_3 = 150 ohms surge impedance of counterpoise
R_3 = 40 ohms leakage resistance of counterpoise
l = 200-foot length of counterpoise
N = 2 counterpoises per tower
R = 200 ohms tower footing resistance
T = 1 microsecond wave front
E = 10,000-kv lightning stroke voltage (incident wave)

$$1/r = (N/Z_3 + 1/R + 2/Z_1) = (2/150 + 1/200 + 2/500) = 0.0223$$

$$1/r' = (N/R_3 + 1/R + 2/Z_1) = (2/40 + 1/200 + 2/500) = 0.0590$$

$$A = \frac{1 + Z/r'}{1 + Z/r} = \frac{1 + 400 \times 0.0590}{1 + 400 \times 0.0223} = 2.5$$

$$\sigma = \frac{R_3}{Z_3}\frac{T}{6l} = \frac{40}{150}\frac{1 \times 1{,}000}{6 \times 200} = 0.22$$

Therefore, the maximum voltage on the ground wire is

$$e_{max} = \frac{2E}{1 + Z/r'} f(\sigma, A) = \frac{20{,}000}{24.6} \times 1.55 = 1{,}260 \text{ kv}$$

Allowing 30 per cent coupling between ground wire and line wire and 5 per cent additional coupling due to the counterpoise, the voltage across the insulators would be:

$$1{,}260(1 - 0.35) = 820 \text{ kv.}$$

Multiple Counterpoise Wires

Since it has been shown that the additional coupling due to the counterpoise is of secondary importance as compared with its impedance effect, it is at once apparent that a given length of wire is more efficiently employed as a number of radial counterpoises than as one continuous wire. Figure 3 of this discussion shows 1,000 feet of wire having a final leakage resistance of 10 ohms and an initial surge impedance of 150 ohms per wire. If this is used as a single long counterpoise the impedance decreases from 150 ohms to 10 ohms in about 10 microseconds. If, however, the 1,000 feet is used as 2 500-foot counterpoises, the impedance starts at 75 ohms and reaches 10 ohms in about 5 microseconds. Further subdivision reduces the initial impedance and shortens the time of transition, both highly beneficial effects. However, it is evident that a region of diminishing returns is approached by 4 wires, and this is accentuated by the fact that for very short wires the end effects become pronounced, reflections are not wiped out, mutual inductance between wires plays a more important part and, most important of all, the leakage resistance may exceed the surge impedance for very short wires. *The proper length of each counterpoise wire should be such that its leakage resistance is substantially less than its surge impedance, but otherwise its length in thousands of feet need not exceed $^1/_4$ the shortest front in microseconds of any lightning surge to which it may be subjected.* This criterion ensures that the full length of the counterpoise will have been reduced to substantially its leakage resistance by the time the shortest front wave has reached its crest, and that the voltage will not exceed that permitted by the surge impedance only. If a longer counterpoise is used its minimum resistance will not be available for the shortest front waves, although the additional length would prove beneficial for longer fronts, but not so much so as is obtainable by using more of the shorter wires. These considerations suggest that the standard counterpoise length should be from 200 to 300 feet (if this is sufficient to reduce the leakage resistance below 150 ohms) and that as many wires be used as necessary to secure the desired reduction in voltage as given by the curves of figure 2 of this discussion.

Waldorf points out in his discussion that in many actual installations a length of from 200 to 300 feet is not sufficient to reduce the final leakage resistance below the surge impedance, and he inquires as to the maximum number of counterpoise wires which may be used in parallel before the mutual surge impedance between wires becomes excessive. He also asks what shape the transient surge impedance curve has when the leakage resistance is higher than the surge impedance.

In accordance with the above criterion, if from 200 to 300 feet are not sufficient to

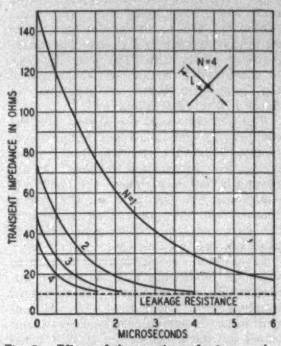


Fig. 3. Effect of the number of wires on the counterpoise impedance

reduce the leakage resistance below the surge impedance, say 150 ohms, then longer lengths should be used, and this will usually mean continuous tower-to-tower counterpoise wires. If the leakage resistance exceeds the surge impedance, then the transient impedance initially decreases, reaching a minimum approximately in time $t = 6l/1{,}000$, then increasing and reaching a maximum equal to the leakage resistance.

An exact determination of the mutual surge impedances between radial counterpoise wires is rather awkward, but at least 8 wires may be used without much of a boost in surge impedance. If the wires are run parallel along the right of way, a minimum spacing of 10 feet appears permissible.

Fortescue suggests that additional field tests be carried out in soils of different characteristics. While these tests would be very desirable as confirmation of the existing data and theory, yet I do not at all believe that such tests are necessary before a rational counterpoise analysis can be made. Since my paper was written, Hagenguth has made a careful analysis of our records and reported his findings in his discussion of this paper; and I have extended my calculations in this discussion

Table II

Waves leaving starting point	$f_1(v_1)$	$f_2(v_2)$	$f_3(v_3)$
Time of arrival at transition point	l/v_1	l/v_2	l/v_3
Reflections of velocity (v_1)	$_1f_1'(v_1)$	$_2f_1'(v_1)$	$_3f_1'(v_1)$
Time of arrival at starting point	$2l/v_1$	$l/v_2 + l/v_1$	$l/v_3 + l/v_1$
Reflections of velocity (v_2)	$_1f_2'(v_2)$	$_2f_2'(v_2)$	$_3f_2'(v_2)$
Time of arrival at starting point	$l/v_1 + l/v_2$	$2l/v_2$	$l/v_3 + l/v_2$
Reflections of velocity (v_3)	$_1f_3'(v_3)$	$_2f_3'(v_3)$	$_3f_3'(v_3)$
Time of arrival at starting point	$l/v_1 + l/v_3$	$l/v_2 + l/v_3$	$2l/v_3$

to include successive reflections into the second and third generations. The agreement with test results is so good in all respects that I no longer have any doubt that our theory is sufficient and adequate for making routine design calculations once the leakage resistance is known, and this can be measured quite easily.

Fortescue calls attention to the fact that I used the same oscillogram for the ground wire surge and the counterpoise surge in part III, figures 11 and 12 of my paper. The height of our pole was only 30 feet and as our wave front was about 0.4 microsecond we could observe no difference. Furthermore, it must not be thought that connecting the oscillograph to the overhead wire by a separate down lead gives any truer reproduction of the surge on the overhead wire than does connection to the tie between the ground wire and counterpoise as used in my tests because there are successive reflections in both cases.

Calculation of Successive Reflections

In connection with figure 4 of my paper it was pointed out that the reflections obviously showed the characteristics of multivelocity components, and in the text the initial multivelocity wave components were calculated. Since the paper was written the calculations have been extended to include the reflections, and the numerical agreement with the oscillograms in all details has been found to be excellent. The complete calculations are entirely too long to be reproduced here, but a brief résumé and summary of the results seem desirable, since, as far as I know, this constitutes the first evidence of the exact quantitative agreement obtainable by multivelocity theory, and should therefore put at rest those intimations raised during the discussions of my first paper (Attenuation and Distortion of Waves, L. V. Bewley, Electrical Engineering, December 1933, and the discussions at the 1934 winter convention published in the March and April 1934 issues, page 471–3 and 595–8) on multi-velocity theory to the effect that the mathematics was not a true description of the phenomenon.

The insulated counterpoise used in our field tests was 925 feet long, and at its far end was grounded through driven pipes having a ground resistance of 240 ohms. When the surge is applied at the starting end of the counterpoise, multivelocity waves of 3 velocities (100 per cent, 98 per cent, and 84 per cent of the velocity of light) move out on the ground wire, line wire, and counterpoise. These waves arrive at the transition point (grounded end of the counterpoise) at different times, and as each wave arrives it generates reflected waves of all 3 velocities. Thus 9 individual waves start back toward the origin, leaving the transition point at different instants in 3 separate groups, each group consisting of 3 separate wave velocities. See table II of this discussion.

In view of the fact that v_1 and v_2 are so nearly equal we can greatly simplify the work by dealing with only 3 wave groups with respect to their time of arrival at the starting point:

Group A: $({}_1f_1' - {}_1f_2' - {}_2f_1' - {}_2f_2')$ returning approximately at $(2l/v_1 \cong 2l/v_2)$

Group B: $({}_1f_2' - {}_2f_1' - {}_2f_2' - {}_1f_2')$ returning approximately at $(l/v_1 + l/v_2)$

Group C: $({}_1f_2')$ returning at $(2l/v_2)$.

The transition point equations applying at the grounded end (resistance R) of the counterpoise are

$$e_1 + e_1' = e_1''$$
$$e_2 + e_2' = e_2''$$
$$e_3 + e_3' = R(i_2 + i_3')$$
$$i_1 + i_1' = i_1''$$
$$i_2 + i_2' = i_2''$$

Substituting the multivelocity components, these 5 simultaneous equations are then solved for the reflections. Corresponding to the 3 conditions I, II, and III of figure 4 of my paper, the numerical values are as given in table III of this discussion.

Now regarding these reflections as incident waves impinging on the transition conditions at the starting point of the counterpoise, and assuming all components of any group to arrive there simultaneously, new transition point equations can be written for each condition. These equations are given in table IV of this discussion.

Substituting multivelocity components and solving these simultaneous equations for each condition, there finally results:

Table IV

Condition I	Condition II	Condition III
$e_1 + e_1' = e_1''$	$i_1 + i_1' = 0$	$e_1 + e_1' = e_1''$
$i_1 + i_1' = e_1''/Z_1$	$i_2 + i_2' = 0$	$e_2 + e_2' = e_1''$
$i_2 + i_2' = 0$	$i_3 + i_3' = e_1''/Z_1$	$i_2 + i_2' = 0$
$i_3 + i_3' = 0$	$e_3 + e_3' = e_1''$	$i_1 + i_1'' + i_3 + i_3' = e_1''/Z$

Table III

Reflected Wave	Group	Condition I	Condition II	Condition III
${}_1f_1'(v_1)$	A	$0.0145\ E_0$	0	$0.0135\ E_0$
${}_2f_1'(v_1)$	A	0	0	0
${}_2f_2'(v_1)$	B	0	0	0
${}_1f_2'(v_2)$	A	0	0	0
${}_2f_2'(v_2)$	A	$-0.0020\ E_0$	$0.0009\ E_0$	$-0.0010\ E_0$
${}_2f_2'(v_2)$	B	$0.0113\ E_0$	$0.0440\ E_0$	$0.0526\ E_0$
${}_1f_2'(v_2)$	B	0	0	0
${}_2f_2'(v_2)$	B	$0.0112\ E_0$	$-0.0051\ E_0$	$0.0057\ E_0$
${}_2f_2'(v_2)$	C	$-0.0206\ E_0$	$-0.0805\ E_0$	$-0.0964\ E_0$

Condition	Reflection Group	Voltages Due to Reflections on Ground Wire	Line Wire	Counterpoise
I	A	$-0.0031\ E_0$	$-0.0205\ E_0$	$0.0007\ E_0$
	B	$0.0225\ E_0$	$0.0397\ E_0$	$0.0574\ E_0$
	C	$-0.0207\ E_0$	$-0.0363\ E_0$	$-0.1211\ E_0$
II	A	0	0	0
	B	$0.0783\ E_0$	$0.0783\ E_0$	$-0.0347\ E_0$
	C	$-0.1479\ E_0$	$-0.1479\ E_0$	$-0.2740\ E_0$
III	A	$0.0076\ E_0$	$-0.0328\ E_0$	$0.0076\ E_0$
	B	$0.0329\ E_0$	$0.0989\ E_0$	$0.0330\ E_0$
	C	$-0.2846\ E_0$	$-0.2010\ E_0$	$-0.2833\ E_0$

The contribution of these reflection groups is easily identified on the oscillograms of figure 4 of my paper. For example, consider the voltage e_2 on the line wire under condition II:

e_2 Condition II	Calculated	Test
Original Wave	0.064	0.068
+ Groups A and B	0.142	0.136
+ Group C	−0.006	0.00

All points on these oscillograms check very well with the above calculations, within the limits of accuracy of this kind of work. It has, therefore, been shown that the multivelocity theory of traveling waves gives correct quantitative results.

Lightning Investigation on Transmission Lines—IV

Discussion of a paper by W. W. Lewis and C. M. Foust published in the August 1934 issue, page 1180–6, and presented for oral discussion at the lightning session of the Pacific Coast convention, Salt Lake City, Utah, September 5, 1934.

C. L. Fortescue (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): Lewis and Foust have reached the conclusion that the tower top potential is given by the product of tower footing resistance and crest current. We are asked to believe that no matter how severe the stroke may be, it will cause no flashover on a poorly insulated line protected with ground wires if the tower footing resistance is very low, of the order of 1 or 2 ohms. Yet in our laboratory work using artificial lightning surges on actual transmission lines, we have observed potentials of considerable value in 30 or 40 feet of down drop leads to ground. A large tower has, of course, a much lower surge imped-

ance than a single wire, but, on the other hand, it may be 2 or 3 times as high. We estimate, therefore, that where tower footing resistances are below 10 ohms potentials of the order of 1,000 kv reaching crest value at one microsecond and dropping off very quickly may be expected from very severe strokes, due to the reflections in the tower alone. As a rough criterion to determine the likelihood of flashover for varying values of tower footing resistance, the method may have some value especially when the footing resistances are above 50 ohms.

To obtain a perspective of lightning potentials that occur on 100 miles of line by a single cathode ray oscillograph station located at one point of the line would require probably 100 years, and even then the vagaries of lightning storm paths might vitiate the results. To obtain an idea of the severity of lightning strokes that may hit a transmission line the first requisite is an unprotected line which cannot be flashed over by lightning and the second is unlimited time and a large number of observation stations. Quite contrary to the experience implied in the third paragraph of the first column on page 1184, calculations of protection level which we have made show a close correspondence with statistical data obtained on transmission lines new and old. It is possible that heights of ground wire indicated by the theory are on the safe side although the writer feels that it is too early to reach a conclusion. In the Safe Harbor line the ground wire is 30 feet at its maximum separation above the line wire. In the Philadelphia end of the Roseland-Plymouth Meeting interconnection the ground wire according to my recollection is about 22 feet at its maximum spacing above the line wires. The record of the Safe Harbor line up to the time that the authors released their paper is given in table VII as 0.7 outage per 100 miles per year; up to date there have been no further outages on this line although this year's lightning has been exceptionally severe. The Philadelphia end of the Roseland-Plymouth Meeting interconnection according to my information has a perfect record up to date. Another recently installed line that was designed and built according to direct stroke theory is the 132-kv circuit around Indianapolis. Great pains were taken during its installation to keep the tower footing resistance to a low value in the neighborhood of 10 ohms. That these measures were justified the record of this line during the 3 or 4 years of its operation completely bears out. Since 1929 the writer has set the value of 10 ohms tower footing resistance as the limiting value if good lightning performance was desired, provided there are properly placed ground wires. This value was obtained as the result of calculations carried out in accordance with the direct stroke theory bringing in the effect of tower reflections. In particular it has been stated that a design with properly placed and spaced ground wires and with 16 standard insulators would result in a practically lightning-proof line. This has had remarkable confirmation in the statistical data reported in this paper.

The data obtained with the surge crest ammeter is very interesting but further study and records will be required before it can be decided that 100,000 amperes maximum in the stroke for a surge impedance of 200 ohms for the channel is too high for a very severe stroke. When it is remembered that for an isoceraunic level of 30 the frequency of occurrence of strokes of this severity is probably of the order of once per 100 miles every 3 years, the likelihood of obtaining a record on the crest ammeter is not very great.

As regards the mechanism of the lightning stroke a flood of light was thrown on this phenomenon by the investigations recently reported by Dr. Schonland of South Africa. I understand that Dr. Schonland's results have been duplicated at Pittsfield within the past year. I do not agree with the authors' interpretation of Dr. Schonland's photographs. I can find no evidence or theoretical basis for the assumption that the receding highly illuminated channel is due to the stroke proceeding from earth to cloud. It is true that it has this appearance but appearances are often misleading. One obvious reason for discarding the theory put forward is that apparently the illuminated channel which moves toward the cloud does frequently stop so to speak in midair. What then becomes of the surge which is alleged to start from the earth? In my paper entitled "Lightning Discharges and Line Protective Measures" (A.I.E.E. TRANSACTIONS, volume 50, 1931, page 1090–1100) I gave for the first time an explanation of the cloud discharge which seems to agree with Dr. Schonland's test, and later on in my paper before the International Electrical Congress I gave the same explanation in more detail. I gave the speed of movement of the initial streamer in the first paper as less than $^1/_{20}$ the velocity of light, and in the second paper I gave its velocity as being greater than 4.3×10^7 centimeters per second. According to the theory presented in these papers the initial streamer progressed very slowly ($^1/_{20}$ velocity of light) so that the energy of its channel was mostly potential energy. When the streamer reached earth or a highly conducting body, such as a transmission line, this potential energy was instantly changed into $^1/_2$ kinetic and $^1/_2$ potential energy so that a large current began to flow in the channel. The potential energy which can be considered as a standing wave would be instantly changed into 2 traveling waves of equal value and sign, one of which moves down the channel and the other up the channel. Where these 2 waves overlap there is very little current in the surge and the energy is practically all potential energy, but as the negatively traveling wave recedes toward the cloud $^1/_2$ of the potential energy in the channel is released in the form of current which is indicated by the intense illumination of the portion of the channel in which the current flows, giving the appearance of a discharge moving up the channel from earth at $^1/_{10}$ the velocity of light. In other words, the current is due to the component wave moving down the channel and not to the component receding wave. The energy of the surge moving down the channel is at first derived from the initial streamer which leaves the channel ionized and highly charged. It may finally extend into the cloud and derive its energy directly.

While the oscillogram, figure 5, is of great interest as one of the highest surges recorded on a steel tower line, it does not appear to me to justify all the conclusions arrived at by the authors nor do I think that the surge recorder evidence is very conclusive since the leads to the recorder are under the influence of the field of the tower and the recorders may not register the true difference of potential across the 40 feet of tower. The fact that the statistical data presented by the authors, together with other data of the same kind that has been published in the past, apparently bears out the protection levels obtained by taking into account the reflections in the tower, seems to me to be very convincing evidence of the substantial correctness of the theory.

Counterpoise Tests at Trafford

Authors' closure of a paper published in the July 1934 Issue, page 1116–23, and presented for oral discussion at the lightning session of the Pacific Coast convention, Salt Lake City, Utah, September 5, 1934.

C. L. Fortescue and **F. D. Fielder** (both of Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The only point concerning the testing technique that has been raised in this discussion is that of Mr. Hagenguth who has questioned the accuracy of the surge impedance measurements.

The first claim is that the line length between the generator and the entrance to the counterpoise gives rise to oscillations which reduce the value of the results. It is by no means apparent how oscillations can affect the results since the voltage measurement at the counterpoise connection gives the voltage to ground at every instant, while the drop across the increasing resistance gives the current entering the counterpoise at corresponding times. If the applied wave has oscillations both of these measurements are affected, and the oscillations are taken into account. In any case the magnitude of the oscillations is small compared to that of the main waves, as shown by the voltage oscillograms, and, therefore, they can have little effect on the results. Mr. Hagenguth has attempted to show that the oscillations occur at intervals of 0.375 microsecond, and are due to the 185-foot length of line, since this time represents the time for a reflection along this length. The line diagram shows this cannot be true, since there is an additional 100 feet of line back to the surge generator terminal. The resulting period would be at least 0.55 microsecond, which interval is not regularly defined on oscillograms.

The contention is also made that the minimum values are too low, since the minimum values of surge impedance should equal the measured megger resistance (a-c, not d-c). For the test of the guy ground the megger value was 150 ohms, and the surge impedance around 50 ohms after several microseconds. There is no discrepancy because of the short distance down to the true ground plane. The high voltage used for the surge tests and the resulting corona formation could easily lower the surge impedance to a value much less than the steady state value as measured with low voltages. Nor is the argument of the velocity of propagation along the counterpoise valid, because when there is such a

short distance between true ground plane and the counterpoise and when the earth resistivity is low in value, the effect of the distant part of the counterpoise is negligible. The measured effects are approximately the same whether the counterpoise is 200 feet or 1,000 feet in length.

Finally, it is not reasonable that the surge impedance of a counterpoise or guy should be low at the beginning of a surge, and then increase in value, as indicated in the discussion.

At the first instant there is little difference between a counterpoise and a line in air, since the leakage effect has not started. With the progress of time, however, the leakage effect becomes greater, and the impedance, therefore, decreases.

Mr. Hagenguth recommends a surge generator location directly at the counterpoise terminal for the measurement of surge impedance. Such a procedure, however, places the surge generator ground altogether too close to the counterpoise, and leads to false results. Rather it is to be recommended that the surge generator and counterpoise be separated to eliminate reduce this end effect.

Lightning Investigation on a 220 Kv System

Author's closure of a paper published in the August 1934 issue, page 1188–94, and presented for oral discussion at the lightning session of the Pacific Coast convention, Salt Lake City, Utah, September 5, 1934.

Edgar Bell (Pennsylvania Power and Light Co., Hazleton): Professor Waldorf's inquiry of counterpoise resistance measurements can be answered as follows: The practice of the Pennsylvania Power and Light Co. in measuring tower footing resistances is to use a megger ground tester and take sufficient trial measurements that the probable true value of resistance is obtained as recommended by the manufacturer. Normally the current and potential probes are located along the right of way. After the counterpoise was installed over the High Knob section of the Wallenpaupack-Siegfried line it was not feasible to do this, and measurements were made along directions approximately at right angles to to the direction of line (and counterpoise). This necessitated dragging the test leads and probes into the adjacent woods, but time and care were taken to insure that the measurements were accurate.

After the counterpoise was installed, measurements were made under 2 conditions; (1) with counterpoise disconnected and pulled a few feet away from the footings of the tower under test and (2) with counterpoise connected and in final position. Measurements under condition (1) gave values ranging from 2.1 to 3.0 ohms; those under condition (2) were less, ranging from 1.0 to 1.6 ohms.

Mr. Fortescue expresses surprise because I suggest that there is still some mystery to the effect of tower footing resistance in preventing flashovers on transmission lines having overhead ground wires. There is no mystery to the theory proposed; this seems to be essentially correct and the Wallenpaupack-Siegfried data serve to confirm the theory. My point was that published results do not always agree with theory, as Mr. Fortescue admits, although with an explanation that in such cases shielding is "imperfect."

The remaining lines of the Pennsylvania-New Jersey 220-kv Interconnection (Conowingo-Plymouth No. 1 and No. 3, Plymouth Siegfried and Roseland-Plymouth) have suffered 30 tripouts due to lightning. The locations of 13 of the faults are unknown. Of the remaining 17 faults, 10 were caused by flashovers at towers of less than 13 ohms resistance. In 8 cases the resistances ranged from 3 to 7 ohms. These lines are of more recent construction that the Wallenpaupack-Siegfried and ground wires have been more advantageously placed and greater clearances maintained. Because of facts like these, I cannot agree that the results are yet as clear as day.

Data published on measured structure currents due to lightning, and the possible error which can reasonably be assumed to apply to these measurements are as yet quite meager. When we have a reasonable number of representative measurements of structure currents and correlating information as to shielding, footing resistance, flashover, and similar essential data, then the problem of tower footing resistance will be much clearer, probably sufficiently so for all practical purposes.

Simplified Measurements of Sound Absorption

Discussion and authors' closure of a paper by Arthur L. Albert and Tom B. Wagner published in the August 1934 issue, page 1160–2, and presented for oral discussion at the selected subjects session of the Pacific Coast convention, Salt Lake City, Utah, September 7, 1934.

R. B. Bonney (Mountain States Telephone and Telegraph Co., Denver, Colo.): Since these measurement deal with sounds of varying frequencies over a wide range, it occurs to me that they should be made with this in view. I should like to ask if it is not necessary, in making the measurements, to carry on a considerable number of tests over a wide range of frequencies in order to get accurate results.

E. W. Templin (Electrical Research Products, Inc., Los Angeles, Calif.): It is pointed out in this article that sound absorption coefficients obtained by the tube reflected wave method and by the reverberation chamber method may not agree due to a difference in panel vibration under the 2 conditions. Another factor is present which may, over the measurable frequency range, introduce discrepancies greater than those due to panel resonance.

In the tube, the sound impinges against the material at normal incidence, whereas in the reverberation chamber it impinges against the material at random incidence. Consequently, it may be expected that the difference in coefficients obtained by these 2 methods will vary with the porosity and roughness of the surface of the material being measured.

Another point worthy of mention is that in adjusting the length of the tube to obtain standing waves at any frequency, the optimum length of the tube is a function not only of the frequency but also of the material under test. This is because for materials which absorb sound the apparent end of the tube is not at the surface of the material due to the phase angle introduced when the reflection takes place. It is necessary to adjust the tube length carefully for each particular material being tested so that a maximum intensity is obtained at the plane of the sound source at each frequency.

Our experience indicates that due to the highly irregular frequency characteristic of loudspeakers, slight variations in their performance with use may noticeably change their output efficiency at certain frequencies. For this reason, more accurate and more consistent measurements of absorption may be made if the microphone is so mounted that it can explore the tube and pick up the maximum and minimum positions at each frequency. The coefficient of absorption will then be obtained from the difference in intensity at these 2 positions rather than from a single absolute measurement. It can be seen that coefficients obtained by the former method are independent of minor changes in the sound source output.

Comparative measurements have indicated that in general for wallboard materials having a comparatively smooth finish of low sound absorption, the tube method gives results in close agreement with those obtained with the same material rigidly mounted in a reverberation chamber. However, for materials which provide greater absorption due chiefly to rough, porous, or perforated surfaces, the discrepancy between measurements made by the 2 methods may be quite large. For such materials the reverberation chamber method more nearly approximates the conditions under which the material is used in rooms or auditoriums and, therefore, the coefficients so obtained are the more reliable.

A. L. Albert (Oregon State College, Corvallis) and **T. B. Wagner:** As Mr. Bonney brings out in his question, sound absorption measurements should be made over a wide range of frequencies if reliable data are to be provided. In our studies, tests were made at frequencies from 256 to 4,096 cycles per second. For sake of brevity curves for this entire range were not included in the paper.

Mr. Templin points out that it is probable that the manner in which the sound waves impinge against the absorbing test specimen with the tube method is somewhat different from the random incidence of the reverberation chamber. It should be mentioned, however, that with the inverted cone radiator of the moving-coil loud speaker that was used, and with the cone close to the test specimen, the wave pattern was very complex.

We note with interest that others have found that the actual "image" plane of an absorbing material may not be the actual

surface of the material, and that it is necessary to adjust for this image reflecting surface rather than for a dimensional fraction of the wave length. In our tests, this actual maximum reflecting point was carefully located.

It is probable that, as Mr. Templin mentions, more accurate and consistent measurements can be made if several wave lengths are included and the microphone used to explore the values of several maximum and minimum points. We were interested in making the tests as simple as possible consistent with engineering reliability, and for this reason the method described in our paper was adopted. Subsequent tests have proved our system to be satisfactory for most engineering work.

Mr. Templin discloses interesting information in stating that comparative measurements indicate that for smooth surfaces of low absorbing qualities the tube method and the reverberation chamber method agree, but that for materials of high absorbing properties they do not agree so closely. In this, we presume that Mr. Templin refers to coefficients calculated from data taken by the tube method. Since in our tests the coefficients were not calculated, but were obtained by direct comparison with materials standardized by the reverberation chamber method, these discrepancies should be materially reduced.

Electrical Figures on Plates in Air

Discussion and author's closure of a paper by J. Gibson Pleasants published in the February 1934 issue, page 300–07, and presented for oral discussion at the selected subjects session of the Pacific Coast convention, Salt Lake City, Utah, September 7, 1934.

W. A. Hillebrand (University of California, Berkeley): That an insulated body, which may be either a conductor or an insulator, can acquire and retain an electrostatic charge is, historically, one of the earliest facts learned in the study of electricity, although its practical implications seem to be but little appreciated. An example of the practical importance of surface charge, aside from the use of condensers, is found in the "corona disappearance" voltage of high tension insulators. As the voltage applied to an insulator is raised a corona discharge will take place when the appropriate potential is reached. If the voltage is raised above this point and then reduced, corona will disappear at a voltage lower than that at which it appears on increasing voltage. The cause is unquestionably to be found in the positive space charge which collected on the glazed surface during the positive half wave while above the corona point and which, when the electrode becomes negative, increases the voltage gradient about it and causes air breakdown at a lower applied voltage.

Although the veins and boundary of the Lichtenberg figure mark the electron tracks, they are actually due to the repulsion between gas ions that have charged the sulphur or other dust used. Accordingly they show not only electron track but residual charge and therefore their sharpness of definition is largely determined by the amount of absorbed moisture, particularly if the dust is applied after the discharge has taken place.

Dr. Pleasants' explanation of the difference in rate of growth of positive and negative figures as due to the angle at which the electrons, with rod negative, impinge upon the glass plate is not convincing to me. As indicated by the author himself, the difference in the rate of growth of the 2 figures would seem to be completely accounted for by the positive surface charge which, when the rod is positive, in effect extends the electrode and the radius of ionizing potential, whereas its effect is to reduce it when the rod is negative.

The subject treated by Dr. Pleasants is important, the Lichtenberg figure offers a valuable means of studying it, and the contribution of the paper to our knowledge is welcome.

J. Gibson Pleasants (California Institute of Technology, Pasadena): Mr. Hillebrand's discussion of the "corona disappearance" voltage on insulators, that is, on the disappearance of the corona at a lower voltage than that at which it appeared, is very interesting as another example of the family of hysteresis effects so well known in connection with both magnetic and electrostatic systems.

I should like to comment particularly on the paragraph of Mr. Hillebrand's discussion beginning with the sentence, "Although the veins and boundary of the Lichtenberg figure mark the electron tracks, they are actually due to the repulsion between gas ions that have charged the sulphur or other dust used." Let us recall that the veins appear only in the positive figures. The negative figure is composed of a very great number of very fine, strictly radial lines, practically equal in intensity and spacing, as is to be expected with the moving particles repelled from the center. In recording the figures, the dust was applied a few seconds after the occurrence of the surge, when no more gas ions were present as such, but only the surface charge on the plate. There was no movement of the dust as it settled on the plate; it simply adhered to that portion of the plate which carried a charge, and avoided the portion that did not. The veins in my positive figures simply indicated canals which were free of charge, due to the neutralization of the positive surface charge by the flow of electrons back to the electrode through these channels. The light veins in positive figures obtained on photographic plates are no doubt due (1) to the action of photons given off during the recombination going on in these channels of flow of the electrons, and (2) perhaps also to direct action of the electrons themselves on the plate.

Mr. Hillebrand is surely justified in finding my explanation of the difference in rate of growth of the 2 figures (as being due to the angle of motion of the electrons with respect to the glass) not very convincing. It is offered only as a suggestion, and is not altogether satisfactory to me, although, even after a review of many opinions on the subject, I can come upon no other picture of the situation which suits me as well.

Just as my theory admitted but one moving particle, i. e., the negative one, Mr. Hillebrand's theory seems to admit of but one kind of surface charge, the positive one. Now, actually, a very heavy negative surface charge remained on the plate after the formation of the negative figure, as evidenced by the adherence of the red lead to it (the dust was a mixture of red lead and sulphur, the former taking on a positive charge, the latter a negative, when shaken together), just as the adherence of the sulphur after the positive surge proved the existence of a positive surface charge. It is possible that as the concentric, negative "wave" of electrons expands around the electrode during the negative surge, a surface charge of positives is left behind, due to the lower mobility of the positive ions and this would introduce another difference in the conditions between the formations of figures of the 2 polarities in addition to the direction of motion of the electrons. No trace of this inner, positive surface charge is found afterward, however, when the figure is registered with dust.

Together with Mr. Hillebrand, I should welcome more exact data, and a sounder analysis of the course of this intricate and interesting phenomenon.

Insulator Arcover in Air

Discussion and author's closure of a paper by F. W. Maxstadt published in the July 1934 issue, page 1062–8, and presented for oral discussion at the selected subjects session of the Pacific Coast convention, Salt Lake City, Utah, September 7, 1934.

W. A. Hillebrand (University of California, Berkeley): Whenever an insulator or insulating material is used we have 3 regions to consider, the dielectric itself, the surrounding material which must be another dielectric, and the surface boundary between the 2. The properties of the bounding surface are often more important than those of the 2 dielectrics. It is this surface, which is extremely difficult to define in the first place, whose properties Dr. Maxstadt has studied so successfully.

The author's analysis of the mechanism of surface breakdown as given on page 1065 is, I believe, correct.

Also, the results given in tables I and II, showing an almost twofold increase in breakdown strength of bakelite and glass rods by properly corrugating the surface, cannot fail to interest any one concerned with the use of insulation because they establish the limit of improvement obtainable under ideal conditions.

In paragraph 4 of his introduction the author says: "If transmission line voltages are to be pushed to considerably higher magnitudes than at present, some advantage no doubt will have to be taken of the greater arcover strength obtained by providing a uniform field in the neighborhood of the insulator." This statement overlooks the fact that the potential gradient over the suspension insulator is as good as or better than that in free air between conductor and crossarm. Any shield that increases insulator arcover must also cover the conductor

for such a distance on either side that dimensions become prohibitive and clearances to towers are reduced. It is difficult to see how any material improvement can be expected from such a device.

The errors inherent in the conventional air density correction of arcover values have long been recognized but with no clear understanding as to how they can be eliminated. It is occasionally necessary to compare flashover values from different laboratories, which demands correction of some sort for the effect of air density so that I cannot agree with the author's contention on page 1065 that such a correction should not be made.

On page 1067 is the statement that "in dry arcover different shaped insulators, exclusive of apparatus bushings, having the same arcing distance, have roughly the same arcover strength." This is true only up to the point where the unit section length has been so extended that general cascading takes place.

G. M. Barrow (Westinghouse Elec. and Mfg. Co., Derry, Pa.): From the viewpoint of commercial engineering and production of insulators, satisfactory explanation of the phenomena of flashover is still lacking as the author suggests. In many respects, however, the problem of insulator arcover in commercial testing is becoming simplified by improvements in methods of test and determination and use of correction factors for the several variables affecting it.

The physical picture depicted of arcover at normal frequency is logical. The suggestion that higher impulse breakdown is due to the time consumed in evaporation, however, does not agree with the accepted theory of the relation between ionization and time lag and both the normal frequency and impulse arcovers respond similarly to corresponding changes in humidity.

Literature of the Institute reviews comprehensive tests which definitely establish that the flashover value of commercial insulators varies on the order of 2 per cent per grain over the normal range of absolute humidity.

The effect of flanges in offsetting the effects of humidity are not proved conclusively, I believe, by the data in tables I and II on the flashover of bakelite and glass rods having 260 threads per inch. It would be very interesting to compare similar data on rods without the threaded surface under identical conditions of test. It is suggested also that the results of such a test be reported on the basis of absolute rather than relative humidity.

Referring to the data on the bakelite rod, and disregarding the values where the arc struck along the sample, the data show an average value of 151.5 kv at an average of 31 per cent relative humidity and 160.5 kv at a relative humidity of 95 per cent. This performance indicates that changes in humidity did have an effect on the flashover of the bakelite rod. This is a variation of 6 per cent and is greater than would normally be considered satisfactory after applying the usual corrections in commercial testing.

The author probably will agree that for practical intents and purposes the use of a linear relation for air density correction over the atmospheric range from 0.850 to 1.10 will introduce very little error. Relative to insulation for the higher transmission voltages, the improvement that can be obtained with closely spaced flanges is covered in Torok and Archibald's paper on "Diameter and Spacing of Suspension Insulators" presented at the Milwaukee meeting in 1932.

The paper does not give any data or explanatory discussion of the author's reference in the last sentence of the paper to the influence of geometrical details of the insulator on impulse flashover.

J. C. Rah (Joseph C. Rah and Co., Chicago, Ill.): There are several important points brought out in this paper, one of which is the author's mention of the discrepancies that occur in measurements of flashover voltages by various observers. There is no question that the measurements should be more standardized and that the technique of measurement should be adapted so as to eliminate such wide discrepancies upon which theories sometimes are built that are confusing rather than illuminating. A definite step toward uniformity therefore would be very welcome.

Under the subheading "Surface Effects" in the first paragraph, the author says that all the difficulties are eliminated because of a simple testing apparatus. I do not believe that this is exactly correct. As I understand it, the flashover is a puncture of air near the surface and does not depend entirely upon the surface condition. It has been shown that under certain circumstances flashover has been improved by some dirt or oil on the surface and then there are conditions where flashover was lowered. Reduction of flashover may also be due to the fact that there is a slight pressure normal to the surface of the insulator which facilitates the production of corona in the air thus rarefied near the surface, as given in "Mechanical Forces at Contact Surface of Life Conductors and Insulators," by H. Stauffer in Revue Générale de l'Electricité, Nov. 24, 1923, page 765–72. The assumption made that there is an electrolyte on the surface of the insulator puts somewhat of a different aspect on this matter of flashover, as this supposition seems plausible if one observes the "tracking" produced by arcovers on insulators. However, as there are so many reasons given at the present time for flashover, other conditions, no matter how small, should be taken into consideration.

The author of this paper also states that if the insulator is of a smaller diameter the effective flashover is closer to the air puncture, which is true. But if all is a matter of area alone, then how would an insulator with grooves extending from one electrode to another in a spur gear-like shape behave? If all difficulties are eliminated by the simple apparatus used by the author, then what will be the effect of such an increased area in this gear-shaped insulator? Also, how would a tubular insulator, using electrodes which are doughnut-shaped so that the air inside and outside of the tube is the same, behave when subjected to flashover tests? Will it flash over inside as well as outside of the tube, or with repeated flashes where would it flash more, inside or outside?

In many instances an insulator, particularly one made of porcelain, will flash over at higher voltages when wet. Such an instance does not seem to be explainable by the electrolyte theory. It seems to be more explainable by the reference mentioned above, as the normal component is considerably reduced on the surface of the porcelain in contact with water. However, this may not be a complete explanation and possibly it is something more than just a coincidence that a completely wet insulator gives a much higher flashover strength.

One explanation may be that the potential distribution is considerably improved by the somewhat conducting film of water.

I also wish to mention at this point the Smith suspension wood insulator which has been in service for a number of years without failure. In this insulator a so-called hollow field was created, whereby the surface of the insulators separating the 2 terminals was in a field of such low density that flashover at the surface of the wood was made practically impossible. I don't think that this is a scientifically sound design, but just one of the things to take into consideration when flashover near the surface of insulators is being considered.

While it is possible that glass and porcelain may produce electrolytes on their surfaces, especially since glass is somewhat soluble in water, will electrolytes also be generated on the surface of other insulating materials not soluble in water? Following the author's argument, if we put the electrodes with the insulators in oil, or any other medium which can be made dry, in such a manner that no electrolyte is generated on the surface of the insulators, the flashover should be the same as the puncture of the oil without the insulators. I have not found this to be the case with commercial insulators of various shapes.

I agree that corrugations on the surface of a porcelain or any other insulator increase its flashover value, as has been proved by many observers. However, a general statement like this is not correct, as I have found from my experience that there is a certain definite proportion and relation between corrugations and the dimensions of the insulator. If the corrugations are too large, very often instead of flashing over the corrugations are punctured. This may also happen to smaller corrugations when flashed over in oil. In other words, corrugations are not only a function of the general dimensions of the insulator, but also depend upon the medium in which they are to be used.

On page 1067 is the following sentence: "The spread of the points in any individual test is practically equal to the spread of points from *radically different classes of structures*." There is some question as to the exact meaning of the words italicized. If it refers to design, I wish to say that I do not think that there are "radically different insulator designs." There are only different shapes which are so far from the correct design that none of these variations in shape can be considered to constitute a different design. Between the limits of commercial production such variations do not change their electrical characteristics, even though they may change the mechanical characteristics. However, if it means materials, then it would be much clearer if it were reworded, as the meaning is somewhat ambiguous in the present form.

There are designs, particularly of bush-

ings, in which the flashover voltages are higher than the ordinary ones. If we eliminate the question of flashover as a controversial one, we still can see that some bushings do not have streamers, but only corona discharge up to flashover potentials. I know of at least 2 such designs, one in this country and one in Germany.

I believe that in the matter of insulation design there is too much empiricism and, therefore, papers like this should be very much encouraged, since there is a great deal to be done to overcome the tradition built on erroneous conceptions. Furthermore, there should be more fundamental research done, not to prove a commercially advantageous point, but to get to the bottom of scientific truth and to establish relationships.

F. W. Maxstadt (California Institute of Technology, Pasadena): In the second paragraph of his comments, Mr. Barrow objects to the explanation that higher impulse than normal frequency arcover strength is due to time consumed in the evaporation of the electrolyte film from the insulation surface. His criticism is justified when commercial insulators with flanges or with shield rings spaced a smaller distance than the useful length of the insulator surface are under consideration. In such a case needle gap or rod gap conditions should apply, since a major portion of the ultimate flash is in air alone far removed from the insulation. The well-known time lag is thus due to lack of abundant initial ionization. The evaporation suggestion applies more specifically to the simple test specimens whose fundamental properties were reported. They were in homogeneous electric fields which notably exhibit for air alone almost no time lag or distinction

Table I—Arcover Strength of 7.62 Cm Bakelite Rod, Smooth, With Varying Relative Humidity

Temperature 20–24 deg C, barometer 74 cm, protective resistance 0.2 megohm, flat electrodes with curved edges 50 cycles, transformer impedance 10,000 ohms

Crest Voltage, Kv	Crest Gradient, Kv per Cm	Per Cent Relative Humidity
153	20.2	33
154	20.3	36
153	20.2	35
152	20.0	38
146	19.2	48
118	15.5	63
115	15.1	70
74	9.7	95
73	9.6	95
71	9.3	98
41	5.4	Wet

between normal frequency and impulse breakdown. It is, however, not true that "both normal frequency and impulse arcovers respond similarly to corresponding changes in humidity." Torrok and Archibald show in their paper, "Suspension Insulator Assemblies," A.I.E.E. Transactions, volume 51, 1932, page 684, figure 4, that up to 2 microseconds time lag there is no difference between wet and dry impulse arcover voltage and up to 20 microseconds the difference is only about 8 per cent, whereas the ratio between normal frequency arcover for, say, 30 per cent relative humidity and wet has been shown on page 1063, figure 2, of the present paper to be 3 to 1 or 2 to 1, depending upon which experimenter's results are chosen.

It is very common to accept empirical data such as the value of 2 per cent increase in flashover voltage per grain increase in absolute humidity. The practice simplifies

Table II—Arcover Strength of 9.3 Cm "Pyrex" Rod, Smooth, With Varying Relative Humidity

Temperature 24–26 deg C, barometer 74 cm, protective resistance 0.2 megohm flat electrodes with curved edges 50 cycles, transformer impedance 10,000 ohms

Crest Voltage, Kv	Crest Gradient, Kv per Cm	Per Cent Relative Humidity
186	20.0	29
135	14.6	44
131	14.1	44
119	12.8	50
93	10.0	62
91	9.8	65
64	6.9	95
56	6.0	Wet

certain comparisons and small extrapolations and in the absence of better knowledge is to be tolerated, but if a true curve of variation is known, the narrow limits of satisfactory application of the simple rule are evident. If one did not know a magnetization curve beyond the straight line portion he would be justified in assuming, for convenience, constant permeability but we are not content with such treatment of the magnetic quantities, so why be content with such for the relation of humidity to arcover voltage? It is only a fortuitous circumstance that makes part of the arcover voltage vs. absolute humidity curve follow a straight line. There is no physical or other basis for the relation and since the absolute humidity scale does not indicate the point of discontinuity where dry conditions change over to rain, it should be discarded and a relative humidity scale substituted so as to show the true condition of the atmosphere.

For comparison of smooth samples with the rods on which fine threads were cut, see tables I and II of this discussion. The bakelite piece is the same one reported in table I, page 1065, of the paper but without threads. The Pyrex piece is one of slightly larger diameter but the same material and tested in the same manner. A smaller series protective resistance was used for the tests in tables IV and V, also larger diameter electrodes, but those details do not spoil the comparison.

Regarding the small effect due to changes in humidity when the threaded rods were under test, it is to be expected that some effect will be observed since lack of symmetry, end conditions, and a little collection of dust make it quite unlikely that any specimen can be absolutely free from humidity influence in the normal frequency arcover. It is to be noted that the 6 per cent variation observed for the threaded rods is in place of a 3 to 1 variation for the smooth samples.

So far as the author knows no other test or explanation similar to the one concerning the ideal spacing of flanges as reported in the paper has appeared in the literature.

Practically, the linear relation for the air density correction is satisfactory but here again we want to know the true law of variation so as not to make grave errors when departing widely from the usual range. Air as a dielectric and insulators in air are sometimes used at several hundred pounds per square inch for purposes of obtaining greater breakdown strength. Either very low or elevated temperatures may also be encountered.

The influence on impulse arcover of geometrical details of the insulator, referred to in the closing sentence, may be determined for suspension insulators, pillars, and apparatus bushings by consulting A. O. Austin's paper, "An Improved Type of Limiting Gap," A.I.E.E. Transactions, volume 51, 1932, figures 1, 3, and 5, pages 677–9.

Mr. Hillebrand has pointed out a weakness in the statement in numbered paragraph 4 of the introduction to the paper, where uniform fields were suggested for transmission line insulators in order to obtain greater arcover voltages. I think, however, that if a large enough shield is used to obtain the desired results with respect to the insulator, it will almost completely cover the vulnerable portions of the tower cross arm and line conductor. Obviously the whole electric field of the line will have to be considered and at present big improvements are not in sight.

In his second paragraph Mr. Rah points out that "under certain circumstances" flashover has been improved by some dirt or oil on the surface. C. W. Rice (reference number 13) made some tests in uniform fields in which a coating of oil increased the arcover voltages of glass, hard rubber, and other substances. Between certain humidity limits dirt may improve the arcover strengths of commercial insulators.

The "very slender fibers" whose flashover voltages were abnormally high were almost microscopic threads. Insulators with grooves parallel to the electric field will act no differently from smooth cylinders. Doughnut-shaped electrodes do not produce the simple, uniform field used in the experiments reported, hence should be tested, until we have far more complete rules for insulator design than are now available.

The effect of moisture on a commercial insulator or any other insulator having small or nonplane electrodes seems to be to improve the voltage distribution up to a certain point beyond which more moisture brings about the short circuiting of useful surface.

A discussion of arcover of insulators under oil is not included in the scope of the paper, but keeping in mind that the best purification obtainable commercially still leaves 3 parts per million of water in the oil, there is no reason why the electrolyte explanation should not apply.

On page 1067 of the paper, radically different classes of structures mean everything tested, including cotton rope, smooth glass rod, smooth porcelain tube, commercial suspension strings, and insulator pillars as well as pin insulators.

News
Of Institute and Related Activities

The 1935 Winter Convention

IN SPITE OF New York's 17-inch snowfall, which occurred during the Institute's recent winter convention and which crippled traffic facilities in and about the city, attendance at sessions of the convention was good; a total of 1,114 members and guests registered. The percentage of attendants from outside New York City showed a further increase over last year; those registered from out-of-town (outside of District 3) this year comprised 38 per cent of the total registration, compared with 34 per cent for 1934, and 28 per cent for 1933.

Table I—Registration at Recent Winter Conventions

1935	1,114	1929	1,375
1934	1,227	1928	1,475
1933	1,099	1927	1,317
1932	1,429	1926	1,423
1931	1,589	1925	1,445
1930	1,607	1924	1,738

That the snowstorm had a direct influence on the total registration is evidenced by the fact that the first day's registration was 633 compared with 584 for the first day last year; the second days' figures were 301 and 433, respectively. Since the storm was at its height on the second day of the convention, the abrupt drop in registration on that and succeeding days was attributed directly to the storm. Of particular interest were the facts that attendance at the smoker and inspection trips was about double that of last year. These and other interesting facts are revealed by the accompanying tabulations. Brief reports on the principal features of the convention are given in the following paragraphs.

Opening Session

The convention was opened at 10 a.m., Tuesday, January 22, by C. R. Jones, chairman, general winter convention committee. Mr. Jones extended a hearty welcome to all members and guests attending the convention, particularly those from out of town. At the conclusion of his remarks, Prof. W. H. Timbie, vice president A.I.E.E. North Eastern District (number 1), read an address, "The A.I.E.E. as an Educational Institution," prepared by President J. Allen Johnson, who had been ill and was not sufficiently recovered to deliver it. In this address, President Johnson described the educational activities of the A.I.E.E. and urged members to "realize the dependence of their individual professional standings upon their continuing education, and make full use of the opportunities offered by the Institute." Full text of President Johnson's address may be found on pages 146–8 of this issue.

Following President Johnson's address, R. N. Conwell, chairman of the technical program committee, made brief announcement concerning the procedure to be followed in the technical sessions.

Technical Sessions

No detailed report of the technical sessions will be included here, inasmuch as all technical papers discussed have been published in previous issues of ELECTRICAL ENGINEERING, and the discussions of these papers will be published in future issues. Most of the sessions were featured by lively and interesting discussions; those on general overhead line problems, transformers, and electronics were most widely discussed.

Demonstration Lecture on Illumination

Following the medal presentation ceremonies held in the Engineering Auditorium on Wednesday evening, January 23 (reported in detail on succeeding pages), a demonstration lecture, entitled "Artificial Light—the Engineer's Greatest Gift to Mankind," was given by A. L. Powell, president of the Illuminating Engineering Society, and member of the A.I.E.E. committee on production and application of light.

Mr. Powell traced briefly the history of lighting from early times down to the present, and demonstrated on the stage a great many types of lighting equipment ranging from the pine knot our forefathers used down to a modern 90,000,000 candle power searchlight. Apparatus illustrating some of the most recent advances in illumination was demonstrated, including applications of arc lamps in industry, medicine, and projection, as well as the newest forms of gaseous conductor lamps—the high intensity mercury and sodium vapor lamps. His lecture was illustrated also by many lantern slides, most of which were in color.

Attendance at this lecture was particularly good, about 350 being present, considering the fact that New York's recent snowstorm was at its height during the evening.

Inspection Trips

Continuing the plan introduced last year, the last day of the convention, Friday, January 25, was reserved for inspection trips. In addition to those held on Friday, several trips were conducted earlier in the week. To say which trips were most popular would be difficult because the attendance on some was limited to a previously determined figure. However, the trip to Warner Brothers moving picture studio and Hudson Avenue generating station of the Brooklyn Edison Company, and the all-day trip to the Edgewater plant of the Ford Motor Company, the Okonite-Callender Cable Company, and Wright Aeronautical Corporation were complete "sell outs" early on the first day of the convention; attendance on these trips was limited to 61 and 59, respectively.

The trip to Radio City Music Hall drew the largest attendance, 141 having registered for that event. Other popular trips with attendances were: General Electric House of Magic, 116; steamship "California," Panama Pacific Line, 87; radio patrol system, New York Police Department (2 trips), 84; and RCA Radiotron Company, 56. Smaller groups went on the several other prearranged trips. The trip to Newark (N. J.) airport and flight were cancelled because of unfavorable ground conditions resulting from the recent snowstorm. In all, 815 persons were registered for trips, compared with a total of 363 for the 1934 winter convention.

The committee in charge of arrange-

Table II—Analysis of Registration at Recent Winter Conventions

District	1933	1934	1935
New York City and Foreign (3)	791	812	694
North Eastern (1)	130	179	194
Middle Eastern (2)	132	161	153
Great Lakes (5)	23	40	38
Canada (10)	14	16	21
South West (7)	2	11	5
Southern (4)	4	5	6
North Central (6)	2	2	1
Pacific (8)	0	1	1
North Western (9)	1	0	1
Total	1,099	1,227	1,114

Table III—Attendance at Special Features of Recent Winter Conventions

	1933	1934	1935
Total registration	1,099	1,227	1,114
Smoker	650	550	1,025
Dinner dance*	350	464	442
Inspection trips	720	363	815

* Dinner-dance and dance-buffet supper combination introduced first in 1934.

ments for these fine trips was headed by S. A. Smith, Jr.; he was assisted by G. E. Dean, Henry Kurz, L. C. Miller, W. J. Quinn, H. O. Siegmund, H. B. Stoddard, E. R. Thomas, R. H. Twiss, W. Y. Vedder, and R. L. Webb.

Smoker

Departing from the custom of the past 6 years of holding the annual smoker in the Engineering Societies Building, the affair this year was held at the Casino de Paree at 254 West 54th Street, New York City. That this change met with the widespread approval of members of the Institute was evidenced by the fact that reservations had been made to the extent of the full capacity of the Casino well in advance of the opening day of the convention. A total of 1,025 members and guests attended this event.

Those attending the smoker this year enjoyed a full course dinner served in spacious surroundings and an excellent floor show after the dinner. As in former years, the high spot of the affair was the opportunity afforded the members to meet their engineering friends and to renew former acquaintances. Most important of all, perhaps, was the fact that all this was provided at a price lower than in previous recent years. The smoker committee was headed by George Sutherland; he was assisted by E. S. Banghart, R. F. Brower, C. A. Butcher, G. D. Edwards, W. H. Farlinger, W. H. Harden, William Jordan, J. E. McCormack, H. C. Schlaikjer, D. W. Taylor, E. F. Thrall, H. G. Wood, and L. A. Zima.

Dinner-Dance-Buffet Supper

For many years the outstanding social event of the Institute's winter convention, the dinner-dance, proved no less so this year. The combination dinner-dance and dance-buffet supper, which was offered for the first time last year, was so successful then that the innovation was continued this year. In addition, several lounge rooms for beverage service and for bridge and other games were provided this year; these added features proved to be highly popular.

A total of 187 members and guests attended the dinner-dance, 182 the dance-buffet supper, and 73 the combined dinner-dance-buffet supper, making the total attendance 442 persons. The committee in charge of this year's affairs consisted of C. S. Purnell, chairman, P. L. Alger, T. S. Bacon, C. M. Gilt, J. E. Goodale, H. L. Huber, W. A. Kietzman, Thomas Maxwell, J. A. McHugh, J. H. Pilkington, H. S. Sheppard, D. M. Simmons, and W. R. Smith.

Women's Entertainment

In addition to the regularly scheduled social events of the convention that are of particular interest to the women, a special program of entertainment was arranged to keep them occupied while their husbands were discussing the more weighty problems of electrical engineering. The luncheon and bridge at the Engineering Woman's Club, which has become a popular feature among women attendants to the convention, was held on Wednesday, January 23; more than 50 attended. Some 60 women visited the Good Housekeeping Institute, where tea was served, on Thursday. The radio broadcast by Walter Damrosch on Friday morning was attended by 25, and the tour of Radio City Friday afternoon by 46; the latter was followed by a tea in the British room.

In charge of the women's activities was Mrs. H. R. Woodrow; she was assisted by Mrs. C. R. Beardsley, Mrs. H. C. Dean, Mrs. A. F. Dixon, Mrs. Tomlinson Fort, Mrs. H. H. Henline, Mrs. A. H. Kehoe, Mrs. E. B. Meyer, and Mrs. G. S. Rose. A total of 75 women was registered at the convention.

Directors and Committees Meet

As is the usual custom, a meeting of the Institute's board of directors and meetings of several Institute committees were held during convention week. A report of proceedings at the board of directors' meeting, which was held on Monday, January 21, may be found elsewhere in this issue. Reports of the various committee meetings are scheduled for inclusion in the March issue. Meetings of the following Institute committees were held: automatic stations, communication, electrical machinery, electrochemistry and electrometallurgy, electrophysics, finance, instruments and measurements, lightning arrester subcommittee of protective devices, power generation, power transmission and distribution, research, standards, and technical program.

Much credit is due to the general winter convention committee for the splendid events arranged and for the splendid manner in which all arrangements were made. The committee was headed by C. R. Jones; he was assisted by T. F. Barton, C. R. Beardsley, C. O. Bickelhaupt, R. N. Conwell, A. F. Dixon, H. S. Osborne, D. M. Simmons, W. R. Smith, George Sutherland, and R. H. Tapscott.

Membership—Meeting the Bogey

Mr. Institute Member:

The membership committee has adopted the bogey of obtaining more applications for membership each month than for the corresponding month of the previous year. For the immediate months the results are:

	Number of Applications Received	
	1933	1934
September	15	55
October	45	98
November	53	78
December	58	60

Your contribution to this work is to send to the chairman of your Section membership committee the names of persons who you feel should be invited to join the Institute.

Your membership committee thanks you for your past helpfulness in this work and hopes for its continuance in even greater abundance. Perhaps you have a name or 2 in mind that you can send in—right now.

Everett S. Lee

Chairman National Membership Committee

A.I.E.E. Directors Meet at Institute Headquarters

The regular meeting of the board of directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, N. Y., on January 21, 1935.

Present: *President*—J. Allen Johnson, Buffalo, N. Y. *Past-Presidents*—H. P. Charlesworth, New York, N. Y.; J. B. Whitehead, Baltimore, Md. *Vice Presidents*—R. B. Bonney, Denver, Colo.; A. H. Hull, Toronto, Ont.; F. O. McMillan, Corvallis, Ore.; F. J. Meyer, Oklahoma City, Okla.; R. W. Sorensen, Pasadena, Calif.; R. H. Tapscott, New York, N. Y.; W. H. Timbie, Cambridge, Mass.; A. M. Wilson, Cincinnati, Ohio. *Directors*—L. W. Chubb, East Pittsburgh, Pa.; F. M. Farmer, New York, N. Y.; N. E. Funk, Philadelphia, Pa.; H. B. Gear, Chicago, Ill.; P. B. Juhnke, Chicago, Ill.; G. A. Kositzky, Cleveland, Ohio; Everett S. Lee, Schenectady, N. Y.; A. H. Lovell, Ann Arbor, Mich.; A. C. Stevens, Schenectady, N. Y.; H. R. Woodrow, Brooklyn, N. Y. *National Treasurer*—W. I. Slichter, New York, N. Y. *National*

Future AIEE Meetings

South West District Meeting,
Oklahoma City, Okla., Apr. 24–26, 1935

Summer Convention,
Ithaca, N. Y., June 24–28, 1935

Pacific Coast Convention,
Seattle, Wash., Fall 1935

Great Lakes District Meeting,
Indianapolis—Lafayette Section territory (date to be determined)

Secretary—H. H. Henline, New York, N. Y.

Minutes were approved of a meeting of the board of directors held on October 19 and of a meeting of the executive committee held on December 7, 1934.

A resolution was adopted in memory of George A. Hamilton, a former national treasurer of the Institute, who died on January 10, 1935. (The resolution appears elsewhere in this issue.)

Reports were presented and approved of meetings of the board of examiners held December 19, 1934, and January 16, 1935. Upon recommendation of the board of examiners, the following actions were taken: 3 applicants were elected and 3 were transferred to the grade of Fellow; 15 applicants were elected and 41 were transferred to the grade of Member; 123 applicants were elected to the grade of Associate; 257 Students were enrolled.

The finance committee reported disbursements for the month of December 1934 amounting to $13,883.86 and for January 1935 amounting to $18,939.58. Report approved.

Upon recommendation of the committee on Student Branches, authorization was given for the establishment of Student Branches of the Institute at Johns Hopkins University, Baltimore, Md., and Tufts College, Medford, Mass.

A resolution was adopted that the 1935 annual meeting of the Institute shall be held on Monday, June 24, at Ithaca, N. Y.

The following schedule of meetings for 1936, recommended by the committee on coördination of Institute activities, was adopted: winter convention, New York, N. Y., January 28–31; summer convention, Los Angeles, Calif., June 22–26; North Eastern District meeting, New Haven, Conn., early in May; Middle Eastern District meeting, Akron, Ohio, dates to be determined later.

Approval was given to revisions in the rules for the award of national and district prizes of the Institute as recommended by the committee on award of Institute prizes and the committee on coördination of Institute activities, to go into effect in connection with awards for the year 1935.

The board voted to sanction a plan for the accrediting of engineering schools which had been prepared by the Engineers' Council for Professional Development. (See item page 249, this issue.)

A report was presented of the special committee to review election procedure which had been appointed in accordance with the board's action in August 1934. Upon the recommendation of that committee, the board voted that steps be taken to amend the constitution in the spring of 1935 to permit the holding of the meeting of the national nominating committee (held early in December under the present provisions) during the winter convention, in January, with the resulting later publication of information concerning the nominations. This involves changing the date of mailing the election ballots from the first week in March to the first week in April, and changing the time limit for the return of the ballots from the first day of May to the first of June. The committee was continued in order that it may make a more thorough study of all aspects of the election procedure and submit a final report to the board of directors not later than January 1936.

Other matters were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.

Edison Medal for 1934 Presented to Doctor Whitney

THE Institute's highest award, the Edison Medal, was presented for 1934 to Dr. Willis R. Whitney for "his contribution to electrical science, his pioneer inventions, and his inspiring leadership in research," at a special session of the Institute's recent winter convention, Wednesday evening, January 23, 1935. Doctor Whitney has been an Associate member of the Institute since 1901, and is vice president and director of research of the General Electric Company, Schenectady, N. Y.

R. B. Bonney presiding over the ceremonies

In the absence of J. Allen Johnson, president, A.I.E.E., R. B. Bonney, vice president, A. I. E. E. North Central District (Number 6), Denver, Colo., presided over the ceremonies. After brief introductory remarks, Mr. Bonney introduced Mr. C. E. Stephens, chairman, Edison Medal committee (for full personnel of committee see page 1332 of the September 1934 issue of ELECTRICAL ENGINEERING) who spoke briefly regarding the history of the medal and recipients during previous years.

Following Mr. Stephens's remarks, Mr. H. H. Barnes, Jr., past manager (1910–13) and past vice president (1913–15) of the Institute read an address briefly touching upon some of the high lights of Doctor Whitney's career, prepared by Dr. E. W. Rice, Jr., past-president (1917–18) of the Institute, who was unable to be present. Doctor Rice's address as read by Mr. Barnes follows.

High Lights in Whitney Career Outlined by Dr. E. W. Rice, Jr.

"I will not consume precious time in tracing the history of our medalist, as it already has been set forth in 'Who's Who' and other publications. It is well known that Doctor Whitney has received degrees in course and degrees honorary; that he is many times a doctor—doctor of science, doctor of philosophy, and even doctor of laws—a teacher, inventor, executive, member and past-president of many scientific societies, trustee of institutions of learning, a notable chemist, and now his friends are delighted that he should be awarded the electrical engineers' great prize, the Edison Medal.

"I regard it as a great honor that I should be selected to give a few reasons for the bestowal of this medal by his fellow engineers. Whitney very early in his professional career showed the qualities that have made his career so useful and notable. Doctor A. D. Little says in substance that this early work was in the field of chemistry, to which by 'brilliant experimental work, he added much to our knowledge of solubility of colloids and the corrosion of metals, the effect of the ions on the precipitation of colloids, he found that the corrosion of metals was an electrochemical process, and was among the first to focus public attention upon the great economical wastes resulting from preventable corrosion.' Naturally, we of the electrical profession believe that Whitney's greatest achievement has been his leadership of modern industrial scientific research, best exemplified by his administration of the research laboratory of the General Electric Company at Schenectady, N. Y.

"Most of the years of my life have been devoted to engineering work, and it has been my good fortune to meet many of the distinguished engineers and scientific men of the world. This acquaintance with scientific men should be taken into account in weighing the value of my opinion that we were particularly fortunate in obtaining Dr. Willis R. Whitney to take charge of our research laboratory. This new venture, a truly great industrial event, was initiated many years ago, at the opening of the new century. The time, the year 1900, was most propitious. Our company and its predecessors had had some 20 years' experience in manufacturing electrical material

C. E. Stephens outlines the Medal history

The electrical industry had grown to a considerable volume. Elihu Thomson, Edison, and many others had made most of their original and important contributions to the art. The panic and depression of 1893 to 1896 had shaken things down. The prejudices and crudities of the pioneer days had largely passed away. We had learned that there was a field for all the various applications of electricity, whether of alternating current or of direct current, such as the arc lamp, incandescent lamp, and electric street railway, and we were busy welding these together.

H. H. Barnes, Jr., reads Doctor Rice's address

"The opinion seemed to have been generally held that no radically new development could arise. Copper was the best conductor of electricity; iron the best for magnetism; carbon the best for electrodes of arc lamps, for filaments of incandescent lamps, and for brushes for commutators. As far as we could see, it was likely that these materials always would remain the best for these respective purposes. Such at least was the opinion of most engineers. However, there were a few who thought differently; and it was at this period of comparative calm that the research laboratory at Schenectady was started. The research laboratory started most modestly in a small way, with few men and few facilities, and increased in size only as it demonstrated its usefulness.

"The first 'valuable find' that resulted was in that borderland between chemistry and physics that has proved such a fruitful field for exploration. This was the metallized carbon filament for incandescent lamps. It resulted from an experiment by Whitney to see if he could prevent the blackening of incandescent lamp bulbs, which limited the useful life of the lamp. As has been often told, he placed some treated carbon filaments in a high temperature electric furnace he had devised, and found when these filaments were tested afterward in lamps that he had produced a new product, a new type of filament, one in which the electrical resistance had a positive or metallic characteristic. The resistance of the existing carbon filaments decreased with temperature, or, as it is called, had a negative characteristic. Whitney thus was able to produce a lamp that was at least 25 per cent more efficient, that is, gave 25 per cent more light for the same energy, with even a longer life than the standard lamp. This was a most remarkable contribution and naturally made us all happy. Also, it at once established the practical value of the research laboratory.

"I shall never forget the beautiful and convincing method by which Whitney arrived at the best 'prospect' for a metal filament. This was back in 1902. Osmium had shown an efficiency greater than carbon. John Howell pointed out that this shook our belief in the infallibility of carbon as a filament. It is true osmium was too rare, but it was more efficient than carbon, so there might be and probably was some other metal. Platinum and iridium had been tried and failed. Whitney took up the problem and proved to our satisfaction, by reference to the periodic law, that of all the remaining elements whose properties were unknown, tungsten and thorium were the only ones that theoretically could possess the necessary properties of high resistance and high melting point.

"It is not my purpose to describe the subsequent history of the laboratory under Doctor Whitney's direction, the story of the production of ductile tungsten, the new X ray tube, and the cathode ray tube by Coolidge; of the discoveries and inventions of Langmuir in high vacua and electronics, the gas filled lamp, and atomic hydrogen welding. This has been told often and told better by others.

"No one, however, will ever know the actual extent of his contribution. If was his fixed habit for many years to visit every room in the laboratory daily, and to offer freely the suggestions that came from his fertile mind, but without attempting to take the credit that lesser men would have deemed merely their right. If he had elected to pursue the solitary path of the inventor, he doubtless would have become one of the world's most famous and prolific inventors; but fortunately he saw and seized an opportunity for greater service, the building of a great research organization. So he sacrificed his personal researches and devoted less of his time to scientific discoveries and concentrated on the making of men.

"After he became director of research, he found time, incredible as it may seem, to make a number of personal contributions in addition to the metallized filament already mentioned. He discovered that, contrary to prevailing ideas, the positive electrode was not an essential factor in an arc lamp, and contributed the nonconsuming positive electrode used in the well known magnetite lamp.

"He discovered the effect of high frequency radio waves in producing artificial fever. By his own experiments he demonstrated the usefulness of such treatment in curing certain diseases of dogs, and stimulated the medical profession to develop its application to the relief of various human ailments.

"To the broadest scientific knowledge, Whitney added a contagious enthusiasm and undaunted courage, and insatiable curiosity. He is a keen but kindly critic, yet generous to a fault. He won confidence; disarmed suspicion; dissipated jealousy. He was not afraid to surround himself with great men, and made every effort to secure the services of the brainiest men in science. He secured Coolidge and Langmuir, Hull, Hawkins, and many others, and opened to them the door of opportunity and kept it open.

"Thus he has built up an organization that, inspired and stimulated by his leadership, has performed wonders. In a very real sense the work of his organization has been his work. His success is demonstrated not only by the material results but by the confidence and affection that he has inspired in all with whom he has come in contact. He deserves all the honors and the credit that have been showered upon him by a grateful and appreciative world, and it is characteristic of the man that he always accepted such honors as in trust for his organization.

"It was also characteristic of Whitney that he never thought of himself, that he never wanted fine offices, or expensive buildings or equipment. He was ever impatient with any procedure that took time from experiments, red tape, committee meetings, and even reports; he merely tolerates and omits them whenever possible.

"He is preeminently one of those rare men who are sufficiently expert to pass with certainty on suggestions of abnormally good minds. He allowed himself, as he says, 'To be led by Nature, instead of trying to force Nature along lines seemingly desirable.' While it is true that the shop and the soil are great sources of wealth, the human intellect excels all, and a research laboratory is a wealth producer par excellence because it is an organization of men who systematically use their brains to reach for new things, new facts, new combinations, new truths."

Doctor Whitney Describes Experiments on Lamp Filaments

Immediately following the reading of Doctor Rice's address by Mr. Barnes, Mr. Bonney presented the medal and engraved certificate to Doctor Whitney, who responded as follows:

"Perhaps no other person could feel a greater pleasure at this honor than I. I lived through the whole period of Mr. Edison's historical work. I recall seeing one of the first carbon filament lamps, when it was thought to be just an interesting novelty. It looked pretty small compared with the existing arc lights, and it could not be installed in houses since no one had wiring for it.

"Now, for nearly 35 years, I have been in particularly close contact with incandescent lamp work, as well as with many of those other electrical developments so dear to Mr. Edison himself. It seems fitting for me at this time, therefore, to add a little to the records of studies that we at the research laboratory of the General Electric Company made to continue Mr. Edison's researches on carbon filaments.

Doctor Whitney responds

"In the early days of our laboratory, we studied experimentally all those chemical elements we could procure that had higher melting points than platinum or had not been melted. The father of the incandescent lamp had worked on platinum as a filament and there were still several promising metals that had never been made into filaments. Carbon still seemed promising, too, and for many years we continued re-

search upon it. It is bad engineering to assume that a thing is perfected. It is usually improved by some unforeseen process.

"At that time the carbon filament had undergone many improvements which hardly warranted general publicity. It had not stopped at the earlier carbonized threads, or the slivers of bamboo. When I think of possibilities, as they sometimes develop, I wonder if someone might not yet discover another superior form of carbon.

"Remember that I can recall the time when no one had made graphite, thought it was found in nature, and also that Moissan had shown me tiny diamonds he had made from coke. Black diamond, or bortz, was known, and the question was, 'How many other forms or isomers of this fertile carbon can we find or make?' Moreover, efficient arc lamps used carbon for electrodes, and carbon motor brushes had displaced the metal ones. It seemed as though carbon was particularly designed for electrical services.

"One line of our own work should be described, if for no other reason than to make available to some future student of carbon, details of speculation and of knowledge not generally available. The product itself was described as a new form of carbon by Mr. John W. Howell before the A.I.E.E. in 1905.

"About 30 years ago, the best incandescent filament was a combination of 2 different allotropic forms of carbon, a coke and a graphite. The filament had actually a core or base of coke, carrying a complete coat, shell, or sleeve of graphite carbon. This core was made by dissolving cotton in zinc chloride solution and squirting the product through suitable dies into a coagulating or fixing liquid. This thread was then washed, dried, shaped, and carbonized. The carbonizing consisted in packing the formed loops into fireproof crucibles with a protective mass of previously carbonized peat dust. This protected the filaments from burning. Each such base was at best a very poor lamp filament. It was then heated individually by electric current while held in a low pressure of hydrocarbon vapor. By the proper selection of the vapor, its pressure, and the time and temperature of the treatment, a thin, shiny, dark gray coating was put over the dead black carbon base. The criteria, chemical and physical, that were then available forced us to call the base a coke carbon and the hard, shiny coat a form of graphite.

"Our production of a new kind of graphite at this time permitted an improvement in the lamp that was equivalent to about 20 per cent in luminous efficiency. This developed into the so-called metallized-filament lamp.

"Its actual discovery illustrates one of the pleasures of research—the uncertainty. It is not always necessary to have the right hypothesis for a research, provided the suggested work can be carried out. Poor hypotheses sometimes lead to new utilities, just as the wrong horse sometimes wins the race. The original idea responsible for the production of metallized carbon might occur to someone else and seem as intriguing and promising as it did to us. This makes me want to explain it.

"As the base filament was made from cotton, it contained practically all the mineral matter of that original cellulose; that is, it left a little mineral ash on being burned in air. This ash was a complex mixture of silicates of iron, calcium, aluminum, and other metals, and contained combined oxygen. At the temperature of the gas furnace, which carbonized the filaments, part but not all of such oxides would be reduced. It seemed probable that small quantities of oxides, such as magnesium, aluminum, calcium, and silicon, might not be reduced. They would probably continue as oxides in the finished filament. Could they do harm there? That seemed possible. It was an old story even 30 years ago to connect accurately the length of useful life of a lamp with its burning efficiency at definite voltage. One of the limits to useful life was the blackening of the inside of the bulb, and the blackening was carbon from the filament.

"When a lamp had lost 20 per cent of its initial candlepower, whether from blackening or other causes, it was called dead. Good lamps lived under the test conditions 500 hours. The vacuum was as good as we could make it; but we knew that while this actually improved during early burning, it grew poorer as time went on. The question naturally arose, 'Can there be a slow reaction within the burning filament between residual oxides and carbon?' If so, the blackening could be explained very simply. I became quite excited about this point.

Dr. Willis R. Whitney (right) being presented the Institute's 1934 Edison Medal by R. B. Bonney, vice president of the Institute representing the North Central District, during the special presentation ceremony on January 23, 1935, which was part of the recent winter convention

"Chemists knew that coke burns to carbon monoxide and dioxide, and that under temperature conditions existing within the lamp 2 molecules of the monoxide could react to set free one atom of carbon and form one molecule of carbon dioxide. The atom of carbon certainly would deposit on the glass walls and begin the blackening; but that constituted only an infinitesimal portion of the possibilities, for the molecule of dioxide most certainly would come into contact with the hot filament and oxidize it so that we could have 2 new molecules of the monoxide. These at lower temperatures could react as before, give us our second free carbon atom and a new dioxide molecule, and so on, *ad infinitum*. In other words, a single molecule of carbon dioxide might act as a perpetual 'ferryboat' to carry carbon from filament to glass. We could visualize the dioxide, and the transported carbon was evident.

"It was this that led us to try to remove the very last traces of oxides from the base filaments. At this time we had already made electric furnaces for much higher temperatures than those attained by gas furnaces. The furnace was a carbon tube packed in powdered carbon. It could be heated, by passing current through it, to such a temperature that it sublimed or distilled away very rapidly at the hottest part. The temperature was about 3500° C. For our work we actually destroyed the furnace by its sublimation at each heating of a filament charge.

"Our first experiments did not disclose any useful improvements in the lamps, but there were so many possible explanations of the failure that we attempted a more careful repetition.

"Our stock of filaments had been taken from the factory and our lamp tests were made there. Through some error in shipment, the new stock of filaments were not the simple base or coke material we had used previously, but were the finished, complex filaments with their graphite coats. When these were put through our heating process, they came out looking very bad indeed. The surface was wrinkled and irregular, and there were countless hollow warts or tiny burst balloons of graphite on them. These balloons had been blown up by the gases coming from the impure coke base, which could not penetrate so easily the semi-liquid or dense graphite coat. In spite of their condition the life of these filaments in lamps was better than usual. I was sure of the value of the oxide hypothesis, and it seemed only a question of preheating the bases before putting on the graphite, in order to get rid of the irregularities.

"Mr. Howell, dean of lamp makers, early called our attention to the fact that we had made a new form of graphite, to which the improved quality of lamp was to be attributed. Perhaps we had sintered or melted the graphite coating into an unusually dense but continuous form by our combination of very high temperature with an atmosphere saturated with carbon. This would explain why it could not be done by heating the filament to the same temperature in vacuum.

"The electrical resistance of the graphite coat had been reduced to about $^1/_4$ of its previous value, and the temperature coefficient, like that of the pure metals, was positive. For this reason it soon was called metallized graphite. Later products, in which the base was heat purified and then with its added graphite coating again subjected to the electric furnace, gave us the filament for the improved lamp. Under these conditions it was no great disappointment to learn that the explanation of the new quality was not necessarily dependent on the starting hypothesis."

John Fritz Medal for 1935 Presented to a Son of the Late Frank J. Sprague

FOR "distinguished service as inventor and engineer through the application and control of electric power in transportation system," the John Fritz Medal and engraved certificate of award for 1935 were presented to Robert C. Sprague, son of Dr. Frank J. Sprague to whom the medal was awarded on October 19, 1934. Doctor Sprague died on October 25, 1934, 3 days after he had received notification of the award. Doctor Sprague was president of the A.I.E.E. 1892–93, and was elected an honorary member in 1932. The presentation took place during the evening of Wednesday, January 23, immediately following the presentation of the 1934 Edison Medal.

The John Fritz Medal is awarded not oftener than once each year, for notable scientific or industrial achievement, without restriction on account of nationality or sex. In memory of John Fritz of Bethlehem, Pa., one of America's great pioneers in the iron and steel industries, the medal was established in 1902 by friends and associates. It is awarded by the 4 national societies of civil, mechanical, mining and metallurgical, and electrical engineers, having a composite total of more than 50,000 members.

The first medal was given to John Fritz at a dinner for him on his eightieth birthday, August 21, 1902. Subsequent awards of the medal have been as follows:

1905 LORD KELVIN (HM'92). For his work in cable telegraphy and other scientific achievements.

1906 GEORGE WESTINGHOUSE (A'02). For the invention and development of the air brake.

1907 ALEXANDER GRAHAM BELL (A'84, M'84, and past-president). For the invention and introduction of the telephone.

1908 THOMAS ALVA EDISON (A'84, M'84, HM'28, and member for life). For the invention of the duplex and quadruplex telegraph, the phonograph, the development of a commercially practical incandescent lamp, the development of a complete system of electric lighting, including dynamos, regulating devices, underground system, protective devices and meters.

1909 CHARLES T. PORTER. For his work in advancing the knowledge of steam engineering and in improvements in engine construction.

1910 ALFRED NOBLE. For notable achievements as a civil engineer.

1911 SIR WILLIAM H. WHITE. For notable achievements in naval architecture.

1912 ROBERT W. HUNT. For his contributions to the early development of the Bessemer process.

1913 No. award.

1914 PROFESSOR JOHN E. SWEET. For his achievements in machine design, and pioneer work in applying sound engineering principles to the construction and development of the high-speed steam engine.

1915 DR. JAMES DOUGLAS. For notable achievement in mining, metallurgy, education, and industrial welfare.

1916 DR. ELIHU THOMSON (A'84, M'91, F'13, HM'28, member for life and past-president). For achievement in electrical invention, in electrical engineering and industrial development, and in scientific research.

1917 DR. HENRY M. HOWE. For his investigations in metallurgy, especially in the metallography of iron and steel.

1918. J. WALDO SMITH. For achievement as engineer in providing the City of New York with a supply of water.

1919 GENERAL GEORGE W. GOETHALS. For achievement as builder of the Panama Canal.

1920 ORVILLE WRIGHT. For achievement in the development of the airplane.

1921 SIR ROBERT A. HADFIELD. For the invention of manganese steel.

1922 CHARLES PROSPER EUGENE SCHNEIDER. For achievement in metallurgy of iron and steel, for the development of modern ordnance, and for notable patriotic contribution to the winning of the great war.

1923 SENATORE GUGLIELMO MARCONI (HM'17). For the invention of wireless telegraphy.

1924 AMBROSE SWASEY (HM'28). For achievement as a designer and manufacturer of instruments and machines of precision, a builder of great telescopes, a benefactor of education, and the founder of Engineering Foundation.

1925 JOHN FRANK STEVENS. For great achievements as a civil engineer, particularly in planning and organizing for the construction of the Panama Canal; as a builder of railroads, and as administrator of the Chinese Eastern and Siberian Railways.

1926 EDWARD DEAN ADAMS (A'10). For great achievements as engineer, financier, scientist, whose vision, courage and industry made possible the birth at Niagara Falls of hydroelectric power.

1927 ELMER AMBROSE SPERRY (A'84, M'93, and member for life). For the development of the gyro-compass and the application of the gyroscope to the stabilization of ships and aeroplanes.

1928 JOHN JOSEPH CARTY (A'90, M'03, F'13, HM'29, member for life and past-president). For pioneer achievement in telephone engineering and in the development of scientific research in the telephone art.

1929 HERBERT HOOVER (HM'29). As engineer, scholar, organizer of relief to war-stricken peoples, public servant.

1930 RALPH MODJESKI. For notable achievement as an engineer of great bridges combining the principles of strength and beauty.

1931 ADMIRAL DAVID WATSON TAYLOR. For outstanding achievement in marine architecture, for revolutionary results of persistent research in hull design, for improvement in many types of warships and for distinguished service as chief constructor of the United States Navy during the World War.

1932 MICHAEL IDVORSKY PUPIN (A'90, F'15, HM'28, member for life and past-president). Scientist, engineer, author, inventor of the tuning of oscillating circuits and the loading of telephone circuits by inductance coils.

1933 DANIEL COWAN JACKLING. For notable industrial achievement in initiating mass production of copper from low-grade ores, through application of engineering principles.

1934 JOHN RIPLEY FREEMAN. Engineer—preeminent in the fields of hydraulics and water supply, fire insurance economics, and analysis of earthquake effects.

1935 FRANK JULIAN SPRAGUE (A'87, M'97, F'12, HM'32, member for life and past-president). For distinguished service as inventor and engineer through the application and control of electric power in transportation systems.

Roy V. Wright, present chairman of the John Fritz Medal board of award (the board consists of the 4 most recent past presidents of the 4 participating societies) officiated during the ceremonies. He first spoke briefly about the history of the medal and the man for whom it was established, then introduced Dr. Gano Dunn, president, J. G. White Engineering Corporation, and long time friend of the medalist, who outlined briefly the accomplishments for which Doctor Sprague is most widely known. His address follows:

Doctor Sprague's Career Sketched by Doctor Dunn

"On account of the death of Frank Julian Sprague after the award to him of the great distinction of the John Fritz Medal, but before its presentation, it is with a sense of deep sadness accompanied by a sense of pride, that I undertake the honor of setting forth the grounds on which the award of the medal was made.

"A mere enumeration of Sprague's accomplishments would be impressive, but when they are read in the light of the state of the electrical art at the time each accomplishment was produced, admiration for his results rises to the point of transcendent respect and recognition of genius.

"He stands out in the minds of engineers and of the informed public, as having given to the world the early constant speed motor, the electric railway, the electric elevator, and particularly the multiple unit system of train operation; in use all over the world. Each of these generic items, is, however, but the chapter heading covering hundreds of other auxiliary items playing into it which the world calls inventions also, but which Sprague used to delight in calling "solutions."

"Since the remarkable demonstration of respect and appreciation in this hall 3 years ago, on the occasion of his 75th birthday, when his work was recognized by the tributes of a distinguished audience who were present, as well as by large numbers who were absent, claims have been made in various quarters that Sprague was not the first in the conception of several of the items that have been attributed to him.

Roy V. Wright officiating over the John Fritz Medal ceremony

"Such claims always arise in the wake of great achievement. They have arisen against the names of James Watt, Robert Fulton, Elias Howe, Alexander Graham Bell, Thomas A. Edison, and others.

"Without conceding at this time the validity of any of these claims, although some of them undoubtedly have merit, attention should be called to the fact that what the world honors in the industrial field, as distinguished from the field of pure science, are the gifts it has received through accomplishment rather than the gifts of fractional and undeveloped conception.

"It is recognized that Shakespeare borrowed many of his plots, but the authors of those plots cannot successfully claim to have given us Shakespeare.

"With all this in mind, Sprague's fame in connection with the constant speed motor, the electric railway, the electric elevator, and multiple unit train operation, is secure.

"There are those here who will remember that in the early days of electrical distribution, the emphasis was upon lighting, accomplished by a system in which a direct current that was constant actuated arc lamps in series with each other. Hundreds of inventions were made to produce motors that would successfully adapt themselves to these systems of constant current supply and at the same time run at a constant speed. As a class these motors were fearfully and wonderfully made, and as a class they were unsuccessful, so that while electric lighting was growing on all sides, there was practically no electric power. Alternating current systems of distribution had not yet arrived and the Tesla motor was unborn.

"Edison's great conception of the constant potential multiple arc system of distribution as distinguished from the existent constant current series system, was a conception so great that it has practically superseded every other system of distribution today. He worked it out to enable the subdivision of consumption into small units, controllable without affecting other units in the system. It is probable that Edison realized also that in solving thus the problem of the distribution of electric lighting, with primarily the incandescent lamp in view, he was also solving the problem of the distribution of electric power.

"Following Sprague's resignation from the United States Navy in 1883, he was Edison's assistant for about a year. Impressed with the power possibilities of the constant potential system of distribution, which Edison had introduced into New York in the Pearl Street Station in 1882, Sprague set himself with brilliant success to developing a motor that would run at constant speed on constant potential systems. He not only produced the upright type of motor among others for this purpose, but introduced the differential series winding to compensate for a rather high internal armature resistance, which otherwise would cause a drop in speed. The net result of all this was that Sprague motors began to be used everywhere on Edison circuits and were finally officially endorsed by the Edison companies on account of their simplicity, effectiveness and the growing use of electric current which they began to bring about.

"For the manufacture of these motors, and with an eye on the application of electric power to street cars, Sprague, in 1884, organized the Sprague Electric Railway and Motor Company.

"But it was not until 1887, that he astonished the technical world by taking a contract to build and equip in 90 days, an electric street railway in Richmond, Va. The problems that were successfully and brilliantly solved in the design and construction of the Richmond road and its equipment, and the methods by which Sprague met emergency after emergency arising out of unexpected failures of details and out of unforeseen requirements, so impressed the technical world as well as the public, that they founded the title by which he was called: "The Father of Electric Traction."

"So spectacular was the accomplishment of Sprague in the Richmond road, notwithstanding many imperfections that were later removed, that within 2 years, his company had closed contracts for 110 more roads, and in 1890, it was merged with the Edison General Electric Company, which later became the General Electric Company.

"With the taking over of his electric railway work by the Edison General Electric Company, Sprague, like Alexander, sighed for more worlds to conquer, and turned his attention to the elevator field, which was becoming increasingly important with the increasing height of buildings, made possible through fundamental developments in the art of steel making. Sprague regarded this as turning his attention from the field of horizontal to the field of vertical transportation.

"Hydraulic elevators had reached an unparalleled perfection for ordinary heights. Steam elevators were considerably used, and there was some use of electric elevators in the form of slow moving second class equipment, but all of these failed adequately to meet the demands for higher speeds and longer runs called for by increasing skyscraper construction.

"Sprague saw from his electric railway experience how increased speeds had markedly increased line capacity and earnings, and with this experience in horizontal transportation before him, he foresaw that similarly increasing the capacity of elevator shaftways would not only save the time of passengers in transit but would also favorably react on the earnings of tall buildings, of which the height was already beginning to be limited by the greater and greater proportions of total floor space necessarily subtracted by the shaftways of slow running elevators.

"In conjunction with Charles R. Pratt, he developed the Sprague-Pratt Electric Elevator, and in 1892, organized for the purpose of manufacturing this and other advanced types of electric elevators, and controlling mechanisms, the Sprague Electric Elevator Company, which company built nearly 600 elevators when it was absorbed by its then greatest competitor, the Otis Elevator Company.

"In 1926 Sprague made the remarkable proposal of operating 2 elevators in the same shaft, the lower one for local and the one above it for express service, rendered possible by the perfection of the controlling devices which he had invented.

"The merit of Sprague's elevators was fully as much, if not more in the inventions devised for their control, as it was in the inventions devised for their mechanical operation. High speed demanded not only freedom from oscillation on arrival at a floor, but ability to control that arrival with precision and smoothness.

"Electrical devices in the hands of Sprague became ideally adapted to such control to an extent that led to the development of high speeds with safety and comfort and to the working out of the unattended automatic or so-called push button type of elevator now so much in use in private houses, apartment houses, and other locations, where the traffic is not dense enough to require an operator.

"While developing the high speed and the automatic electric elevators in which the control of the hoisting machinery was effected indirectly by small pilot motors and other control devices located near this machinery, these pilot motors in turn being operated by signaling circuits from the car, Sprague saw that through the principle of pilot operation and signal circuit control, he had discovered not only a means of effectuating more rapid, more precise, and more flexible control of a single car, but also a means of controlling cars in groups in all sorts of predetermined and un-predetermined combinations with each other.

"The demand for group control did not exist at that time in the elevator field, but Sprague with the unerring insight of a great inventor, saw what could be accomplished with such group control if applied to the railroad field, where the idea of concentrating the whole tractive power of a train in a locomotive at its head held sway.

Doctor Dunn sketches Doctor Sprague's career

"Trolley cars had been accustomed to haul trailers but that is about as far as making up a train of trolley cars had got, because of the impossibility of coördinating the tractive effort of more than one power car in a train.

"In 1895 Sprague conceived his multiple unit system for the operation of trains of trolley cars and about 1897 applied it to the operation of the Southside Elevated Railroad in Chicago. His multiple unit system abolished the customary locomotive at the head of a train and distributed its power elements along the train without reducing the tractive effort which the train as a whole could exert upon the rails in starting. As a matter of fact, the tractive effort was not only not reduced but greatly increased. By this means so great an increase in acceleration was made possible, that the limit was no longer the point at which the wheels of a locomotive would slip, but the point at which passengers would be made uncomfortable or, if standing, be thrown to the floor by the rapidity with which the train got under way.

"This increased acceleration brought about by the Sprague multiple unit system so greatly increased average speed that under certain conditions it nearly doubled the capacity of a road without increasing at all the maximum speed at which its trains must run. These accelerations resulting in vastly increased line capacity, were not the only advantages deriving from Sprague's great invention. Trains could be made up at will of any number of units, large or small, and could be broken up at junction points and combined at other points without reference to presence or absence of locomotive equipment.

"It has not been attempted to cite all of Sprague's work, which would be impossible on this occasion, but it is necessary to point out that the great accomplishments that have been enumerated have in every case

(Continued on page 245)

With the Inquiring Photographer

at the 1935 Winter Convention: the Edison and John Fritz Medal Presentation Ceremony and the Annual Dinner-Dance.

(1) Director H. R. Woodrow pays careful attention to a good story

(2) Past Presidents Arthur E. Kennelly (left) and Bancroft Gherardi awaiting the medal presentation ceremony

(3) National Secretary and Mrs. H. H. Henline in conversation with W. K. Vanderpoel (right) who was a member of the Institute Board of Managers 1923–27

(4) George Sutherland (right), chairman of the committee that staged a sell-out smoker at the Casino de Paree, learns from D. H. Moore and Lindsey Ellms (left) that the customers all survived

(5) F. M. Felker (left), executive secretary of American Engineering Council evidently impressed General Robert I. Rees, S.P.E.E. representative on the executive committee of the Engineers Council for Professional Development

(6) D. M. Simmons, chairman of the Institute's power transmission and distribution committee apparently did not put his story across so well with Mrs. George Sutherland

(7) C. O. Bickelhaupt, chairman of the Institute's publication committee interests Mrs. H. P. Charlesworth; Past President Charlesworth looks on

(8) Past President Bancroft Gherardi discussing a point of mutual interest with Mrs. K. S. McHugh while the inevitable chicken gets cold

(9) J. W. Barker, chairman of the Institute's committee on the production and application of light, commands the attention of Mrs. Robert I. Rees (left) and Mrs. Walter I. Slichter

(10) J. K. Sprague (son of the late Dr. Frank J. Sprague, 1935 John Fritz Medallist), Past President J. B. Whitehead, and Treasurer Walter I. Slichter (right) await the medal presentation ceremony; George T. Seabury, national secretary of the American Society of Civil Engineers, may be seen between Doctor Whitehead and Mr. Slichter

(11) J. O'R. Coleman, engineer for the Edison Electric Institute and member of the Institute's communication committee, apparently putting on a fire-eating stunt while H. R. Huntley (extreme left) observes, perhaps in awe

(12) Chairman C. S. Purnell (seated) of the dinner-dance committee checking notes between courses with Chairman Sutherland of the smoker committee

(13) Vice President Royal W. Sorensen of Pasadena, Calif., through whose consistent long-time efforts the 1936 summer convention will go to Los Angeles, evidently was startled to find himself in the camera's eye

(14) Vice President F. O. McMillan of Corvallis, Oregon (right), might have been discussing E.C.P.D. matters with General Rees across Mrs. Henline's dessert

(15) Edward B. Meyer (left), president-designate, present vice president, and many-time chairman of important Institute committees, seems to be not too deeply impressed by A. H. Kehoe's story

Photos by Harold J. Torgeson

spread their influence vastly beyond their own fields.

"The constant speed motor favorably reacted upon the introduction of electric power into factories, with all that that has meant; the electric street railway, now in eclipse, owing to the development of free wheeled rubber tired vehicles, was the progenitor of the present suburban and subway electric train; the high speed electric elevator with its competent indirect control, has reacted upon the building industry and the development of great cities.

"The creation of the multiple unit system of train operation and control has brought about the daily transportation of millions, with speed and safety, which, without it, would be impossible.

"Sprague had a dynamic personality, characterized by an insatiable passion for invention. He fired the enthusiasms and the ambitions of unnumbered others to great achievement in the electrical and related fields. His qualities were the admiration and delight of hosts of friends, who will see in the discernment of the John Fritz Medal board of award which selected Frank Julian Sprague for the medal, a complete vindication of the purpose of the founders of the medal and an additional tribute of honor to the name of John Fritz as well as to the name and fame of Frank Julian Sprague."

Response of Robert C. Sprague

Following Doctor Dunn's address, Mr. Wright presented the medal to Robert C. Sprague, son of the late Dr. Frank J. Sprague, who responded as follows:

"I am here tonight as a representative of my father's family to receive the award of the John Fritz medal to my father, Mr. Frank Sprague. I only regret that he is not here himself to acknowledge the award and to hear the many gratifying things which have been said about him and his work by the distinguished speaker who has paid tribute to him here tonight.

"Although destiny and his life span prevented his being here, you will be glad to know, I am sure, that he received notice of the award and was fully cognizant of its significance before he died.

"I was with him for a short time on Monday night, October 22nd, when my mother read to him the notice of award from Mr. Tally, chairman, at that time, of the award committee, and dated October 19th. His mind was very active then, as it was until the end, and he spoke of his great pleasure at this further recognition of his work by a committee representing the 4 great national engineering societies.

"I was fortunate as a small boy to have been present when my father was awarded the Edison Medal in 1911, and going over some of his papers recently, I was impressed with many parts of his acceptance of that award. Many of his thoughts at that time are equally applicable on this occasion, so I think it would be proper for me to read excerpts, which, I am sure, express what he would like to convey to you tonight.

"His acknowledgment started: 'I would indeed be strangely constituted if I were not deeply sensitive to and profoundly moved by so great an honor as this present award. In truth, I am glad to be thus honored and to pretend otherwise would be to violate one of the essential tenets of our profession, which above all, teaches us to be exact in statement and that I do with a very full heart.

"'I am not, however, unmindful of a first-hand knowledge of my own shortcomings and I know how unwarranted it would be to assume this compliment is limited to a personal recognition of the work which, as an engineer, it has come to my hand to do, and the possibility of which is so largely a matter of professional training, ripeness of the times, and existence of opportunities.

"'The committee, it is true, has been good enough to individualize me in this happy manner, but what would have been the result if the loyal support, vital at critical times, had not been forthcoming? Rarely, is there an industrial development on any large scale except by the combined effort of many people. I would, therefore, be indeed remiss if I did not thank you not alone for myself, but also on behalf of my beloved alma mater, the United States Naval Academy, and for those who in business and professional ways when discouragements crowded thick and fast, as well as when hopes ran high, were an ever-present help.'

R. C. Sprague responds for the Sprague family

"In referring to Mr. Edison at that time, and dad's comments would be equally applicable in referring to Mr. John Fritz on this occasion, he went on to say, 'It is the fortune of but few for whom training, inclination, opportunity and fortuitous circumstances combined to give the privilege of blazing the path of new industries, but in any event, one can be glad to be a member of that profession which, above all others, forms the advance guard of civilization and typifies the restless creative energy of our age and which is, of necessity, imbued with the romantic spirit of adventure.'

"Referring again to his beloved profession, he said, 'The profession of engineering is not only an honorable one, but according to biblical history, it is one of the oldest. An engineer is trained not only to ask questions and find weaknesses, but to correct them, to build up, not to pull down, to create, not to destroy. His training is along the lines of exactness and honesty and investigation and conclusion, and designing and construction constitute the very foundation of his professional ethics.'

"In conclusion, he said, 'So, too, in our profession, there are surely new paths to blaze, fresh histories to make, unending worlds to conquer. The heritage of greatest value which we can leave to those who bear our names is that of high aims realized and creative work well done.'"

Student Convention Held at Harvard University

The first New England student convention including all the A.I.E.E. student Branches in the North Eastern District, number 1, was held somewhat over a year ago (December 1933) under the sponsorship of the Massachusetts Institute of Technology. This convention was so successful that it was decided to make it an annual affair. As a result, the second student convention of this District was held December 15, 1934, at Cambridge, Mass., under the sponsorship of Harvard University.

The afternoon session began at 2:30 with an address of welcome by Dean Harry E. Clifford of Harvard Engineering School. This was followed by an address "A New Field for Engineering Graduates," by Prof. W. H. Timbie of Massachusetts Institute of Technology and Institute vice president for District number 1. Albert Haberstroh, vice chairman of the Harvard Branch, opened the technical sessions with papers by members of the Branches; these papers were followed by a short discussion. The papers, in order of presentation were as follows:

Ultra High Frequency Measurements, by T. F. Hammett, Worcester Polytechnic Institute.

A Study of 3-Phase Open-Y Connections of Transformers, by H. B. Pancher, Brown University.

A High Fidelity Sound System, by R. Applegarth, Massachusetts Institute of Technology.

This Business of Amateur Radio, by R. W. Bradley, Tufts College.

Measurement of Losses in Oscillator Tubes by Thermal Methods, by F. P. Cowan, Harvard University.

After the discussion period, R. T. Gibbs of the Harvard Engineering School described the high voltage laboratory, following his talk by a spectacular demonstration. The students were then divided into 2 large inspection groups. The first group inspected the dynamo, telephone, and rectifier laboratories in Pierce Hall, and the 100,000 volt storage battery in the Cruft laboratory. The second group inspected the communication laboratory and the 100,000 volt battery, both in Cruft laboratory. There were also a few scattered groups headed by special students or instructors. Professor Cassagrande demonstrated some phenomena connected with the soil mechanics laboratory, and Professor J. P. DenHartog conducted experiments in the applied mechanics laboratory.

For dinner, the students were again divided into 2 groups, one-half going to Winthrop House and the other to Adams House. Those present from other colleges were thus given a chance to look over the new Harvard house plan and see it in operation. After dinner, the groups returned to the Cruft laboratory, where Dr. A. A. Noyes gave a lecture and demonstration of experiments on "supersonic phenomena." High frequency sound modulation was compared with high frequency radio modulation. Following the main lecture, Prof. H. R. Mimno demonstrated his new short wave transmitter to a number of interested students.

As reported by R. B. Power, in charge of registration, there were 111 registered at the convention, divided as follows:

Harvard University	26
Massachusetts Institute of Technology	22
Worcester Polytechnic Institute	13
Brown University	16
Northeastern University	12
Tufts College	9
New Hampshire University	5
University of Vermont	4
Yale University	3
Rhode Island State College	1
Total	111

It was agreed that the convention was a decided success from all points of view, including interest and coöperation.

In Memoriam

GEORGE A. HAMILTON

THE death, on January 10, 1935, of George Anson Hamilton, at the age of 91 years, removed from the membership one of the few individuals who had been actively interested in Institute affairs throughout its entire life.

Mr. Hamilton, a Charter Member, one of the first vice presidents (1884–86), and national treasurer 1895–1930, was transferred to the grade of Fellow in 1913, and was elected an Honorary Member in 1933. He was a member of the first editing committee, the committee on permanent quarters, and several other Institute committees.

RESOLVED: That the board of directors of the American Institute of Electrical Engineers hereby expresses, upon behalf of the membership, its keen regret at the death of Mr. Hamilton, and its sincere appreciation of his many contributions to the development of the activities of the Institute, and be it further

RESOLVED: That these resolutions be entered in the minutes and copies be transmitted to members of his family.

—A.I.E.E. Board of Directors, January 21, 1935

Members Warned Against Employment Exploitation

Information considered to be of some general importance to the membership of the Institute has been brought to the attention of headquarters by members of the Institute who have had experiences with some commercial employment "services," or who have had occasion to investigate the operating practices and procedure of such "services." A typical case investigated and recently reported to Institute headquarters is one currently advertising in industrial and trade magazines. These advertisements by statement and inference purport to show a peculiar ability to serve technical and professional men and executives in the higher income brackets.

A personal investigation of this typical agency led to a report that can be summarized as follows:

1. The client is required to pay a substantial advance fee and is required to pay for all postage on all ensuing correspondence or circularization; in short, is required to assume all liability.

2. The agency then prepares a list or lists of names to be circularized; the responsibility for checking and approving these lists resting on the clients. A typical set of lists checked by the reporting investigator gave every indication of having been compiled from obsolete directories, and was full of duplications and other errors.

3. The agency prepares a circular letter mentioning the qualifications of the applicant; the letters investigated were purely circular in form and appearance, with the exception of the addressee's name typed in at the top. In a typical case, no replies other than one or two mere acknowledgments were received, although several hundred letters were mailed out at the expense of the client.

4. A personal visit to the agency's offices indicated that, in spite of high sounding names and impressive stationery, the so-called personal advertising service was nothing but a desk-space proposition carried on as an adjunct to a very ordinary employment bureau.

5. There was every evidence that the methods used were such that the possibility of a client securing employment such as described would be remote even in boom times and practically impossible under any other circumstances.

Members considering the services of commercial employment agencies are urged to be skeptical, and to make a thoroughgoing personal investigation before spending any money. There are no doubt many reputable employment agencies capable of serving professional and technical men, but there are certainly many times that number, who are interested only in providing themselves with dividends. Even in the case of agencies having on file actual employment openings, and consequently able to refer clients to direct correspondence or contact with employers definitely seeking professional services, the question of advance payment should be considered carefully.

Capable and experienced persons long associated with professional personnel placement are strong in the opinion that best results are obtained through a personal contact campaign carried on directly by the individual seeking employment, and that second place goes to a correspondence

campaign likewise carried on directly by the person seeking employment. The person seeking employment is in the best position to know where he could apply himself most effectively, and has available through libraries or usually otherwise can obtain up-to-date trade and commercial directories that will help him in remote localities with which he may be personally unfamiliar.

In an effort to serve those who may be seeking employment, ELECTRICAL ENGINEERING has republished an article "Finding Work" in the news section of the December 1934 and January 1935 issues. This article was prepared by a recognized authority and offers many pertinent suggestions.

E.E. Fellowships in Sweden Offered

A number of travelling fellowships for study in the Scandinavian countries during the academic year 1935–36 will be awarded by The American-Scandinavian Foundation to students of American birth. These fellowships, as in previous years, will carry stipends of $1,000 each. Among these fellowships is the Irving Langmuir fellowship in electrical engineering, for research in electrical engineering in Sweden. Instructors and graduate students in electrical engineering are especially invited to apply for this fellowship, which will be awarded through the usual routine followed by the Foundation.

The jury which makes the final selection for the Foundation will meet in April and nominations must therefore be in the hands of the Foundation on or before March 15, 1935. All requests for information should be addressed to Neilson Abeel, secretary of The American-Scandinavian Foundation, 116 East 64th Street, New York, N. Y.

Prominent Engineering Educator Dies. Palmer C. Ricketts, president and director of Rensselaer Polytechnic Institute, Troy, N. Y., died at Johns Hopkins Hospital, Baltimore, Md., December 10, 1934. Doctor Ricketts was 78 years of age, had been a member of the Rensselaer faculty since his graduation there in 1875, and for the past 42 years has been the active head of the institution. Doctor Ricketts was an honorary member of the American Society of Civil Engineers, a member of The American Society of Mechanical Engineers, and the American Institute of Mining and Metallurgical Engineers, as well as the Institution of Civil Engineers of Great Britain.

J. F. Kelly, Association Executive, Dies. John Frederick Kelly, managing director of the Association of Iron and Steel Electrical Engineers, and editor of the *Iron and Steel Engineer*, died November 16, 1934. Mr. Kelly was one of the best known figures in the iron and steel industry and had long been active in advancing the interests of electrical engineers in this industry, and in encouraging the application of electrical methods. He was born in McKeesport, Pa., November 25, 1880. After being connected with various steel mills in the Pittsburgh district, he became associated with the Westinghouse Electric and Manufacturing Company, where he was employed in the office of the manager of works. In 1909 he left the Westinghouse company to go to the electrical department of the National Tube Company at McKeesport. In 1917 he was elected national secretary of the Association of Iron and Steel Electrical Engineers, leaving the National Tube Company in 1918 to establish the A.I. and S.E.E. offices in Pittsburgh. He was later made managing director of the association and editor of the *Iron and Steel Engineer*.

Faraday Medal Awarded Dr. F. B. Jewett

The council of the Institution of Electrical Engineers (of Great Britain) unanimously awarded its Faraday Medal for 1935 to Dr. Frank B. Jewett (A'03, M'10, F'12, and past-president), vice president of the American Telephone and Telegraph Company, and president of the Bell Telephone Laboratories, Inc., New York, N. Y. The action was taken at a meeting of the council on January 24, 1935.

The Faraday Medal of the Institution of Electrical Engineers is a bronze medal awarded not more frequently than once a year either for notable scientific or industrial achievement in electrical engineering, or for conspicuous services rendered to the advancement of electrical science, without restriction as regards nationality, country of residence, or membership of the Institution.

The first Faraday Medal was awarded to Oliver Heaviside (HM'18) in 1922. Other members of the A.I.E.E. who have received the Faraday Medal are S. Z. de Ferranti (A'03, M'06, HM'12) 1924; Elihu Thomson (A'84, M'91, F'13, HM'28, member for life and past president) 1927; Guido Semenza (A'02) 1929; Charles H. Merz (A'95, M'10, F'13 and member for life) 1931; and Dr. F. B. Jewett (A'03, M'10, F'12, and past president). Of these, Doctor Thomson, Mr. Merz, and Doctor Jewett are now living.

A brief biographical sketch of Doctor Jewett's career appears in ELECTRICAL ENGINEERING for January 1935, page 140, in connection with his election to honorary membership in the Institute of Electrical Engineers of Japan (the "Denki-Gakkwai"). Doctor Jewett joined the Institution of Electrical Engineers in 1922 with the grade of "member."

Oklahoma City District Meeting Plans Under Way

The annual meeting of the Institute's South West District (number 7) will be held at Oklahoma City, Okla., on April 24–26, 1935, with headquarters at the Skirvin Hotel. Four technical sessions are planned for this meeting in addition to the Student session. Papers will be presented by several engineers of national reputation; these papers will deal with various phases of electrical distribution, telephone communication, insulation coördination, and engineering education.

Those in attendance at the sessions will hear presented the facts and problems in power distribution system regulation and investment, and in turn will hear discussed modern means for improved voltage regulation at minimum investment per kilowatt-hour. Modern trends in metering design and application will be covered. The questions as to why definite insulation levels have been recommended for transformer insulation, and why various types of insulation and impulse levels have been utilized for transmission lines will be answered. Results obtained from applying these insulation levels to transmission lines will be reviewed.

Those attending the sessions also will hear numerous features of telephone communication technique and application discussed, including details of telephone protective devices and the application of telephone equipment to the power industry. A general discussion of modern trends in engineering education and the colleges' adaptation to these trends also will be presented.

The program also includes an inspection trip and a banquet. A special entertainment is being arranged by the committee for the ladies at the Oklahoma City Golf and Country Club.

Oklahoma City is situated almost at the center of the area composing District 7 of

1935 Pacific Coast Convention Transferred to Seattle

Instead of being held in Los Angeles, Calif., as previously announced, the Institute's 23d Pacific Coast convention will be held in Seattle, Wash., under the sponsorship of the Institute's Seattle Section, according to telegraphic information received just as this issue was going to press. According to Vice Presidents R. W. Sorensen of Pasadena, Calif., and F. O. McMillan of Corvallis, Ore., the exchange has been effected incident to the fact that the Institute's 51st annual summer convention will be held in Los Angeles or the immediate vicinity in June 1936, and it is expected that the 1936 Pacific Coast convention will be consolidated with it.

the A.I.E.E., and is favored with splendid transportation facilities radiating in all directions. The city has a population of approximately 200,000; it entertains over 350 conventions each year and possesses excellent sports and amusement facilities, including 12 all-year golf courses.

Complete details of the arrangements for this district meeting are scheduled to appear in the March 1935 issue of ELECTRICAL ENGINEERING. The general committee in charge of the meeting consists of the following:

F. J. Meyer, vice president, District 7; C. W. Mier, secretary, District 7; A. C. Bookout, chairman, entertainment and arrangements committee; R. F. Danner, chairman, papers committee; W. A. Kitchen, chairman, attendance and publicity committee; A. Naeter, chairman, Oklahoma City Section; C. E. Bathe, secretary, Oklahoma City Section; E. B. Jennings, chairman, reception and registration committee; and F. D. Freeman, chairman, transportation and trips committee.

Joint Meeting Held by Alabama Branch and Section

The University of Alabama Branch and the Alabama Section of the A.I.E.E. held a joint meeting on the University's homecoming day, November 10, 1934. The object of this meeting, at which social and entertainment features rather than technical features were stressed, was to attempt to repay the courtesies and interest shown in this Branch in the past by the Alabama Section of the Institute. As a secondary objective, it was desired that the members of the Alabama Section become more thoroughly acquainted with the members of the student Branch and their activities.

The following members of the Alabama Section were present:

H. J. Scholz, chairman
W. D. Ketchum, member of the student activities committee
W. W. Ballew, past chairman
H. M. Woodward, secretary
B. B. Bessesen, member of the Alabama Section and superintendent of power of T.V.A.

Others attending were E. B. Thornton, illuminating engineer, D. D. Wendell, district engineer of the Alabama Power Company, and Prof. L. H. Fox of Mississippi State College.

The program for the day included the review of the R.O.T.C. in honor of Major-General Moseley, commander of the Fourth Corps Area; joint meeting of the A.I.E.E. in the engineering library; the football game between the University of Alabama and Clemson College; and the Athletic Club dance.

While the men inspected the electrical engineering laboratories, the women guests were conducted on a sightseeing tour of the campus and buildings by Mrs. Fred Maxwell, wife of the student counselor.

At the joint meeting, Mr. Scholz and Mr. Bessesen made 2 interesting talks. Mr. Scholz spoke on the benefits of the A.I.E.E. organization, both in college and in the profession; he emphasized the need for continuation of contact with the Institute after graduation. Mr. Bessesen gave a vital talk in connection with the choice of engineering as a profession. It was felt that the meeting was a success in every respect, affording not only valuable contact, but assisting the student to close the mental gap between college work and later professional work.

A.S.M.E. Names New National Secretary

The council of The American Society of Mechanical Engineers has appointed Clarence E. Davies national secretary of that Society. He succeeds the late Dr. Calvin W. Rice (A'97, F'12) who died October 2, 1934. (A biographical sketch of Doctor Rice's career was given in ELECTRICAL ENGINEERING for November 1934, page 1557–8.)

The new national secretary, Mr. Davies, has served on the staff of the A.S.M.E. for nearly 15 years, and his natural ability coupled with the training which he has received during this period, admirably fit him for his new position. He graduated from Rensselaer Polytechnic Institute, Troy, N. Y., in 1914, and then entered the production department of the Remington Typewriter Company. During the war he served in the ordnance department of the U. S. Army and was assigned to the Frankford Arsenal on the manufacture of artillery, ammunition, and fuses. He now holds the rank of lieutenant colonel in the Ordnance Reserve Corps and participates actively in the organization and operation of the New York Ordnance District.

C. E. DAVIES

Colonel Davies first became connected with the headquarters staff of the A.S.M.E. in 1920, when he was appointed associate editor, and has continued without interruption since that date. In 1921 he was appointed managing editor and assistant secretary, and in 1931 was appointed executive secretary, in charge of the administration of the headquarters office. With his recent appointment as national secretary, the offices of secretary and executive secretary are combined.

Colonel Davies has been active in the Engineers' Council for Professional Development, and in 1934 was made its first secretary. He is honorary corresponding secretary for North America of the Newcomen Society (England) for the study of the history of engineers.

Columbia University Offers E. E. Scholarships

The governing bodies of Columbia University have placed at the disposal of the A.I.E.E. each year, a scholarship in electrical engineering in the school of engineering of Columbia University for each class. The scholarship pays $350 toward the annual tuition fees which vary from $340 to $360, according to the details of the course selected. Reappointment of the student to the scholarship for the completion of his course is conditioned upon the maintenance of a good standing in his work.

To be eligible for the scholarship, the candidate recommended will have to meet the regular admission requirements, in regard to which full information will be sent without charge upon application to the secretary of the University or to the national secretary of the Institute, 33 West 39th St., New York, N. Y.

In a letter addressed to the national secretary of the Institute, an applicant for this scholarship should set forth his qualifications (age, place of birth, education, reference to any other activities, such as athletics or working way through college, references, and photograph). A committee composed of W. I. Slichter, *chairman*, Francis Blossom, and H. C. Carpenter will consider the applications and will notify the authorities of Columbia University of their selection of a candidate. The last day for filing of applications for the year 1935–36 will be June 1, 1935.

The course at the Columbia school of engineering is a graduate course which may be either elective leading to the degree of master of science or prescribed leading to the degree of electrical engineer. For the former, requirement for admission is the completion of a 4 year course in electrical engineering as evidenced by a bachelor's degree from an approved institution. For the professional degree, the requirements are more specific as to course content and include a considerable proficiency in mathematics, physics, and chemistry, and some knowledge of the humanities, as well as the usual undergraduate technical courses. The candidate is admitted on the basis of his previous collegiate record without undergoing special examinations. Other qualifications being equal, members of the student Branches of the A.I.E.E. will be given preference.

The purpose of this advanced course is to produce a high type of engineer, trained in the humanities as well as in the fundamentals of his profession. It is hoped that Enrolled Students and others qualified will show a keen interest in this scholarship.

F. L. Stuart, Prominent Railroad Engineer, Dies. Francis Lee Stuart, former chief engineer of the Erie, and Baltimore and Ohio railroads, and past president of the American Society of Civil Engineers, died at Essex Fells, N. H., January 15, 1935. Mr. Stuart, born at Camden, S. C. in 1866, became a rodman on the B. & O. Railroad immediately upon graduation from college. Subsequently he progressed through many phases of railroad work. In 1897 Mr. Stuart was in charge of hydrographic sur-

veys for the Nicaragua Canal Commission; and later, as division engineer for the Isthmian Canal Commission he was on canal work until 1899 when he returned to the B.&O. In 1905 he became chief engineer of the Erie Railroad, and in 1910 chief engineer of the B. & O. Since 1915, he had been in private practice, except during the war, when he served on the War Industries Board and with the U. S. Railroad administration.

Engineers' Liabilities Under the Securities Act

Under the Securities Act of 1933 as amended by Title II of the Securities Exchange Act of 1934, grave responsibility is placed on the engineer in connection with reports that may be made concerning projects against which securities are to be issued, and severe penalties are provided for dereliction of duty. Thus, every engineer who undertakes to supply any portion of the facts upon which an issue of securities may be based, should realize fully the responsibility that he assumes thereby under the Securities Act and the nature of the penalty to which he subjects himself for inaccurate, incomplete, or unwarranted statements.

In the January 1935 issue of *Civil Engineering*, the American Society of Civil Engineers published a "Digest of the Securities Act of 1933 as Affecting Engineers" and "Comment on Act as Applied to Engineers" prepared by W. W. Colpitts, member of that society and consulting engineer of New York, N. Y. The society has announced the availability of 14-page 6 x 9 inch pamphlet reprints of the article at A.S.C.E. headquarters, 29 West 39th Street, New York, N. Y., at 25¢ per single copy, or at 15¢ per copy in lots of 100.

E.C.P.D. Reports Substantial Progress During 1934

ENGINEERS' Council for Professional Development, which was founded in 1932 as an agency of the united engineering profession to enhance the status of the engineer, has completed the second year of its work. In entering upon its third year various phases of its program are being carried on with renewed activity.

Particularly significant at this time to members of the Institute is the approval given by the Institute's board of directors in a resolution adopted January 21, 1935, giving approval to the plan of accrediting engineering schools proposed by the E.C.P.D. committee on engineering schools. This resolution is as follows:

BE IT RESOLVED

First: That this board hereby consents to the plan of accrediting engineering schools proposed by E.C.P.D. in its communication of November 19, 1934.

Second: That it is the desire and hope of this board that a simpler and less costly plan of accrediting engineering schools may be found possible after trial of and experience with the proposed plan.

Third: That a copy of this resolution be transmitted to E.C.P.D. and to each of this Institute's representatives thereon.

The procedure for developing a list of accredited schools by this committee has advanced through the experimental stage, and it is expected that early in 1935 active steps will be taken to carry on this accrediting.

In addition to the Institute, the following societies have approved the E.C.P.D. as the accrediting agency for engineering schools: The American Society of Mechanical Engineers, American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, Society for the Promotion of Engineering Education, and the National Council of State Boards of Engineering Examiners. Special arrangements for accrediting curricula in chemical engineering have been arranged with the Institute of Chemical Engineers.

The work of the committee during the past year falls into 2 general divisions: (1) The revision of the questionnaire to be used in the accrediting program; and (2) the study and recommendation of a method of procedure and form of organization for carrying out the actual work of such accrediting. The plan recommended is essentially as follows:

1. The committee on engineering schools shall be the operating organization in the accrediting process.
2. The inspection of the schools shall be performed by committees of competent individuals, designated as "delegatory committees" representing and nominated by the committee on engineering schools.
3. The names of those so nominated shall be submitted to the constituent societies for their approval of the persons who represent their particular field of engineering.
4. The schools shall be inspected on a regional basis, the country being divided into approximately 7 regions. For each region the delegatory committee shall consist of 5 members and 3 alternates living in or near the region. At least one member of each delegatory committee shall be an engineer not on the staff of an engineering school.

The program of actually doing the accrediting involves 2 procedures, as follows:

1. The filling out by officers of the school of a questionnaire covering factual information on the curricula to be accredited, and on the school and faculty involved.
2. An inspection by the delegatory committee.

The delegatory committee will report to the committee on engineering schools which in turn will report to the council of the E.C.P.D., whose action shall be final. The expense of visits of inspection will be met by standardized charges against the schools whose curricula are involved.

ACTIVITIES OF THE 3 OTHER COMMITTEES

Two phases of the work of the E.C.P.D. will require the coöperation and enthusiasm of engineers throughout the country. The first of these phases is that dealing with the selection and guidance of the young men in a secondary school who are interested in entering engineering school and who wish to follow an engineering career. The sections of the engineering societies of the country are being requested to organize local committees and to make contact with the authorities in the secondary schools so that the advice and guidance of the engineers in the community will be made available to aid young men who wish to enter the engineering field. The procedures for this work are being developed by the committee on student selection and guidance.

The second phase of the program in which engineers of the country are concerned is that dealing with the stimulation and development of the younger engineer to obtain the standing of the full-fledged engineer. This work is being carried on by the committee on professional training. This committee has developed a pamphlet of suggestions for junior engineers which may be secured at 10 cents per copy from the E.C.P.D., 29 West 39th Street, New York, N. Y. This pamphlet contains a scheme of self-appraisal and a reading list for junior engineers which includes selected titles on natural science, philosophy, economics, sociology, psychology, business and industrial management, literature, history, biography, travel, and fine arts. (Sections of this list are appearing whenever space permits in the news section of ELECTRICAL ENGINEERING, starting with the December 1934 issue.)

The committee on professional recognition is at work correlating the various grades of membership with the requirements for licensing of engineers, and it is expected that during the coming year there will be developed a plan which will simplify considerably the detail work of this problem.

OFFICERS, REPRESENTATIVES, AND COMMITTEE MEMBERS

At the second annual meeting of the E.C.P.D. held in the Engineering Societies Building, New York, N. Y., October 23, 1934, the chairman of the E.C.P.D. and chairmen of the 4 standing committees were reëlected. At this meeting, an information committee was established under the chairmanship of H. C. Parmelee, vice president of the McGraw-Hill Publication Company, New York, N. Y. Officers of the E.C.P.D., representatives of the participating societies, and the members of the standing committees are as follows:

Executive Committee

DR. C. F. HIRSHFELD (A'05), *chairman*, chief research engineer, Detroit (Mich.) Edison Company, Detroit.

G. T. SEABURY, *secretary*, secretary, A.S.C.E., New York, N. Y.

J. VIPOND DAVIES, (A.S.C.E.), consulting engineer, New York, N. Y.

DR. F. M. BECKET (A.I.M.E.), vice president, Electro Metallurgical Company, New York, N. Y.

DR. W. B. WICKENDEN (A'07, M'13) (A.S.M.E.), president, Case School of Applied Science, Cleveland, Ohio.

DR. C. F. SCOTT (A'92, M'93, F'25, HM'29, member for life and past-president) (A.I.E.E.), professor of electrical engineering emeritus, Sheffield Scientific School, Yale University, New Haven, Conn.

DR. H. C. PARMELEE (A.I.Ch.E.), vice president, McGraw-Hill Publishing Company, New York, N. Y.

GEN. R. I. REES (S.P.E.E.), assistant vice president, American Telephone and Telegraph Company, New York, N. Y.

DR. D. B. STEINMAN (N.C.S.B.E.E.), president, National Council of State Boards of Engineering

A Substation Near Oklahoma City, Scene of a Forthcoming A.I.E.E. Meeting

A VIEW of the Reno Street 66 kv switching and regulating substation of the Oklahoma Gas and Electric Company is shown here; it is one of the points which will be inspected by those attending the A.I.E.E. South West District meeting in Oklahoma City, April 24–26, 1935. This substation is located just east of the city and adjacent to the Oklahoma City oil fields. A 60,000 kva, 10 per cent buck and boost voltage regulator, equipped for automatic control, is located in the station.

Examiners, and consulting engineer, New York, N. Y.

Representatives of the A.S.C.E.

J. Vipond Davies (1935), consulting engineer, New York, N. Y.
H. P. Eddy (1936), Metcalf and Eddy, Boston, Mass.
J. P. H. Perry (1937), vice president, Turner Construction Company, New York, N. Y.

Representatives of the A.I.M.E.

D. F. Irvin (1935), Oliver United Filters, Inc., New York, N. Y.
B. F. Tillson (1936), consulting engineer, Montclair, N. J.
Dr. F. M. Becket (1937), vice president, Electro Metallurgical Company, New York, N. Y.

Representatives of the A.S.M.E.

Dr. W. E. Wickenden (A'07, M'13) (1935), president, Case School of Applied Science, Cleveland, Ohio.
Dr. C. F. Hirshfeld (A'05) (1936), chief research engineer, Detroit (Mich.) Edison Company.
To be appointed (1937).

Representatives of the A.I.E.E.

Dr. C. F. Scott (A'92, M'93, F'25, HM'29, member for life and past-president) professor of electrical engineering emeritus, Sheffield Scientific School, Yale University, New Haven, Conn.
L. W. W. Morrow (A'15, F'25 and director) (1936), editor, *Electrical World*, New York, N. Y.
C. O. Bickelhaupt (M'22, F'28) (1937), assistant vice president, American Telephone and Telegraph Company, New York, N. Y.

Representatives of the S.P.E.E.

Dr. D. C. Jackson (A'87, M'90, F'12, member for life, and past-president) (1935), professor of electrical engineering, Massachusetts Institute of Technology, Cambridge.
Gen. R. I. Rees (1936), assistant vice president, American Telephone and Telegraph Company, New York, N. Y.
H. P. Hammond (1937), professor of civil engineering, Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

Representatives of the A.I.Ch.E.

J. M. Weiss (1935), president, Weiss and Downs, New York, N. Y.
Dr. H. C. Parmelee (1936), vice president, McGraw-Hill Publishing Company, New York, N. Y.
A. B. Newman (1937), professor of chemical engineering, Cooper Union, New York, N. Y.

Representatives of the N.C.S.B.E.E.

T. Keith Legare (1935), secretary, N.C.S.B.E.E., Columbia, S. C.
Dr. D. B. Steinman (1936), consulting engineer, New York, N. Y.
P. H. Daggett (A'08) (1937), dean, college of engineering, Rutgers University, New Brunswick, N. J.

Committee on Student Selection and Guidance

R. L. Sackett (1936), *chairman*, dean of college of engineering, Pennsylvania State College, State College.
O. J. Ferguson (A'05, F'13) (1935), dean, college of engineering, University of Nebraska, Lincoln.
W. B. Plank (1935), professor of mining engineering, Lafayette College, Easton, Pa.
H. N. Davis (1936), president, Stevens Institute of Technology, Hoboken, N. J.
T. Keith Legare (1936), secretary, N.C.S.B.E.E., Columbia, S. C.
R. H. Jacobs (1937), Englewood, N. J.
V. M. Palmer (1937), industrial economy engineer, Eastman Kodak Company, Rochester, N. Y.

Committee on Professional Training

Gen. R. I. Rees (1936), *chairman*, assistant vice president, American Telephone and Telegraph Company, New York, N. Y.
R. A. Seaton (1935), dean, director of engineering, Kansas State College, Manhattan.
W. B. Updegraff (1935), vice president, Watson Stillman Company, New York, N. Y.
D. S. Kimball (1936), dean, college of engineering, Cornell University, Ithaca, N. Y.
A. D. Smith, Jr. (1936), president, George W. Smith Woodworking Company, Philadelphia, Pa.
A. R. Stevenson (A'20) (1937), engineering general department, General Electric Company, Schenectady, N. Y.
A. B. Newman (1937), professor of chemical engineering, Cooper Union, New York, N. Y.

Committee on Engineering Schools

K. T. Compton (F'31) (1936), *chairman*, Massachusetts Institute of Technology, Cambridge, Mass.
H. A. Curtis (1935), director of research and development, Vacuum Oil Company, Paulsboro, N. J.
A. A. Potter (1935), dean, Purdue University, Lafayette, Ind.
P. H. Daggett (A'08) (1936), dean, college of engineering, Rutgers University, New Brunswick, N. J.
H. P. Hammond (1936), professor of civil engineering, Polytechnic Institute of Brooklyn, Brooklyn, N. Y.
G. M. Butler (1937), dean, college of mines and engineering, director, Arizona Bureau of Mines, University of Arizona, Tucson.
I. C. Crawford (1937), state engineer, public works administration, University of Idaho, Moscow.

Committee on Professional Recognition

C. N. Lauer (1935), *chairman*, president, Philadelphia Gas Works, Pa.
J. P. H. Perry (1935), vice president, Turner Construction Company, New York, N. Y.
J. W. Barker (M'26, F'30) (1936), dean, school of engineering, Columbia University, New York, N. Y.
H. C. Parmelee (1936), vice president, McGraw-Hill Publishing Company, New York, N. Y.
Dr. D. B. Steinman (1936), consulting engineer, New York, N. Y.
Dr. F. M. Becket (1937), vice president, Electro Metallurgical Company, New York, N. Y.
F. L. Bishop (1937), secretary, S.P.E.E., University of Pittsburgh, Pa. (H. S. Rogers, alternate for Professor Bishop.)

Illumination Commission to Meet in Germany

The 1935 session of the International Commission on Illumination will be held in Berlin, July 2–9, according to an announcement by the United States national committee.

The committee, which held its annual meeting in New York, N. Y., November 9, 1934, includes among its membership representatives from the American Institute of Electrical Engineers, the Illuminating Engineering Society, the Optical Society of America, American Physical Society, and the Bureau of Standards. E. C. Crittenden (A'19, M'22) and G. H. Stickney (A'04, F'24) were reelected respectively to the offices of president and secretary-treasurer of the United States committee, as well as being reappointed United States members of the international executive committee, of which body Dr. C. H. Sharp (A'03, F'12, and member for life), vice president, is also a member.

The United States committee reviewed the reports of its representatives on the 27 technical committees and made plans for participation in the Berlin meetings. The United States secretariats manage 3 of these technical committees, namely: factory and school lighting, aircraft lighting, and lighting education. In factory and school lighting, world-wide statistical surveys are being made on conservation of eyesight, special attention being given to the welfare of school children with defective vision. Because of the international character of aerial navigation, important standards for lighted signals are being set while the practices are still flexible. An English-French-German vocabulary of special terms is being established.

The commission is coöperating with the International Committee on Weights and Measures, an organization established under international treaty to which this country is a party. Progress is well under way to the establishment of a primary standard of light and toward the elimination of certain discrepancies in light measurement, which have proved embarrassing. The accurate measurement of the new gaseous tube electric illuminants, which is becoming more and more important is also engaging scientific attention.

These and many other vital questions are scheduled for discussion in Berlin, not the least of which are street and automobile lighting, in connection with which considerable differences of opinion exist in various countries.

The national committee is endeavoring to secure a large attendance of American experts in order to insure an adequate expression of the viewpoints prevailing in this country.

American Engineering Council

A.E.C. Holds Annual Meeting in Washington

THE annual meeting of American Engineering Council was held at the Mayflower Hotel in Washington, D. C., January 10–12, 1935, the main points stressed being the coöperation of engineers in the broad work program being planned by the federal government, and the better coördination of the existing system of engineering societies throughout the country. Membership in American Engineering Council, which may be termed the "Washington Embassy" of engineers, specifically includes 7 national, 4 state, and 11 local engineering societies. Delegates from these and other societies were present at the annual meeting.

Principal features of the annual meeting were sessions at which prominent federal officials described the engineering features of the recovery program; a conference of the secretaries of national, state, and local engineering societies; a "good fellowship" dinner; and the election of officers.

Resolutions Adopted

Action before the executive, public affairs, and other committees of Council led to the adoption of the following resolutions by the assembly:

1. New membership plan. A flat rate plan of nominal dues for local societies with delegates to Council meetings paying their own expenses; division of the country into 9 districts so that a group of societies in any district may jointly send a delegate to meetings at the expense of Council. Delegates from individual societies under such a joint plan may attend at the expense of their own societies. (Adoption of the plan automatically brings into Council the Engineers' Club of Philadelphia and the Engineering Societies of New England which voted previously to join contingent upon the plan's acceptance. At least a dozen other societies have announced their intention of joining.)

2. Division of the public affairs committee into subcommittees, the chairmen of which are to be members of the main body and are to coördinate with similar committees of the engineering societies toward joint action upon common objectives.

3. A public affairs committee to be set up in each state, members to be key men from local sections and societies, to provide a network of organization for deliberation and action upon public matters of moment to the profession.

4. Continue support of the national mapping program.

5. On motion of Robert McCuen, who pointed out that rural electrification work is scattered through several federal agencies, to pool facts in this field under the U. S. Bureau of Agricultural Engineering, assembling data already collected by engineering groups throughout the country.

6. To continue the conference of secretaries from time to time.

7. Flood control committee considered 3 bills before the past Congress, advocating that they be opposed, should they come up again. The bills had to do with development of the Arkansas River and tributaries. Development was considered too large a job to be undertaken as a single project. T.V.A. type of operation was thought too new an experiment to be extended until it has proved itself. The projects require further study as to feasibility, it was stated.

8. Ralph E. Flanders turned over an A.S.M.E. report on machine hour limitation requesting that A.E.C. present it before the forthcoming production hearing of N.R.A.

9. At request of Los Angeles and San Francisco sections of A.S.C.E., to support continued seismological studies of the U.S. Coast and Geodetic Survey to provide basic data regarding earthquakes.

10. Continue efforts to have old canal, at Great Falls on the Potomac near Washington, D. C., be made a memorial to George Washington, the engineer, who laid out the work.

11. Coöperate with other agencies including Purdue Research Foundation, National Bureau for Economic Research, and Board of Surveys and Maps of the Federal Government.

12. (Disfavored) The committee on uniform classification of engineers in telephone directories was discharged with thanks and its report not accepted.

Another important step was the increasing of the 1935 budget of Council $^1/_4$ over last year, thus enabling Council to render more effective service. (The Institute's 1934–35 appropriation for Council is $9,000. compared with an appropriation of $7,625 for 1933–34, and an average appropriation of $16,227 per year for the 5 year period ending September 30, 1933.

Engineering Features of Recovery Program

Because of the importance of the federal program in terms of engineering development, the principal focus of discussions was toward an interchange of ideas and information between the delegates and federal officials in responsible charge of construction, planning, and other engineering functions of the government. In effect, the meeting resulted in a symposium of the recovery program.

The executive committee of American Engineering Council, photographed during the recent annual meeting held in Washington, D. C., January 10–12, 1935. All members of executive committee were present with the exception of Dr. William McClellan who was unable to be present. In the back row are, left to right: C. O. Bickelhaupt, vice president; W. H. Woodbury, vice president; and Col. Paul Doty, vice president. In the front row, left to right are: C. E. Stephens, treasurer; F. M. Felker, executive secretary; J. F. Coleman, president; and A. J. Hammond, vice president

R. E. Flanders, President of the A.S.M.E., led the discussion on the outlook for durable goods industries. Wm. P. Witherow, vice-chairman, Industrial Advisory Board, N.R.A., spoke at a luncheon meeting, January 11. Confusion in N.R.A. objectives has disappeared, he declared. N.R.A. is opposed to restrictive provisions in codes and the Administration is positively in favor of the profit system. Industry, he asserted, favors minimum wage provisions.

R. E. W. Harrison, chief of the machinery division, U. S. Bureau of Foreign and Domestic Commerce, stressed the increasing of efficiency in railroad and merchant marine equipment as one of the steps toward recovery of the durable goods industry. The importance of P.W.A. to this industry, he said, cannot be overemphasized. Modernization of navy yards, he stated, is resulting in the replacement of machinery in use 25 to 30 years while machine efficiency has trebled. Engineers should do more to encourage the development of patents, in Mr. Harrison's opinion. The volume of new patents, he said, has followed the downward trend of the business cycle.

The session on planning and natural resources development was led by G. W. McCuen, president of the American Society of Agricultural Engineers. Dr. H. S. Person, acting director, water resources section, National Resources Board, described the general concept of planning as it has grown under the stimulus of the several new federal agencies entering this field. Engineers may enter the planning movement, he said, as members of planning boards or technical advisory committees to such boards, and may share in the resultant design and construction. He advocated the setting up of functional committees under the professional societies to develop data and technical standards for planning.

Dr. Isador Lubin, director of the U. S. Bureau of Labor Statistics, describing progress on the survey of the engineering profession which his organization is about to make in coöperation with Council and engineering societies throughout the country. More than 100,000 questionnaire schedules will be mailed, he said, urging engineering societies to use all means at their disposal to insure prompt and accurate returns.

The survey and mapping program of the federal government was discussed by Capt. R. S. Patton, director, U. S. Coast and Geodetic Survey, who pointed out that only $^1/_3$ the nation has been mapped and only $^1/_4$ adequately mapped. Captain Patton told of the C.W.A. work under his organization which employed 10,000 men last winter, most of whom were engineers, and has continued on a smaller scale under state relief administrators. The National Resources Board has reported to the president a $117,000,000 plan for completion of the map of the United States in 10 years employing 7,500 to 10,000 men, half of whom will be engineers, Captain Patton said.

The Administration's agricultural policy was explained by M. L. Wilson, Assistant Secretary of Agriculture, who spoke in executive session.

M. S. Eccles, Governor of the Federal Reserve Board, gave a most illuminating talk on the coördination of private and governmental expenditures toward the common objective of recovery.

Led by A. J. Hammond, vice president of A.E.C. and past-president of the A.S.C.E. and the Construction League of America, construction trends were discussed in their federal, private, and relief aspects. Mr. Hammond stated that, with a $^4/_5$ drop in the construction industry during the depression, the construction worker is the real forgotten man.

Col. D. H. Sawyer, director of the Federal Employment Stabilization Office, and former P.W.A. administrator, spoke on private construction, saying that the spirit of salesmanship must be revived in the industry without so much leaning upon the federal government. The creative spirit still exists among engineers, he said, and these are the men who must devise projects, prove their feasibility, and sell them to bankers and industrialists if the construction industry is to move forward once more.

Thomas Hibben, chief engineer of the F.E.R.A., told of the development of work relief along lines of engineering construction with the 2-fold purpose of turning out socially useful work and enabling skilled men to retain their skill and their self-respect. Thousands of engineers have served in supervisory phases of the program.

Clarence McDonough, chief of the engineering division, P.W.A., stressed the importance of the National Resources Board findings in future development; he made no predictions as to the future of P.W.A. while the president's new work program is yet pending.

C. C. Anthony, industrial adviser, Federal Housing Administration, urged engineers to get behind the housing program and to keep posted on its progress. Engineers and architects, he said, can find active work in the modernization program as well as in new construction.

Good Fellowship Dinner

The A.E.C. dinner, preceded by an "hour of good fellowship," proved to be the largest engineering function ever held in Washington. More than 400 attended. Governor Eccles of the Federal Reserve Board was the guest of honor. William McClellan, chairman of Council's finance committee, was toastmaster. The 4 presidents of national engineering societies in attendance and the chairman of the secretaries' conference made short addresses pledging their support to Council's program for the coming year.

The principal speaker was Dr. Harold G. Moulton, president of the Brookings Institution, which research organization has been making a detailed study of economic trends over the past 30 years. Underconsumption rather than overcapacity was indicated by Doctor Moulton's charts. In the boom years, capacity in most industries did not run far ahead of the demand for goods and services.

Conference of Secretaries

A conference of some 40 secretaries of engineering societies, national, state, and local, was held during the first day and a half of the A.E.C. sessions under the chairmanship of C. E. Sabin, secretary of the Cleveland Engineering Society. This was the largest meeting of its kind yet held. The first secretaries' conference met in 1923 with the A.E.C. meeting at Washington of that year and the group assembled in other cities biennially thereafter until 1929, lapsing until this year.

A committee on coördination of engineering organizations was set up by the conference to study the problem of overlapping dues and more effective joint action of the scattered societies. Representatives of 2 national, 1 state, and 2 local societies are on the committee under the chairmanship of O. L. Angevine, secretary of the Rochester Engineering Society. A progress report is to be rendered at the next conference tentatively set for June 1936, in Pittsburgh, Pa., under the chairmanship of K. F. Treshow, secretary of the Engineers Society of Western Pennsylvania.

Opening Thursday morning, January 10, the conference heard an address of welcome by J. F. Coleman, president of A.E.C. Frederick M. Feiker, executive secretary of A.E.C., presented charts as to the distribution of engineers and engineering societies geographically throughout the country, giving strong evidence of the need for coördination. The conference then discussed the problems of society management, topic by topic, exchanging ideas as to successful methods.

A review of relief activities was led by G. T. Seabury, secretary of the A.S.C.E., for national societies, and E. S. Nethercut, secretary of the Western Society of Engineers (Chicago), for local societies. Mr. Seabury described the work in the New York metropolitan area of the Professional Engineers' Committee on Unemployment. The discussion showed how action developing spontaneously among engineering groups throughout the country has resulted in the raising of private funds or the coöperation of public relief officials has results in providing cash or relief work to unemployed engineers.

Col. F. M. Gunby, president, emergency planning and research bureau, Engineering Societies of New England (Boston), told how his bureau collected a private fund of $100,000 to employ engineers in compiling city records, planning activities, and other useful projects. C. E. Sabin, told how in Cleveland engineers operated a farm for subsistence. Cleveland is reported to have the only full time employment service operated by a local society; it is expected that the service will be self-supporting this year.

Other subjects discussed at the secretaries' conference were problems in connection with dues of unemployed members, handling of bills, arrangements for successful meetings of technical societies, and new types of service and activities for local organizations.

Discussion as to interrelation of national and local activities resulting in the appointment of a continuing committee was led by C. E. Davies, secretary of the A.S.M.E., for the national societies, and J. S. Dodds, secretary of the Iowa Engineering Society, for the local societies.

Election of Officers

At the election of officers, no change was made in the present executive committee of Council. J. F. Coleman continues as president, having been elected for the 2 year term, 1935–36. Two of the 4 vice presidents, Paul Doty (A'04, M'12) and A. J. Hammond also are hold-over officers, serv-

ing for the 1934–35 term. The other 2 vice presidents, C. O. Bickelhaupt (M'22, F'28) and W. H. Woodbury were reelected for the 2 year term beginning January 1935. C. E. Stephens (M'22) was reelected treasurer to serve during the year 1935, as was William McClellan (A'04, M'09, F'12, and past-president) to serve as chairman of the finance committee for 1935. F. M. Felker was reappointed executive secretary for 1935.

Representatives of the A.I.E.E. on the assembly of American Engineering Council, in addition to Messrs. Bickelhaupt, McClellan and Stephens, are F. J. Chesterman (A'20, F'22), J. Allen Johnson (A'07, F'27, and president) and H. H. Henline (A'19, M'20, and national secretary) alternate.

Another A.E.C. meeting is tentatively set for October when it is planned to bring together the boards of control of all the national societies toward the furtherance of unity of action.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or to reject them entirely.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Mapping of Fields

To the Editor:

In Doctor Weber's paper on "Mapping of Fields" (see ELECTRICAL ENGINEERING for December 1934, page 1563–70) an excellent outline of the mathematical treatment of field problems is given, but graphical methods are only mentioned. In practical engineering work most field problems can be solved with sufficient accuracy by the graphical method sometimes referred to as the "method of curvilinear squares" or "curvilinear rectangles."

There are many worth while contributions by American authors to the development of the theory and application of this practical graphical method, in addition to those cited by Doctor Weber (references 15 and 22). The following list of additional references is not complete but should be of value to any one interested in acquiring a working knowledge of a practical method of solving field problems:

1. THE RELUCTANCE OF SOME IRREGULAR MAGNETIC FIELDS, John F. H. Douglas. A.I.E.E. PROC., v. 34, 1915, p. 1067–1125.

2. MAPPING MAGNETIC AND ELECTROSTATIC FIELDS, A. D. Moore. *Elec. Jl.*, v. 23, 1926, p. 355–62.

3. FUNDAMENTAL THEORY OF FLUX PLOTTING, A. R. Stevens, Jr. *G. E. Rev.*, v. 29, Nov. 1926, p. 794–804.

4. SYNCHRONOUS MACHINES, R. E. Doherty and C. A. Nickle. First of series of articles appearing in the A.I.E.E. TRANS., v. 45, 1926, p. 912–42.

5. ADDITIONAL LOSSES OF SYNCHRONOUS MACHINES, C. M. Laffoon and J. F. Calvert. A.I.E.E. TRANS., v. 46, 1927, p. 84–96.

6. GRAPHICAL DETERMINATIONS OF MAGNETIC FIELDS, A. R. Stevenson, Jr. and R. H. Park. A.I.E.E. TRANS., v. 46, 1927, p. 112–35.

7. GRAPHICAL DETERMINATION OF MAGNETIC FIELDS, E. E. Johnston and C. H. Green. A.I.E.E. TRANS., v. 46, 1927, p. 136–40.

8. A PRACTICAL APPLICATION OF GRAPHICAL FLUX MAPPING, J. F. Calvert. *Elec. Jl.*, v. 24, Nov. 1927, p. 543–7.

9. GRAPHICAL FLUX MAPPING—I, II, III, IV, V, VI, J. F. Calvert and A. M. Harrison. *Elec. Jl.*, v. 25, 1928; March, p. 147–50; APR., p. 179–82, May, p. 245–8, July, p. 362–5, AUG., p. 399–401, and Oct., p. 510–13.

10. ANALYTICAL DETERMINATION OF MAGNETIC FIELDS—SIMPLE CASES OF CONDUCTORS IN SLOTS, B. L. Robertson and I. A. Terry. A.I.E.E. TRANS., v. 48, Oct. 1929, p. 1242–59.

11. FORCES IN TURBINE GENERATOR END WINDINGS, J. F. Calvert. A.I.E.E. TRANS., v. 50, March, 1931, p. 178–94.

12. SURGE PROOF TRANSFORMERS, H. V. Putnam. A.I.E.E. TRANS., v. 51, Sept., 1932, p. 579–84.

Reference 1 above is important due to the variety of experimentally determined examples and the immense bibliography or experimental work which is presented. References 2, 3, and 4 give in clear style the principles for simple fields. References 5, 6, and 9 give the basic principles for mapping electromagnetic fields either inside or outside the current source. Reference 9 gives the widest range of solutions with practical, though difficult, boundary conditions. Reference 7 compares experimental results with graphical determinations. Reference 10 shows mathematical solutions which check the data obtained graphically by the authors of some of the previously mentioned papers. References 8 and 11 show important applications to loss force and reactance problems. Reference 12 shows the introduction of the graphical method to complicated 2 and 3 dimensioned electrostatic problems which involve 2 or more dielectrics.

Very truly yours,

L. A. KILGORE (A'29)
(Power Engg. Dept., Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.)

To the Editor:

In his paper on "Mapping of Fields" (see ELECTRICAL ENGINEERING for December 1934, page 1563–70) Doctor Weber has set forth the position of field problems in contradistinction to circuit problems. I intend to discuss this point of view and hope to add certain other features which will be of interest.

In electrical engineering most problems may be divided as to time into steady state and transient, and as to space into circuit and field problems. The circuit problems are those in which the phenomena vary with time and with distance along paths of one dimension. Field problems deal with steady state or transient conditions in 2 or 3 dimensions. In the past, electrical engineers have found it most convenient to approximate the field problems by circuit analogies. The so-called magnetic circuit is perhaps the best known example. Such analogies no longer need be resorted to for the older types of problems and such analogies will not yield satisfactory solutions for the newer problems. In fact, there are many field problems encountered today in electrical engineering which require new methods based directly upon the fundamental concepts of physics, but in which simple methods of application have been devised.

It is in this latter particular that Doctor Weber has attached hardly sufficient importance to the graphical method of mapping by use of curvilinear squares for 2-dimensional problems, and by the use of suitable curvilinear rectangulars for 3-dimensional problems and for 2-dielectric problems. I should state here that some of the first efforts to develop and to illustrate numerous elements of this work, in its early stages of development for engineering use, were made by Prof. A. D. Moore at the University of Michigan. These methods, in which due consideration has been given to the graphical interpretation of the equations of La Place and Poisson, have been taught in the Westinghouse educational work since 1925. It has been found that a man possessing average ability for free-hand drawing can become sufficiently proficient after 3 to 4 weeks of intensive practice to use this method of solution for any field problems that he may encounter. This is a far less investment of time and energy than would be necessary to perfect the mathematical technique which would be required to solve even very simple problems. Incidentally, the mathematical methods are applicable only to problems with extremely simple boundary conditions as no others have been solved to date. The man with the training in graphical mapping does not encounter these limitations of hopelessly difficult boundary conditions. He should be able to solve 2-dimensional problems with any boundary condition whatever and any 3-dimensional problems which are cylindrically symmetrical, regardless of their boundary conditions. Also he should be able to solve electrostatic field problems containing materials of different dielectric constants.

This graphical method of solution for field problems is much more rapid than any other. A man with moderate skill should be able to solve almost any 2-dimensional field problem (with the exception, for instance, in the case of electrostatic fields of those containing 2 dielectrics) to an accuracy of about ±5 per cent for the flux density after working for about $^1/_2$ hour. He should be able to obtain an accuracy of 1 to 2 per cent for the flux density within one day. If changing boundary conditions is to be considered (as, for instance, the opening of a contactor), about 4 maps usually will suffice to give satisfactory curve data.

In order that a man obtain such proficiency, it is necessary that he study a carefully selected set of possible boundary conditions. This may be accomplished as follows:

1. By developing the principles regarding: (a) inside and outside corners, (b) slots, (c) the conditions around and within large and small conductors, (d) the method for replacing saturation effects or perhaps special parts of the field by current sheaths and perfectly magnetic material, (e) the use of images, and (f) the numerous methods for introducing and removing boundary conditions to get the greatest benefit from the superposition theorem.
2. To show a variety of boundary conditions which have been solved and to point out the principles used.
3. And most important, to develop skill of hand and eye and proper confidence by mapping fields in which one solves some practical problem.

I may say then that the graphical method is the most powerful with the possible exception of the experimental method, and it is certainly the best adapted for engineering use of any of the known methods for solving steady state field problems. The mathematical details can be omitted almost entirely. In fact, the rapid advances in this phase of the art only occurred after these mathematical details were omitted. In this particular, the steady state field problems seem to be at the opposite end of the scale from the transient circuit problems, for in attacking transient circuit problems, complex mathematical solutions seem to yield the best and quickest results, and in many cases to furnish the only method of obtaining analytical solutions.

Very truly yours,

J. F. Calvert (A'27)
(Power Engg. Dept., Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.)

Engineers in Elective Public Office

[Note: The writer of this letter was elected Mayor of his home town, in New Jersey, in 1928. In 1929 and 1930, before the depression had turned men's minds toward economy in government, Mr. McNicol reduced taxes locally 36 points in his first year. Following years showed further reductions notwithstanding that a modern incinerator was erected, a half-million dollar school built, a major sewer project carried out, and miles of new concrete sewer laid. To date this town has continued all municipal and school salaries minus only the 10 per cent required by State action in the general relief program. At the end of his first term Mr. McNicol was reelected for 2 more years without opposition from either Democrats or Republicans.]

To the Editor:

For several years before Mr. Hoover took office as President of the United States there had been occasional discussion in engineering circles and in engineering periodicals on the general subject of the engineer in politics. Because in those days engineers were busy men, and making money, too often the talk was of a facetious character. Engineers, in common with most professional men, looked upon "politics" as a somewhat sordid occupation having precarious returns. A result was that there were few engineers who sought public office by the elective route.

The attainment of the high office of President by Herbert Hoover, the engineer, brought to the engineer-in-politics discussions a serious, general entertainment of the idea of public service as individual contributions toward local and national welfare. It was intriguing to read and study the many contributed articles from engineers which appeared in the engineering journals from 1928 until recently, advancing the writers' ideas as to what the engineers' contribution to or participation in government might well be in the interests of the general welfare.

When the debacle of 1929 descended upon the nation, a general mess was precipitated which no individual nor any group will ever admit responsibility for—quite rightly. The political overturn in national administration which followed seemed natural in view of what had been going on for 20 years: "natural" when we stop to analyze what actually had been going on.

Perhaps it was because there had been much discussion of the engineer in politics for some years prior to 1933 that widespread attention was accorded the forced-draught proposals of the "technocrats" early in the days of the present administration. That the technocrats (whoever they were) were accorded a patient hearing, and were granted so much space in the public press, was mainly a sign of the times. 125,000,000 men and women, since the war years had had sold to them annually the glories of an American standard of living to which each and all were said to be by right entitled. In 1932 it was all too plain that the politician-salesmen had failed dismally to make good their campaign promises. The citizenry was stunned. The people were groping. There was somewhat vengeful seeking for scapegoats. And, although scapegoats had been named and had been expelled from Washington, it was late in 1933 before the people at large reluctantly conceded what engineers had known all along, that technocracy contained no panacea—in fact was as grotesque in its fulminations as various others of the shibboleths of 1932 were in 1933 suspected to be, and in 1934 are believed to be.

Engineers who today read the many contributions on economics, social reconstruction and government which appear monthly in their respective trade journals, are aware that they as American citizens are aided most in their thinking by writers who have little faith in nostrums, but who have recalled for consideration as factors human nature, emotional attributes, the old rather than socialistic notions of liberty, and older and saner ideas related to impracticable horizontal standards of living.

Aside from what engineers are thinking about the commonwealth, what they are thinking about their own situation during the present instability, may be epitomized by a quotation from the August message of J. Allen Johnson, president of the A.I.E.E. (Electrical Engineering, August 1934, page 1142). He says: ". . . . . In several of these movements one or the other of 2 objectives seems to predominate. One of these is the *professional* advancement, the other the *economic* advancement of engineers." The context is not difficult to imagine. It is the same as would precede similar statements made by the leaders of numerous trades and professions at the present time.

It is axiomatic in engineering that the bolt must hold if the bridge is to hold. During the long period of industrial expansion and progress in this country it was axiomatic also that a foreman in charge of a small job had the best opportunity to learn the truth about the requirements of larger jobs. An engineer finding himself in an elective public office very early senses that he is engaged in an undertaking that bears some relation to other public offices, as to size and responsibility. He realizes also that no matter what the magnitude of the office he shall continuously be in contact with the same people who would have placed him in any one of the other administrative positions, whether farther up or farther down the scale of magnitude of public office. I say elective office, because if an engineer attains public office he must travel the same route thereto as the practical politician, the ward-heeler who has waited long on the party's waiting list, and the candidates of the lobbies and blocs.

The fact that this is so has deterred very many engineers from seeking public office. This is a fault of their academic education. Could educational authorities realize their opportunities and responsibilities in this respect the halls of learning might make constructive contributions toward good government. It is true that at the moment there is rather a glut of professors in key posts at the seat of national government. These men are in my opinion starting at the top of the ladder. They have missed much that should now be of value to them and to the country had they started at the bottom. My notion is that men (and women should be educated and trained for public office beginning in the smaller offices in their own communities, such as councilmen, assessors, treasurers, municipal clerks, mayors, State assemblymen, and so on.

In almost any municipality in America tonight a hundred, or a thousand educated men are playing bridge, or listening to the radio, while down town at the council meeting one of the town fathers is heard to say: "Youse guys make me sick." And, no doubt, the gentleman has supportable reason for the remark.

The most difficult task an engineer, or anyone else, has in public office is that of being a reasonably good fellow and at the same time give the taxpayer a square deal. Some few men have the faculty. More could measure up in this respect if organized education provided for it. As an indication it may be said that the mayor of a town of, say, 10,000 population, will during his term sign checks paying out 1,000,000 dollars collected from 4,000 taxpayers. An early enlightening discovery is that about one half of the tax money collected is paid out for what the school folks call "free education." With a hospitality of mind and with the knowledge that he is the custodian of all tax money, a mayor, depending upon the type of his business training, may decide to gather data and statistics bearing on school costs. To accumulate even a fairly accurate file on the subject, he is successful in proportion to his persistence, skill in analysis, adroitness, suavity, and any other attributes he may be able to exercise. The fact that this is the case does not mean the educational authorities have anything special to conceal. Their reasons for resenting inquiry are the same as those which should be advanced by all the various other organized groups in America should inquiry be suggested.

Of course a mayor, the custodian of the money gathered in by the tax collector, can without doubt find no end of ways of spending his time, other than bothering about what is done with the money after he signs the appropriation checks, but this is the type of mayor that education should deliver us from if the vast sums appropriated for education are to be expended properly.

In the metropolitan dailies and in magazine articles in recent months there have been charges emanating perhaps from uninformed as well as informed sources to the effect that American educational institutions have become hotbeds of socialism and even of communism. I know many school teachers and I feel sure that each of them would indignantly deny that they themselves are socialists, or socialistic in thought. However, if it is true that altogether too many of present-day school graduates are communistic in thought and in attitude toward life would it be unreasonable to suspect that in reality they have for years passed through an atmosphere that is socialistic without its being recognized as such, either by student or by teacher? Consider the teacher's state of mind with respect to his own and her own status in life; security economically. A woman from the national educational office, Washington, in a recent one of many radio addresses informed the listeners that there are "A million school teachers interested in this . . . . ." What it was they are interested in I did not catch, but the official in Washington, on the taxpayers' payroll said it in a tone that plainly meant "a million votes."

Through this voting power in State assemblies in the past quarter century the school folks have provided themselves with pensions and tenure of office, mandatory legislation, and 14 weeks vacation annually, with full pay, in addition to all the single holidays. All of this is lifted out of the hands of the local taxpayer who pays the bill. These "mandatory" laws are maintained on the statute books by labels pinned on State assemblymen and senators: "Fair to Education," which automatically assures these gentlemen from 25,000 to 50,000 votes over-all, depending upon the State.

In a recent radio address William Allen White reminded his hearers that the one big inducement that both communism and socialism offer is "economic security." Mr. White reminded also that the complement of perfect economic security must be tyranny.

In listening by radio to the propaganda that goes out from the United States office of education at Washington, castigating any citizen or taxpayer who "says a word against education," it is quite plain to this writer why about one-half of the municipal tax collection is expended for education. "In Union there is Strength."

Parents who dream or wish that their sons may become Thomas A. Edisons or James J. Hills, may be puzzled over socialistic ideas brought home from school, but should not blame individual school teachers for this. The teacher may be entirely innocent of exercising such an influence. An outlook on life supported by economic security, on the other hand, may not be just the right influence for boys and girls who are going out into a world where if they are to enjoy liberty and freedom, attain high professional standing, and be in a position to acquire a competence enabling them to maintain liberty and freedom in their later, unproductive days, they must be free from the tyranny which follows leveling economic security dependent upon tax money which itself might likely collapse under the strain.

The remaining one-half of the municipal tax collection is disbursed in the support of a dozen or more public services, each one subject to much the same analysis as is the bill for schools. Now that bureaucracy in the national government is establishing new high records in the number of voters supported on the public payroll there is little point in devoting time to complaining about this situation in the cities and towns. On this score, however, it may be noted here that we shall have socialistic government in the United States, or in its component parts, when those on the public payrolls outnumber the self-supporting taxpayers and voters *who bother to go to the polls on election day.*

Many business and professional men and women wonder why the educational folks do not sense that in justification of the enormous increase in the cost of education, per pupil, during the past 30 years, they should desire to show improvement in output. Demands for "larger" and "better" school buildings very rarely originate among taxpayers, or the parents of school children. The demands are initiated, fostered, and nurtured within the system itself. Consider California. There in sparsely populated communities school edifices supportable from reasonable taxation have been supplanted by magnificent architectural structures located on 10 to 15 acre ground areas. The country is strewn with grade schools which in appearance and equipment rival the large universities.

The taxpayer proverbially remains ignorant of the situation until the day of reckoning comes—when he learns that the public debt is his debt. I have before me the investment folio of one of the mutual insurance companies. The company lists $5,012,875 invested in school district bonds, the investments in 48 districts throughout the United States. Seventeen of these investments are in Illinois and but one in California. In gauging the profit, the output, from the enormous school investment, an analyst not gifted with the prescience enabling him to look ahead 20 years, might perhaps be unfair should he attempt to evaluate what the daily press during the past year reported with respect to conditions, say, in California.

Aside from engineering training, engineering instinct alone prompts one to look for and expect to find commensurate return from investment. In 30 years, while billions of dollars have been appropriated for "education" the educators uninterruptedly encouraged the taxpayers with the reminder that these vast sums were actual investments: that there should be return, with interest, the return being measurable in improved knowledge, self-sustaining capacity, and in citizenship equipped to *support* government.

A question is, is this or is it not the achievement. If the billions appropriated for education have not produced the desired results, should opprobrium attach to any one, even an engineer, who inquires for the reasons for failure?

At the meeting of the New York Section of the Institute on October 10, last, Dr. Virgil Jordan said (see ELECTRICAL ENGINEERING, November 1934, page 1546–51):

"... Among the figures that move in this economic scene, only he (the engineer) can save this great mass of humanity from self-destruction. And he must not expect to be thanked for it. The mob that rules destiny today in all the western world will take his service for granted, it will not show any gratitude for it because they have no understanding of its essential significance at all."

Remember, this *mob* has been put through our schools in the last 2 or 3 decades.

That astute commentator H. L. Mencken, in a recent article in *Liberty*, says with respect to the genus politician:

"How are we to improve him—or get rid of him? The first, I believe, is a sheer impossibility. So long as we want to enjoy the excitement of democracy we must be prepared to endure its curses, and one of them is the fact that when 2 men stand up before a mob, the one honest and the other a fraud, the mob always prefers the fraud."

In order to make himself understood Mr. Mencken exaggerates somewhat when he says "always." However, he speaks of the same school product that Dr. Jordan speaks of.

More and more it appears that the school system has become a sort of Empire in its own right, the laws passed for its perpetuation having been prepared largely by persons on the school payrolls. Often in late years we have heard the belief expressed that the educational system is ingrown. A solution of this vast problem in the interest of the oncoming generations of Americans might be accelerated should the educators settle upon and announce fundamental objectives; decide to devote say 90 per cent of school time and school funds to these objectives, and change the propaganda accordingly.

There is just no question about it but that engineers are particularly equipped for administrative public office, but unless by conference with the educators they can prevail upon these gentlemen to so apply the money appropriated for education that something other than mobs are turned out, we might as well sit back placidly and wait for the circuses supported from tax money to begin, and for the spears of the Numidians to herald the end.

Very truly yours,

DONALD MCNICOL (A'05, F'18)
(Editor, *Radio Engineering*, New York, N. Y.)

First Electric Street Railway

To the Editor:

I am enclosing an interesting clipping from one of our local papers on the above subject which establishes, quite definitely, the date of November 16, 1886 as the date when Scranton's first electric street car was put into service.

There is local pride in the thought that this was the "first electric street car" put into operation and there may be local pride in other localities where cars were placed in operation about the same time and possibly at earlier dates.

You, doubtless, have information on this subject and possibly it may have been pub-

lished and has not come to the writer's attention.

I will appreciate any advice you may be able to give on this subject.

Very truly yours,

W. A. Thomas (A'05, F'13)
(Consulting Engineer,
Scranton Electric Bldg.,
Scranton, Pa.)

Editor's Note: In response to the above inquiry, the following information is offered.

In Electrical Engineering for May 1934, page 698–701, the late Dr. F. J. Sprague (A'87, M'98, F'12, HM'32, member for life, and president 1892–93) gives some information of his own and some references to other information which may be of value in this connection.

On page 841 of this same issue, there appears under the date of 1888, among other entries, the following: "First electric street railway (Richmond, Va.)." This particular statement unfortunately should have read as follows: "First city-wide urban electrical street railway operated, Richmond, Va." According to the best information that we have been able to obtain, the Richmond installation is generally regarded as the first commercially successful electric street railway "system," although various authorities recognize definitely the fact that a few street cars were operating on short lengths of track in various cities in the United States prior to the completion of the Richmond system. It seems to be authenticated that the Richmond system was given preliminary try-outs in the fall of 1887 and placed in fully commercial operation as a completed system in May of 1888. This system is believed to have comprised some 11 miles of track and 40 cars, which number of cars Doctor Sprague characterized as being more than the total of street railway cars operating in all other cities in the United States at that time.

Further interesting information is given on page 186 of the A.I.E.E. Transactions, volume 4, 1887, where the late T. Commerford Martin (A'88, M'10, president 1887–88) under the title of "A Few Comparative Statistics of Electric Railways," reported the following:

1. Baltimore, Md., 1885, 2 miles of track (single track with turnouts) 6 "motors and motor cars"
2. Los Angeles, Calif., 1887, 3 miles of track, double and single, 8 "motors and motor cars"
3. Port Huron, Mich., 1885–86, 4 miles of single track, 8 "motors and motor cars"
4. Windsor, Canada, 1885, nearly 2 miles of single track, 2 "motors and motor cars"
5. Highland Park, Detroit, Mich., 1886, $3^1/_2$ miles of single track, 2 "motors and motor cars"
6. Dix Road, Detroit, Mich., 1886, $1^3/_4$ miles of single track, 4 "motors and motor cars"
7. Appleton, Wis., 1886, $4^1/_2$ miles of single and double track, 8 "motors and motor cars"
8. Scranton, Pa., 1886, $3^1/_4$ miles of single track with 4 sidings, 3 "motors and motor cars"
9. Denver, Colo., 1886, $3^1/_2$ miles of single and double track, 7 "motors and motor cars"
10. Montgomery, Ala., 1885–86, 11 miles of single and double track, 18 "motors and motor cars." (Special notation that "this line ran 2 cars one year. Has just started other cars.")

The above listing was given as of May 18, 1887, supplemented by brief information on many lines under construction, and concerning many new companies formed and forming for the purpose of building street railway systems in many different cities.

(For the purpose of establishing the correct dates in electrical history of 50 years ago, and giving credit where it is due, further contributions along this line will be welcomed by the editor.)

Personal Items

E. F. W. Alexanderson (A'04, F'20) consulting engineer, General Electric Company, Schenectady, N. Y., has been elected to membership in the Royal Academy of Science, Sweden. Doctor Alexanderson was born at Upsala, Sweden, and graduated from the Royal Institute of Technology at Stockholm in 1900. He later studied in Berlin, and in 1926 received the honorary degree of doctor of science from Union College, Schenectady, N. Y. In 1902 he entered the General Electric Company, but also was chief engineer of the Radio Corporation of America 1920–4. Doctor Alexanderson is well known for his contributions to radio, which include the Alexanderson high frequency alternator, multiple tuned antenna, vacuum tube radio telephone transmitter, and tuned radio frequency receiver. He has been concerned also with television, electric ship propulsion, and railroad electrification, and has presented a number of technical papers. Among the honors which he has received are decoration with the Order of the North Star, Sweden, and the Order of Polonia Restituta, Poland, the gold medal of the Institute of Radio Engineers, and the John Ericsson medal. Doctor Alexanderson is a fellow and past-president of the Institute of Radio Engineers, and a member of the American Physical Society, and Sigma Xi.

C. E. Stephens (M'22) vice president of the Westinghouse Electric and Manufacturing Company, New York, N. Y., was reelected treasurer of American Engineering Council for the term of one year at the meeting held in Washington, D. C., January 10–12, 1935. Mr. Stephens, who is a representative of the Institute on the assembly of Council, has for a number of years been active on committees of the Institute, being at present chairman of the committees on code of principles of professional conduct, and the Edison Medal.

C. O. Bickelhaupt (M'22, F'28) assistant vice president, American Telephone and Telegraph Company, New York, N. Y., was reelected a vice president of American Engineering Council for the 2-year term 1935–36, at its annual meeting held in Washington, D. C., January 10–12, 1935. Mr. Bickelhaupt, a representative of the Institute on the assembly of Council, is also chairman of the Institute's publication committee. A brief biographical sketch of Mr. Bickelhaupt's career was given in Electrical Engineering for October 1934, page 1428.

F. B. Jewett (A'03, M'10, F'12, and past-president), vice president of the American Telephone and Telegraph Company, and president of the Bell Telephone Laboratories, Inc., was unanimously awarded the Faraday Medal of the Institution of Electrical Engineers (of Great Britain) at a meeting of the council of that organization on January 24, 1935. A biographical sketch of Doctor Jewett's career appears in Electrical Engineering for January 1935, page 140.

F. B. JEWETT

William McClellan (A'04, M'09, F'12, and past-president) president of William McClellan and Company, Ltd., and of the Potomac Electric Power Company of Washington, D. C., was reelected chairman of the finance committee of American Engineering Council for 1935, at its meeting held in Washington, D. C., January 10–12, 1935. For a period of over 20 years, Doctor McClellan has continuously served the Institute as a member of its technical committees, being at present a member of the committee on Institute policy, and a representative on the assembly of American Engineering Council. A biographical sketch of Doctor McClellan's career was given in Electrical Engineering for May 1934, page 804.

A. F. Hamdi (A'18, M'21) has become chief of the bureau of electrification in the ministry of economy of the Republic of Turkey, with headquarters at Ankara, the Turkish capital. According to Mr. Hamdi "the bureau of electrification, as its name implies, has been created to develop the energy resources of the republic—coal, water, oil—in order to supply cheap power to the budding industries." A native of Turkey (Constantinople 1891) Mr. Hamdi migrated to the United States in 1911, graduated from Columbia University, New

York, N. Y., in 1916 with the degree of electrical engineer, receiving the next year the degree of master of arts in physics. After graduation in June 1916, Mr. Hamdi served Columbia University as an assistant in the electrical engineering laboratory; for several subsequent years he taught evening school classes at Columbia University and Cooper Union in New York City. Mr. Hamdi was first employed by the New York Edison Company in 1917 as a laboratory assistant in its test department; in 1918 he was made foreman of the standardizing laboratory, and in 1919 was made a general foreman in the test department, a position he held until 1924 when he was promoted to the position of assistant engineer of the test department; from 1927 to 1929 he was assistant engineer in the meter department where he was particularly interested in research and development work in connection with measuring devices and methods, and testing equipment. From 1929 to 1932, Mr. Hamdi served the Hall Electric Heating Company, Inc., of Philadelphia, Pa., as engineer. Subsequently he returned to Turkey.

Ambrose Swasey (HM'28) chairman of the board, The Warner and Swasey Company, has had the Washington Award for 1935 bestowed upon him. Exercises for the formal presentation of this award of the Western Society of Engineers (Chicago) will be held in Chicago, February 20, 1935. Doctor Swasey, famous manufacturer of precision instruments and mechanisms, has long been devoted to furthering the advancement of the engineering profession. It was he who in 1924 founded The Engineering Foundation, research agency of the 4 national societies of civil, mining and metallurgical, mechanical, and electrical engineers. Since its founding, Doctor Swasey has contributed gifts totaling $750,000 to the Foundation. A biographical sketch of Doctor Swasey's career was given in Electrical Engineering for May 1934, page 815.

AMBROSE SWASEY

F. M. Farmer (A'02, F'13) vice president, chief engineer and director, Electrical Testing Laboratories, New York, N. Y., has been reëlected vice chairman of the standards council of the American Standards Association. Mr. Farmer is chairman of the Institute's committee on research and a member of the committees on power transmission and distribution and coördination of Institute activities. A biographical sketch of Mr. Farmer was given in the February 1934 issue, page 231.

R. M. Spurck (A'18) General Electric Company, Philadelphia, Pa., formerly assistant manager of the switchgear engineering department, has been named manager of sales of the circuit breaker section of the switchgear sales division. Mr. Spurck is a graduate of the University of Illinois, and has been with the General Electric Company since 1910. He was a member of the Institute's protective devices committee 1928–30.

J. T. Holmes (M'24) who for 20 years has been chief engineer of The Frink Corporation, Long Island City, N. Y., resigned on January 9, 1935. Mr. Holmes has not as yet announced his future activity, but will probably continue in the line with which he has been associated. He has been a member of the Institute's committee on the production and application of light since 1933.

R. P. Brown (A'10, M'13) president, The Brown Instrument Company, Philadelphia, Pa., has become an officer and director of the Minneapolis-Honeywell Regulator Company with the consolidation of the 2 companies. He will continue as president of The Brown Instrument Company, which will maintain its present offices.

O. B. Blackwell (A'08, F'17) director of transmission development, Bell Telephone Laboratories, Inc., is now a member of the standards council of the American Standards Association, representing the telephone group. At one time Mr. Blackwell served on the Institute's communication committee.

K. T. Compton (F'31) president, Massachusetts Institute of Technology, Cambridge, Mass., has been appointed chairman of the board of technology of The American Society of Mechanical Engineers. Doctor Compton recently was elected president of the American Association for the Advancement of Science.

J. H. Milbyer (A'19) formerly superintendent of the Niagara, Lockport and Ontario Power Company, Olean, N. Y., has recently become district superintendent of the Tonawanda Power Company, North Tonawanda, N. Y.

E. A. Strong (A'30) formerly operator in charge of station CJRW, James Richardson and Sons, Ltd., Fleming, Sask., Can., is now engineer in charge of station CKCK, Leader-Post Publishing Company, Ltd., Regina, Sask.

S. E. Warner (A'31) resigned in June 1934 as instructor in electrical engineering at Rensselaer Polytechnic Institute, Troy, N. Y., to become chief engineer of W1XBS, a pioneer high fidelity radio station at Waterbury, Conn.

J. T. Lusignan, Jr. (A'27) former chief electrical engineer, Ohio Insulator Company, Barberton, Ohio, is now engineering assistant to vice president, of the parent company, the Ohio Brass Company, Mansfield.

W. C. Jessup (A'03) formerly district manager, Cutter Electrical and Manufacturing Company, New York, N. Y., recently became district manager for the I-T-E Circuit Breaker Company with offices in New York.

Alex Dow (A'93, F'13) president, Detroit Edison Company, Detroit, Mich., resigned recently as chairman of The American Society of Mechanical Engineers' committee on the thermal properties of steam.

R. W. MacGregor (A'30) formerly in the commercial department, Winters National Bank and Trust Company, Dayton, Ohio, is now operating a stock farm at Cedarville.

C. B. Seibert (A'32) has recently become an instructor in electrical engineering at West Virginia University, Morgantown. He had previously spent 3 years with the General Electric Company in Lynn, Mass.

A. L. Ross (A'33) formerly junior electrical engineer, Noranda Mines, Ltd., Noranda, Que., Can., is now in the engineering and production department of the Canadian Controllers Limited, Toronto, Ont.

C. F. Walter (A'27) former designing engineer, James R. Kearney Corp., St. Louis, Mo., is now paint supervisor for the Chevrolet Motor Company, Kansas City, Mo.

E. R. Swanson (A'26) formerly district engineer, Wisconsin Power and Light Company, Fond du Lac, has been transferred to Mineral Point, Wis., where he is district manager for the company.

A. F. Briggs (A'33) recently office engineer, U. S. Coast and Geodetic Survey, Port Arthur, Texas, has entered the electrical engineering department of the Sun Oil Company at Beaumont.

L. M. Keating (A'22) who has been with the McGraw-Hill Publishing Company, Inc., in Cleveland, Ohio, is now in the Detroit, Mich., office of the United States Advertising Corporation.

E. C. Curtis (A'31) formerly switchgear specialist with the General Electric Company, Portland, Ore., is now an electrical engineer with Ford, Bacon and Davis, Seattle, Wash.

H. G. Barnett (A'33) Corvallis, Ore., is assisting in an investigation of electric fish screens for the U. S. Bureau of Fisheries, with reference to the Bonneville dam project.

C. H. Lydall (A'20) who recently went to London, England, with the firm of Merz and McLellan, has returned to the United States and is now with Sargent and Lundy, Inc., Chicago, Ill.

I. D. Block (A'34) formerly with the Buffalo, Niagara, and Eastern Power Corporation, Buffalo, N. Y., is now with the 29th pursuit squadron at Albrook Field, Canal Zone.

Crosby Field (A'14, F'22) vice president, Brillo Manufacturing Company, Brooklyn, N. Y., has been appointed a member of the committee on unemployment of The American Society of Mechanical Engineers.

W. J. Rey (A'23) who lately has been in Ober-Arth, Switzerland, is now assistant electrical engineer, national park service, Department of Interior, Washington, D. C.

F. P. Lawrence (A'25) general plant manager, New York Telephone Company, has been transferred from New York, N. Y., to Albany, N. Y.

J. B. Harris, Jr. (A'17) formerly president of Harris and Butler, Philadelphia, Pa., is now connected with the Rumsey Electric Company in that city.

Theodore Varney (A'05) until recently a consulting engineer with offices in New York, N. Y., has accepted a position with Aluminum Limited, Montreal, Que., Can.

A. H. Harvey (A'29) sales engineer, Inniss and Riddle (China) Ltd., has been transferred from Hongkong to Shanghai, China.

L. H. C. Beerstecher (A'19) manager, International General Electric Company, Inc., formerly at Soerebaia, Java, Dutch East Indies, is now at Batavia, Java.

A. H. Brown, Jr. (A'33) until recently in Cleveland, Ohio, is now with the American Transit Association, New York, N. Y.

W. T. Lawrence (A'32) of Chicago, Ill., has accepted a position as sales engineer with the Automatic Electric Company in New York, N. Y.

Sir Archibald Page (F'29) formerly general manager of the British Central Electricity Board, London, England, has been appointed chairman of the board.

G. E. Rolston (A'30) General Cable Corporation, has been transferred from Rome, N. Y., to New York, N. Y.

R. B. MacLaughlin (A'32) Acme Meter Service Corporation, has been transferred from Philadelphia, Pa., to Boston, Mass.

G. F. Rucker (A'32) is now a service engineer with Leeds and Northrup Company, Los Angeles, Calif.

P. F. Munkasy (A'33) of Bridgeport, Conn., is now working with the U. S. Coast and Geodetic Survey, Panama City, Fla.

J. E. Peek (A'32) acoustical engineer, Oklahoma City, Okla., has formed the Film Speaker Company in that city.

M. B. Steele (A'28) sales engineer, Steel and Tubes, Inc., has been transferred from Cleveland, Ohio, to Boston, Mass.

Obituary

George Anson Hamilton (A'84, M'84, F'13, HM'33, and member for life) Elizabeth, N. J., died January 10, 1935. He was one of the 6 living charter members of the Institute, and the last surviving member of the original committee of 5 on organization. Mr. Hamilton was born at Cleveland, Ohio, December 30, 1843. He became interested in electricity, and built a small telegraph line for himself at Limaville, Ohio. In 1861 he became a messenger at Salem, Ohio, but 2 months later was made manager of the Ravenna office of the Atlantic and Great Western Railroad. Illness forced him to relinquish this position in 1863, but upon his recovery he went to Pittsburgh, Pa., as operator and manager of the Inland Company. Two years later he became manager of the office at Franklin, Pa., of the United States Telegraph Company, returning to Pittsburgh in 1866 as chief operator and circuit manager and remaining there until 1873 when the company was absorbed by the Western Union Telegraph Company. During 1873–75 he was assistant to Prof. Moses G. Farmer of Boston, Mass., who was engaged in the manufacture of general electrical apparatus and machinery and who later became an Honorary Member of the Institute. This work afforded him an opportunity to secure valuable practical knowledge of mechanics and to participate in many electrical experiments in telegraphy and other developments. In 1875 Mr. Hamilton was called to New York, N. Y., as assistant electrician to the Western Union Company. During the next 2 years, with Gerritt Smith, he participated in the establishment of the first quadruplex telegraph circuits to be put into operation, and with Mr. Smith was also the first to introduce the system in England. Upon his return to this country he carried out experiments preliminary to establishing the wheatstone high-speed automatic system in this country. In 1889 Mr. Hamilton accepted a position with the Western Electric Company, New York, N. Y., supervising the department for the production of fine electrical instruments. He retired in 1909. In addition to having been a charter member of the Institute and active in its organization plans, he served as the Institute's first vice president for the term 1884–86, and was a member of the first committees on editing and permanent quarters. From 1895 to 1930 he served the Institute as national treasurer, and in 1933 was elected an Honorary Member. He was a member of the Edison medal committee 1908–30, and of the executive committee 1914–30. Mr. Hamilton was a member of the Institution of Electrical Engineers (Great Britain), Société Française des Électriciens, Société Française de Physique, and Société Belge d'Astronomie.

Thomas Augustus Watson (F'15) retired, Boston, Mass., died at his winter home in St. Petersburg, Fla., on December 14, 1934. He is famous as the first person to receive a message over the telephone. Doctor Watson was born at Salem, Mass., January 18, 1854, and attended schools there and at Massachusetts Institute of Technology. In 1875 Alexander Graham Bell (A'84, M'84) inventor of the telephone, who died in 1922, employed Doctor Watson to work with him. The first successful apparatus was made by Doctor Watson, and it was over this that the inventor spoke the first telephone message, "Watson, come here; I want you." As superintendent of the first Bell Telephone Company he did much of the engineering work during the period 1877–81, designing calling and switching apparatus and other mechanical and electrical devices. Doctor Watson was principally responsible for the substitution of the all-iron diaphragm for the membrane with a piece of iron at its center, and he also experimented to find the best size and thickness for the diaphragm and the effect of a closed chamber behind it. The universally-used polarized-armature telephone bell is credited to Doctor Watson, as is also the repeating coil used in producing a phantom circuit between metallic conductors and ground. After leaving telephone development work in 1884 he became a member of the shipbuilding firm of F. O. Wellington and Company, and from 1900 to 1903, when he retired, he was president of the Fore River Ship and Engine Company. He received the honorary degrees of master of arts, Union College, 1919; doctor of engineering, Stevens Institute of Technology, 1921; and doctor of sciences, University of New Hampshire, 1929. Doctor Watson was also a member of the American Association for the Advancement of Science.

W. Roy McCanne (A'19) president and general manager, Stromberg-Carlson Telephone Manufacturing Company, Rochester, N. Y., died November 5, 1934. He was born at Jacksonville, Mo., December 29, 1878. In 1897 he entered the office of Charles H. Ledlie, a civil and electrical engineer of St. Louis, Mo., and while there assisted in the construction and operation of the Kinloch Telephone Company's exchanges in St. Louis and its toll lines in Illinois and Missouri, together with similar work for other telephone and power companies. In 1905 the group controlling the Kinloch properties became interested in the Stromberg-Carlson Company, and Mr. McCanne was sent to Rochester. The following year he was elected treasurer and director of the company. For a short time, 1911–12, he was with the Eastman Kodak Company, Rochester, but returned to the former company as general manager. He was elected

president in 1924, in which year, with his direction, the company expanded to produce radio receivers. Recently he was one of those to confer with officials in charge of the government's industrial control program relative to the radio industry.

ALFRED W. KIDDLE (A'05) patent attorney and senior member of the law firm of Kiddle, Bethell, Montgomery, and Halbert, New York, N. Y., died January 7, 1935. He was born at New York August 9, 1865, and studied at the College of the City of New York and Columbia University, receiving the degree of bachelor of laws from the latter. In 1887 he was admitted to the bar, after having been employed in the patent department of the Edison Electric Light Company since 1883. After admission to the bar he made a specialty of patent law, preparing numerous applications for patents on electrical inventions and including also litigations involving electrical patents. He had served as special counsel to the City of New York on patent cases. During the period 1919–26 he was a member of the library board of the United Engineering Societies, now the United Engineering Trustees, Inc. Mr. Kiddle was a fellow of the American Society of Civil Engineers, and a member of the American Bar Association, American Patent Law Association, New York Patent Law Association, Association of the Bar of the City of New York, and other organizations.

PHILANDER NORTON (A'11) assistant to the president, Bell Telephone Laboratories, Inc., and editor, *The Bell System Technical Journal*, New York, N. Y., died on January 10, 1935. He was born at Elmira, N. Y., March 2, 1882, and was a graduate of Princeton University, receiving the degrees of bachelor of arts in 1907, master of arts in 1908, and electrical engineer in 1910. In the latter year he was employed in development work by the laboratories of the Western Electric Company in New York, this organization later becoming the Bell Telephone Laboratories. Among the devices on which he worked were ringing systems for party lines and protective apparatus, and to him is credited the automatic ringing system commonly used. At the time of the World War he was engaged in the production of vacuum tubes and also on methods for submarine detection. In 1920 he was placed in charge of the testing of new telephone apparatus, and 5 years later, with the organization of the Bell Laboratories, was appointed assistant to the president. Since 1929 he had been editor of the journal.

WILLIAM CORBIT SPRUANCE, JR. (A'06, M'07) vice president and director, E. I. du Pont de Nemours and Company, Wilmington, Del., died January 9, 1935. He was born at Wilmington, September 26, 1873. In 1890 he graduated from the Friends School at Wilmington and entered Princeton University, where he studied civil and electrical engineering, receiving the degree of electrical engineer in 1895. After a short time in the apprentice course of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., he was employed in the office of Montgomery Waddell (A'88, M'88, and member for life) a consulting engineer, where he worked on the design and construction of meters, etc. Following this he was employed by the Wilmington City Electric Company, and in 1899 opened office as a consulting engineer, being concerned with electrical work for the du Pont Explosive Company and subsidiaries. During the World War he served in the ordnance reserve corps and was commissioned a colonel. In addition to his Institute membership Colonel Spruance was a member of The American Society of Mechanical Engineers, the American Institute of Mining and Metallurgical Engineers, the American Academy of Political and Social Sciences, and the Franklin Institute.

DANA PIERCE (A'11, F'28) president, Underwriters Laboratories, Inc., Chicago, Ill., died on December 18, 1934, in Atlantic City, N. J. He was born at Claremont, N. H., April 11, 1871, and received the degree of bachelor of arts from Amherst College in 1892, subsequently taking special work at Cornell and Johns Hopkins universities. From 1900 to 1906 he was an instructor in physics at Pratt Institute, Brooklyn, N. Y., and from then until 1916 was an engineer in the Underwriters Laboratories. In 1916 he became vice president of the laboratories, and president in 1923. Mr. Pierce was chairman of the electrical committee of the National Fire Protection Association for 10 years, and for 2 years, 1926–28, was president of that association. He was active in work on standards and codes for testing and for safety in electrical engineering.

WILLIAM MCLELLAN (A'03, F'13) consulting engineer, Merz and McLellan, Newcastle-upon-Tyne, England, died on December 12, 1934. He was born at Kircudbrightshire, Scotland, in 1875, and studied at what is now Liverpool University, Liverpool, England. The partnership was formed in 1899 and carried out a number of power and railway electrification projects, including work in South America, India, and Australia, as well as in England.

DONALD P. MCNITT (A'27) consulting engineer, St. Louis, Mo., died during 1934, according to word recently received at Institute headquarters. He was born at Red Cloud, Neb., November 25, 1894, and was a graduate of the electrical engineering course at Washington University, St. Louis. For a time he was employed by the LaPorte Water, Light, and Ice Company, LaPorte, Tex., and later by the Continental Motors Company and the Kelsey Wheel Company, both in Detroit, Mich. During 1918–20 he was an electrician in the U.S. Navy. From 1921–27 he was employed by the Weckermeyer Electric Company, East St. Louis, and subsequently became chief electrical inspector in the department of public utilities, City of St. Louis.

Membership

Recommended for Transfer

The board of examiners, at its meeting on January 16, 1935, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Fairman, James F., E.E., Bklyn. Edison Co. Inc., Bklyn., N. Y.
Stryker, Clinton E., chief engr., Fansteel Products Co. Inc., No. Chicago, Ill.

2 to Grade of Fellow

To Grade of Member

Blanchard, Henry, valuation engr., The Bartlett Hayward Co., N. Y. City.
Bradfield, Charles W., engr., Duquesne Light Co., Pittsburgh, Pa.
Cook, Lee E., E.E., Texas Pwr. & Lt. Co., Dallas.
Gorton, W. V., salesman, Westinghouse E. & M. Co., Toledo, Ohio.
Gulliksen, Finn H., E.E., Westinghouse E. & M. Co., E. Pittsburgh, Pa.
Lankford, Charles H., sales engr., Century Elec. Co., St. Louis, Mo.
Love, W. S., foreman, Niagara, Lockport & Ontario Pwr. Co., Olean, N. Y.
Mettendorf, Harry A., supt., Board of Light Commissioners, Westfield, N. J.
Reisig, Carl F., supervisor of stations, Niagara Falls Pwr. Co., Niagara Falls, N. Y.
Rockwell, Edward W., engr., Metropolitan Water District of Southern Calif., Los Angeles.
Smith, Victor G., asst. prof. of E.E., Univ. of Toronto, Toronto, Ont. Canada.
Sparks, Robert, instructor in mathematics and astronomy, Hartford Public High School, Conn.
Wahl, F. S., general supt., Tonawanda Pwr. Co., No. Tonawanda, N. Y.
Work, Hans, R., lecturer of E.E., Tallinna Tehnikum, Tallinn, Estonia.

14 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before Feb. 28, 1935, or April 30, 1935, if the applicant resides outside of the United States or Canada.

Ackerlind, E., Bklyn. Poly. Inst., Bklyn., N. Y.
Anderson, F. A., Sullivan Elec. Co., Cincinnati, Ohio.
Anderson, J. R., Gen. Elec. Co., Cleveland, Ohio.
Anderson, L. D., R.C.A. Victor Co., Camden, N. J.
Andrews, D. H., 429 Oakwood Ave., E. Aurora, N. Y.
Appleyate, O. E., 92 Heck Ave., Ocean Grove, N. J.
At Lee, R. Y., Am. Dist. Tel. Co., N. Y. City.
Baird, J., 402 Pine St., Boulder, Colo.
Bengel, J. E., N. Y. Central R.R., Weehawken, N. J.
Binney, J. O. (Member), Metropolitan Water Dist. of So. Calif., Los Angeles, Calif.
Bittel, H. C., Cato, N. Y.
Blade, E., John Catillon & Sons, N. Y. City.
Bonheimer, H. E., Cleveland Elec. Illum. Co., O.
Brown, J. R., Humble Oil & Refining Co., Houston, Texas.
Brown, M. T., Mohawk Mfg. Co., Detroit, Mich.
Campbell, H. A., Consolidated Aircraft Corp., Buffalo, N. Y.
Campbell, J. D., Gen. Elec. Co., Schenectady, N. Y.
Carmean, J. H., Kansas City, Mo.
Cary, S. P., Buffalo Boat Co., N. Tonawanda, N. Y.
Chapman, A. A., Chapman Elec. Co. Ltd., Yorkton, Sask., Can.
Clarke, R. B., Hilscher-Clarke Elec. Co., Canton, Ohio.
Cobine, J. D., Harvard Engg. School, Cambridge, Mass.
Collonge, F. J., Nevada Consol. Copper Co., McGill.
Compton, J. W., Rocky Gap, Va.
Condon, E. S. (Member) Maydwell & Hartrell Inc., Pasadena, Calif.
Copeland, L. W., Wadhams Oil Co., Milwaukee, Wis.
Cotter, H. G., Toledo, Ohio.
Credle, A. B., Clemson Col., Clemson College, S. C.
Currier, T. H., Natl. Lead Co., N. Y. City.

Dakan, D. L., Hope Natural Gas Co., Lumberport, W. Va.
Dalton, J. L., Reading Co., Glenside, Pa.
Daly, T. A., 45 Webb St., Hammond, Ind.
Dankenschmidt, E. R., Ward Leonard Elec. Co., Mt. Vernon, N. Y.
Diotte, N. I., Johnson Lumber Co., Cannan, N. H.
Douglas, M. J., Southwestern Bell Tel. Co., Kansas City, Mo.
Dynes, W. A., Natl. Park Serv., Washington, D. C.
Eck, R. N., Lake Mills, Wis.
Elkington, G. E., East Kootenay Pwr. Co., Ltd., Fernie, B. C., Can.
Ellis, C. G., Oilgear Co., Milwaukee, Wis.
Faust, D. G., Atwater Kent Mfg. Co., Philadelphia, Pa.
Fegely, H. S., 915 Poplar St., Erie, Pa.
Fleming, D. A., Oklahoma Gas & Elec. Co., Oklahoma City.
Fleming, W. W. (Member), Okonite Co., N. Y. City.
Foote, G. L., Univ. of Southern Calif., Los Angeles.
Gaudefroy, H., 4590 Hutchison St., Montreal, Que., Can.
Geiger, P. E., 178 Overlook Ave., Hackensack, N. J.
Gillespie, J. P., Tennessee Eastman Corp., Kingsport.
Glyn, R. L., Jr., Glyn's Auto Service, Topeka, Kans.
Gordon, H. L., Rhodium Corp. of Am., N. Y. City.
Grant, A. F., Winton Engine Corp., Cleveland, O.
Green, H. D. (Member), Brooklyn Edison Co., Bklyn., N. Y.
Greenberg, J. H., c/o M. R. Scharff, N. Y. City.
Griffith, G. J., General Printed String Co., Milwaukee, Wis.
Gring, M. H., Pa. Pwr. & Lt. Co., Mount Carmel, Pa.
Groo, E. R., Aerovox Corp., Brooklyn, N. Y.
Halligan, C. W., Bell Tel. Labs., N. Y. City.
Hana, T. C., Magnetic Analysis Corp., Long Island City, N. Y.
Harman, M. C., Consumers Pwr. Co., Battle Creek, Mich.
Harolden, E. E., Idaho Geodetic Survey, Moscow.
Hause, J., Reynolds Metals Co., Louisville, Ky.
Hebel, F., Box 186, Carpinteria, Calif.
Hibbard, B. D., Spearfish, S. D.
Hiegel, A. J., Univ. of Notre Dame, Notre Dame, Ind.
Hilford, J. V., 1405½ Massachusetts Ave., Lawrence, Kans.
Hinshaw, F. A., Bell Tel. Labs., N. Y. City.
Hoechstetter, L., c/o M. R. Scharff, N. Y. City.
Hoffmann, H. W., All Am. Cables, N. Y. City.
Hume, E. L., 60 Bellvale St., Malden, Mass.
Janes, C. W., Mich. Col. of Mining & Tech., Houghton, Mich.
Janoff, K. P., 17 Plymouth St., Johnson City, N. Y.
Jarvis, G. B., Indiana Bell Tel. Co., Indianapolis.
Jones, C. B., Union Electric Lt. & Pwr. Co., St. Louis, Mo.
Joss, E. T., Maurice Scharff, N. Y. City.
Joubert, L. P. (Member), U. S. Engineers, Portland, Ore.
Judge, J. E., Univ. of N. D., Grand Forks.
Kent, M. F., Pub. Serv. of N. J., Jersey City.
Killian, T. J., Luminous Tube Ltg. Corp., Seattle, Wash.
Kissinger, W. W., 2128 N. 3rd St., Harrisburg, Pa.
Kluge, M. R., Broadcasting Stations KRKD & KPSG, Los Angeles, Calif.
Koch, J. W., Radio Station KFBQ, St. Joseph, Mo.
Konkel, A. A., Marion, Wis.
Koontz, R. E., National Standard Co., Niles, Mich.
Ladd, G. O., Univ. of Missouri, Columbia.
LaMothe, D. J., Michigan Coll. of Mining & Tech., Hubbell.
Landine, K. W., 302 Belmont, Detroit, Mich.
Leemhuis, W. J., Gen. Elec. Co., Schenectady, N. Y.
Lehmann, G. P., Iowa State Col., Ames.
Lewis, R. C. (Member), elec. & mech. engr., U. S. Navy, Brooklyn, N. Y.
Lichtman, S. W., Detrola Radio Corp., Detroit, Mich.
Linsley, S. E., Minneapolis-St. Paul Sanitary District, St. Paul, Minn.
Love, R. R., Univ. of Manitoba Fort Garry, Manitoba, Can.
McCormick, G., 4530—18th N.E., Seattle, Wash.
McDonald, B., Texas New Orleans Signal Shop, Houston, Tex.
Magowan, A. F., Rim Hill Farm, Brookfield, Mass.
Mann, A. K., Federal Pwr. Commission, Washington, D. C.
Mansur, F., 1129 E. Washington Ave., Santa Ana, Calif.
Marx, N., Purdue Memorial Union, W. Lafayette, Ind.
Marsh, D. G., 988 N. Holliston Ave., Pasadena, Calif.
Martin, T., City of Vancouver, B. C., Can.
Mathews, A. E., Dept. of Water & Pwr., City of Los Angeles, Calif.
Matthews, W. S., Jr., Union Elec. Lt. & Pwr. Co., St. Louis, Mo.
Mayes, T. L., Gen. Elec. Co., Oakland, Calif.
Merlo, C., Michigan Coll. of Mining & Tech., Laurium.
Miller, W. S., Pike Co. Agricultural Adjustment Administration, Waverly, Ohio.
Miner, R. V., Calibron Products, Inc., West Orange, N. J.
Moore, J. K., 1083 Oak St., Salem, Ore.
Moore, R. C., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Morong, T. M., Summer St., Rowley, Mass.
Murphy, C. G., 2766 Woodhull Ave., Bronx, N. Y. City.
Navas, V. P., N. Y. & Queens Elec. Lt. & Pwr. Co., Flushing, N. Y.
Nielsen, A. F., Ikira, Iowa.
Novak, J. L., 1523 W. Superior St., Chicago, Ill.
Nutter, D. S., Shell Oil Co., Long Beach, Calif.
Oliphant, H. A., Gen. Elec. Co., Schenectady, N. Y.
Osterlund, J. A., Intl. Business Machines Corp., N. Y. City.
Park, H. F., Reese Padlock Co., Lancaster, Pa.
Petera, J., Daily News, N. Y. City.
Peterson, H. C., Univ. of Utah, Salt Lake City.
Pfeffer, W. E., Brown Instrument Co., Philadelphia, Pa.
Phillips, R. L., Montgomery Ward & Co., St. Paul, Minn.
Pollock, C., Canadian Westinghouse Co., Hamilton, Ont., Can.
Pros, J. Jr., Omaha Municipal University, Omaha, Neb.
Reimann, R., Rome Co., Long Island City, N. Y.
Reitinger, R. L., E. G. Budd Mfg. Co., Phila., Pa.
Richardson, W. M., Platte Valley Pub. Pwr. & Irrigation Dist. (Sutherland Project), North Platte, Neb.
Ringler, G. F., Narragansett Elec. Co., Providence, R. I.
Rubin, S., Forest House, 17th & Butler Sts., Easton, Pa.
Schantz, J. D., RCA Victor Co., Inc., Camden, N. J.
Schoenfeld, E., RCA Communications, Inc., Point Reyes, Calif.
Seiple, W. M., Penn. Pwr. & Lt. Co., Wilkes-Barre, Pa.
Shong, A. M., 910 N. 25th St., Milwaukee, Wis.
Shore, R. B., Gen. Elec. Co., Schenectady, N. Y.
Smith, C. B., adult education classes, Y. W. C. A., Clinton, Iowa.
Smith, D. B., Phila. Storage Battery Co., Philadelphia, Pa.
Smith, R. C., American Airlines, Inc., Fort Worth, Tex.
Smith, S. W., 31 Evergreen St., Harrisburg, Pa.
Smoyer, H. L., Tonawanda Pwr. Co., N. Tonawanda, N. Y.
Sorensen, A. D., Box 90, Coventry, R. I.
Stavros, T. H., Alabama Pwr. Co., Birmingham.
Stecker, L. H., 4030 Carpenter Ave., N. Y. City.
Stein, L. B., Jr., % Maurice R. Scharff, N. Y. City.
Stivender, F. M., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Strader, F., 217 West 95th St., N. Y. C.
Stresen-Reuter, J. H., Gen. Elec. Co., Chicago, Ill.
Strojny, F. M. W., N. Y. Edison Co., N. Y. City.
Suter, W. V., Southwestern Bell Tel. Co., Little Rock, Ark.
Thiermann, A. H., Jr., Va. Elec. & Pwr. Co., Richmond.
Thompson, D. B. (Member), N. Y. C. R.R., N. Y. City.
Thompson, J. D., Centerial States Elec. Co. of Colo., Sterling.
Trull, C. E., Blackstone Valley Gas & Elec. Co., Pawtucket, R. I.
Turner, L. N., Univ. of Mich., Ann Arbor, Mich.
Ulm, L. G., Ohio Bell Tel. Co., Toledo.
Vassil, P. N., Miller Seldon Elec. & Mfg. Co., Detroit, Mich.
Voshall, R. D., Capital Transit Co., Washington, D. C.
Walte, C. E., El Monte High School, El Monte, Calif.
Warren, C. O., 525 Woodrow St., Columbus, Ohio.
Warren, R. S., Adams & Westlake Co., Elkhart, Ind.
Waters, M. V., Kelley-Koett Mfg. Co., Covington, Ky.
Westendorp, W. F., Gen. Elec. Co., Schenectady, N. Y.
Westin, L. J., Westinghouse Elec. & Mfg. Co., Allentown, Pa.
White, A. R., Square D Elec. Co., Detroit, Mich.
Wield, P. F., N. Y. Tel. Co., N. Y. City.
Williams, R. E., 227 Willowood Drive, Dayton, Ohio.
Wilson, E. S., Intl. Business Machines Corp., Endicott, N. Y.
Worden, O. L., Natl. Lead Co., Bklyn., N. Y.
Young, C. W., Jr., 91 Onderdonk Ave., Manhasset, N. Y.

160 Domestic

Barassi, E., "Accialerie e Ferriere Lombarde Falck," S. I. Via, Gabrio Casati, 1, Milano, Italy.
Cunningham, A. J., Metropolitan Vickers Elec. Export Co., Rio de Janeiro, Arg., S. A.
Laycock, G., Nufsend Power Station, Sheffield, Yorks., Eng.
McEntee, E., Westinghouse Intl. Co., Santa Ana, El Salvador, Central Am.
Valls, R. P., Toro Negro Pwr. Plant, Villalba, Porto Rico.

5 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the address as it now appears on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Demeros, Andrew G., P. O. Box 787, East Pittsburgh, Pa.
Eberhard, Jacob J., 525 Grant St., Santa Clara, Calif.
Fennis, A. M., 4266 Old Orchard Ave., Montreal, Que., Can.
Fracker, Henry E., Bell Tel. Labs., 463 West St., N. Y. City.
Hansen, A. Fred, 2065½ W. 30th St., Los Angeles, Calif.
Ince, Frank Edward, 2282 Yale Ave., Maplewood, Mo.
Jordan, Arthur H., 5729 Chester Ave., Philadelphia, Pa.
Lemen, Foster M., 3009 Seward, Omaha, Nebr.
Mendes, D. P., 6 Division St., Schenectady, N. Y.
Nessler, Aldo E., Delta Starr Electric Co., 2437 W. Fulton St., Chicago, Ill.
Quinn, Robert P., Ohio Brass Co., Mansfield, Ohio.
Ryden, Eric H., Electrolux Servel Corp., 401 E. 111th St., N. Y. City.
Shirley, Charles O., 3433 S. Crawford Ave., Chicago, Ill.
Simpson, Sidney, Deputy Loco. Supt., Eastern Bengal R. R., Kanchrapara, Bengal, India.
Skinner, Dean C., 6014 Walnut St., Pittsburgh, Pa.
Travers, James E., 12 Farwell Blk., Claremont, N. H.
Turnquist, F. A., 4 Birch Road, Wellesley, Mass.
Williams, G. M., 1331 Touhy Ave., Chicago, Ill.

18 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

A.S.T.M. STANDARDS on COAL and COKE, prepared by Committee D-5 on Coal and Coke-September 1934. Phila., American Society for Testing Materials. 108 p., illus., 9x6 in., paper, $1.00. Specifications, methods of test, and the standard definitions of terms relating to coal and coke are conveniently brought together in this publication, which includes all the material on the subject which the Society has issued. The recently approved requirements for classification of coal are also included.

A.S.T.M. STANDARDS on PETROLEUM PRODUCTS and LUBRICANTS, prepared by Committee D-2 on Petroleum Products and Lubricants, Sept. 1934. Phila., American Society for Testing Materials, 1934. 840 p., illus., 9x6 in., paper, $1.75. All the test methods, specifications, and definitions of terms referring to these materials which the Society has issued are included in this volume. In addition, there are included the reports on petroleum products and lubricants, and on gasoline. New standards are given covering fuel oils, emulsified asphalts, the gum content of gasoline, and the separation of liquid asphaltic products. Among the revisions of test methods are those for sulfur in petroleum oils, the color of lubricating oils and for emulsified asphalt.

Great Britain, Meteorological Office, Geophysical, Memoirs No. 60 (Third Number, Vol. 7). OBSERVATIONS of ATMOSPHERIC ELECTRICITY at KEW OBSERVATORY, a Survey of Results obtained from 1843 to 1931. By F. J. Scrase. London, His Majesty's Stationery Office, 1934. 27 p., illus., 12x10 in., paper, $.65 (British Library of Information, N. Y.). This report gives a brief historical sketch of the early experiments, followed by a description of the methods of observation which have been introduced more recently. The values of the potential gradient, air-earth current and positive conductivity are given.

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Front Cover

Boulder Dam, on the Colorado River between Arizona and Nevada, some 30 miles southeast of Las Vegas, Nev. This night view of the upstream face of the dam and appurtenant works was taken on October 20, 1934.

Photo courtesy U. S. Bureau of Reclamation, Department of the Interior

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A Power Company Communication System

By interconnecting and coördinating its private communication facilities with the commercial telephone system, the Tennessee Electric Power Company is building up a comprehensive communication system for the use of all departments of the company. These improved communication facilities are described briefly in this paper. The principal features of the plan are: (1) adequate interconnecting facilities between telephone and power company systems are furnished by the telephone company; (2) telephone equipment retired by the power company is replaced by telephone company equipment; and (3) commercial leased service is considered whenever the power company requires additional facilities.

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ARRANGEMENTS for load dispatching and other communication services recently devised and installed for the Tennessee Electric Power Company are described in this paper. It is offered as a contribution to the subject of equipment arrangements mentioned in an earlier paper. ("Communication Services of Electric Utilities, Underlying Considerations," R. N. Conwell, G. M. Keenan, C. F. Craig, and E. C. Briggs, A.I.E.E. TRANSACTIONS, volume 50, 1931, pages 1285–91.)

Before plans for these arrangements were initiated, the power company was served by 2 practically independent communication systems: (1) the local administrative and commercial departments using commercial private-branch-exchange and exchange facilities, and (2) the operating department using a long private line system built and maintained entirely by the power company. There was only one point of interconnection between the 2 systems and it was incidental and inadequate. The power company had built much of its private telephone system years ago when patrol lines along the transmission line right of way were considered essential. Since that time improved reliability of transmission lines, increased accessibility to right of way, and increased availability of commercial telephone circuits in rural localities and villages, have all served to reduce the need for confining telephone lines to transmission line right of way. Other factors have reduced the necessity for power company owned telephone facilities, such as broader interconnecting privileges with commercial telephone systems, rerouting service on leased lines, and improvements in speed and reliability of commercial telephone service. Sensing these changed conditions, and realizing the manifold advantages of a comprehensive telephone system serving all departments and localities without duplication of instrumentalities, the power company in 1930 signed a general contract with the Southern Bell Telephone and Telegraph Company, looking to a program for improving its communication services by interconnecting and coördinating its private facilities with the commercial telephone system.

Following the contract, the engineers of the telephone and power companies made a joint study of the communication system and requirements of the power company, and planned in detail the steps necessary to carry out the intentions of the contract.

The Tennessee Electric Power Company serves an area in central and east Tennessee about 100 miles wide and 300 miles long, including the important cities of Nashville and Chattanooga. Power is generated at 8 plants, and is interchanged with contiguous systems. In its communication system are more than 1,000 miles of telephone circuit, partly leased, but principally owned by the power company. The headquarters office is in Chattanooga. It has a private branch exchange and associated with it a customers' service switchboard; in addition, the territorial telephone lines of the power company are centered there. The chief dispatcher is located there and subdispatchers are stationed at Nashville and Knoxville. Figure 1 shows these points and other system stations. An inspection of this diagram indicates the general situation dealt with and the switching points requiring special design considerations to render the necessary service. Design also necessitated consideration of the fact that the 3 cities named have dial services, and at Chattanooga the power company's private branch exchange is of the dial type.

The general plan covered the following main features and requirements:

1. Adequate interconnecting facilities between the commercial telephone system and the power company system to be furnished by the telephone company and to be designed particularly for this service.

2. Power company telephone equipment to be replaced by telephone company equipment as it wore out, became inadequate, or otherwise justified retirement in favor of leased service.

3. Commercial leased service to be considered whenever additions to the power company's communication system were required.

As a part of the first requirement, a dispatch switchboard has been designed and installed at Chattanooga, and subdispatch turrets have been

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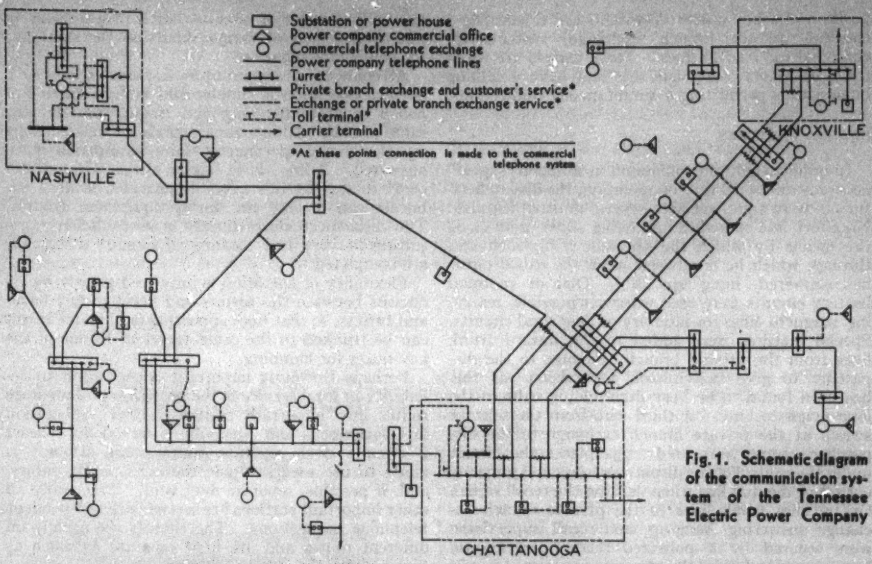

Fig. 1. Schematic diagram of the communication system of the Tennessee Electric Power Company

located at Nashville (West Nashville substation) and Knoxville (Arlington substation).

Dispatchers' and Subdispatchers' Turrets

It was necessary for the turrets (the dispatch switchboard is composed of several detached positions called "turrets") to accommodate and permit switching between a great variety of lines, including: long magneto lines both exposed and unexposed; short magneto lines to local substations; trunk lines to and from the dial private branch exchange; trunk lines to and from dial central office; 2-way common battery toll terminal trunk lines connecting with the toll board; common battery lines in headquarters building; tie trunk lines between turrets. With this variety of lines, it is readily seen that to design a turret to give uniform operation and inter-connection to all lines is an interesting and important problem. Furthermore, the method of operation of the Chattanooga installation is different from the usual power company telephone system in that all calls over the power company long lines, whether operating, commercial, or administrative, are handled and switched by the system load dispatcher, whereas in many systems the load dispatchers handle operating calls only, and the private branch exchange operators handle the commercial and administrative calls.

Fig. 2. Dispatcher's turret

The measure of traffic showed that 2 positions for normal service, and 2 supplementary key boxes for overloads at times of emergency, were necessary. Two one-position single-panel key-operated sloping-face turrets (figure 2) accordingly were designed and installed, together with 2 key boxes in which were multipled the more important lines, arranged for answering and calling but not for interconnection. The relays, coils, and other apparatus in the turret circuits are mounted on a 2-bay relay rack in an adjoining room, so that there is nothing in the turrets except keys and signal lamps. A dial is connected into each operator's telephone circuit and mounted conveniently on one end of the turret, while on the opposite end is a dial for controlling the automatic electric power diagram board.

The turrets are mounted on tables in such a way as to afford ample and convenient room for log sheets, orders, and other supervisory records. The 2 key boxes are mounted on desks, one at each end of the dispatch room, with the dispatch tables between and in line, and all facing the diagram board (figure 3). The whole is an attractive and convenient layout affording excellent working conditions and calculated to handle efficiently all dispatching operations under normal and abnormal plant conditions.

The subdispatchers' turrets each consist of one

position of a key operated switchboard resembling a cordless private branch exchange switchboard, equipped for 7 or 16 lines. These turrets are wired for 2 operators' telephone sets and have 4 talking busses, thus permitting 4 simultaneous connections.

Special Features

In order to gain the maximum in simplicity, speed, accuracy and reliability of operation, the dispatchers' turrets were equipped with several unusual features. No effort was spared in improving supervision (i. e., the means by which the operator is signaled and through which he is advised when the called party has answered, hung up, etc.). Dial or common battery circuits were used wherever possible, reserving magneto lines for intercity or long rural circuits. Special features were added to the inward trunk lines from the private branch exchange to the dispatcher to give switch-hook supervision, as this has been found to be very desirable on calls to the long magneto lines. A third wire from the selector switch at the private branch exchange to the dispatcher's turret was used; this places the circuit under the control of the dispatcher's key and prevents cut-off of the dial line when flashing the recall signal. On out-dial trunk lines to the private branch exchange answering, hang-up, and recall supervision were secured by a polarized relay operating on battery reversal from the connector.

Colored supervisory lamps were provided to permit distinctions between "waiting for the called party to answer" and "hang-up by the called party" on the common battery lines and private branch exchange trunk lines; this has been found to be particularly valuable to the load dispatcher.

The Chattanooga turrets tie magneto circuits directly together metallically, thus avoiding transmission loss where efficiency is needed most. Repeating coils are used on all common battery or dial circuits to provide for interconnection between the various types of circuits. It is also possible to put several lines of various kinds on the same bus for conference purposes.

All connections are put up by keys instead of cords, as such operation is simpler and faster. Each line has a separate listening and ringing key for the same reason. All incoming signals as well as rering signals give a permanent lamp indication until answered. A line alarm buzzer also is left continuously in service, but a key is provided so that the buzzer can be cut out during equipment trouble. The disconnect alarm buzzer is used similarly, resulting in very fast clearing of circuits after calls are completed.

Flexibility of operation is improved greatly by tie circuits between the turrets and between key boxes and turrets, so that lines appearing only in one turret can be trunked to the other turret or to one of the key boxes for handling.

Perhaps the most important contribution to reliability in local service is the provision of 2 separate routes into important stations. Every substation in Chattanooga and Nashville is served by at least 2 circuits over separate routes. An attempt is made to use separate pole routes, separate cables, and, if possible, separate duct runs. Practically all other important stations are served by 2 independent telephone connections. The circuits are usually on different routes and are kept separate as much as possible into the station building.

Every important station on the power company's private communication system now can be reached over commercial toll and exchange lines, the commercial system forming a secondary or back-up system over which, when necessary, business can be transacted as readily as over the private system. Figure 1 shows the points of interconnection and the schematic plan of the dual connecting arrangements, but does not, of course, show the commercial toll lines used.

The separation of inward and outward traffic routes is one of the important features of the tele-

Fig. 3. Dispatcher's room showing turrets on 2 desks in center and one of the key boxes on desk in right foreground

phone service in this system. This applies to general office private branch exchanges as well as to system dispatchers' turrets. Any extensive power failure in a local area results in a multitude of inward calls. To prevent such a volume of inward calls from cutting off the power company's outward service, one-way circuits in both directions for central office and private branch exchange connections are provided.

To facilitate the handling of calls to the load dispatcher from department heads and maintenance employees during times when all the city trunk lines of the power company private branch exchange are busy, 2 unlisted inward lines have been provided between the main exchange and the dispatchers' turrets. The numbers of these lines are known only to those employees who would have occasion to reach the dispatcher in such emergencies.

Progress on the Application of the Plan

In addition to the dispatchers' turrets and their various connections, the unification and coördination plan has been carried out at all substations in the larger cities. Whenever changes were required at any given station, advantage was taken of the opportunity to make that station conform to the plan of coördinated facilities.

An Advanced Course in Engineering

To supplement the training of college graduates in the practical application of fundamental principles and mathematics to engineering analysis, the General Electric Company 11 years ago established its "Advanced Course in Engineering." The course of study given and the objectives to be attained are outlined in this paper which also summarizes the practical value of this special 3 year course as indicated by the work of its graduates.

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In the pioneer era of the General Electric Company, men like Steinmetz, Berg, and Faccioli, all of whom had received their education abroad, furnished the mathematical foundation for the design of apparatus. There then followed a period when engineers were kept extremely busy designing machines, using the heritage of formulas which had been passed on to them by these older men. Relatively little time was taken for extending and improving the theoretical foundation. There was, in other words, an era of what might be called "handbook engineering." This condition, if permitted to exist too long, was bound to lead to a slowing down of progress. The company realized that its achievement thus far had rested in a large measure upon the sound technical foundation laid by the pioneers, and that future progress would depend on filling their places with high caliber men of broad technical training who had the ability to think along fundamental lines and to apply their knowledge to the development of improved apparatus. The full realization of this just after the World War, when things were being arranged on a peace time basis, led the company to establish the advanced course in engineering to train men who could deal with the advanced theoretical aspects of engineering work.

Such work is essentially mathematical in character. This is especially true in electrical engineering, in which one deals with quantities that are more intangible than those in other branches of engineering. Thus in order to deal effectively with such problems one must be able to use mathematics as a tool in the application of the fundamental laws of physics to the problems of engineering, and must have a real appreciation of its significance as an aid in straight thinking.

Engineering graduates from American colleges, however, usually did not have sufficient training along these lines. Most of them had no mathematical training beyond the calculus, and those who had studied differential equations had not learned how to make use of them in the analysis of physical problems. There were coming to the company many excellent, ingenious designers, but relatively few who were thoroughly grounded in methods of analysis. The courses in many colleges had become too practical; men were being taught routine rule of thumb methods of design, and there was insufficient emphasis on thinking problems through by the use of fundamental principles.

At that time the company was recruiting from the technical schools about 400 or 500 men each year. These men entered the testing department, where

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they usually stayed at least a year. About half of this number, after a year or 2 of training, would leave the company to take outside positions; the rest would be distributed throughout the extended activities of the company in commercial, sales, and design engineering. There was, however, no definite, effective training program for those interested in the more technical phases of engineering.

Advanced Course Instituted

After thorough study and planning the "advanced course in engineering" was started in the fall of 1923 under the direction of R. E. Doherty and A. R. Stevenson, Jr., both of whom had been pupils of Doctors Steinmetz and Berg and therefore were prepared in some measure to help guide a new generation to carry on and expand the traditions which had been passed on to them.

The course was instituted primarily to train design engineers so that for the most part only men interested in design work were chosen for it. It was realized from the first that it was impossible to create ability and that it was necessary to select men with creative ability and a high natural aptitude for design, then arrange the course to give them an opportunity to improve themselves, gain experience, and ultimately find positions where they could apply their talents to the best advantage.

The experience of the founders of the course and of those with whom they were associated indicated very definitely that in order to be effective the course should have 2 major objects. These objects were to train men

1. To apply the fundamental principles of engineering to the solution of their problems.

2. To present the results of their work clearly and concisely, whether in written form or orally, so that others might easily understand and use these results.

In the 11 years since its founding these objectives of the course have been adhered to.

During the first few years of its existence, the course was mainly electrical, but as the years went by it was realized that there was great need for similar training in mechanical engineering. Much of the work in electrical design departments required mechanical, as well as electrical engineering, and there were many mechanical engineering departments, such as turbine, refrigerator, and air conditioning. Therefore, the course was expanded somewhat to include the fundamentals of elasticity, dynamics, and heat transfer, and to extend the study of thermodynamics.

Present Organization

The course is organized at present on essentially the same basis as it was during the first years of its existence, although many changes have been made based on experience. It may, therefore, be of interest briefly to describe this present organization.

The complete course comprises 3 years, with about 30 men in the first year, or *A* class, of whom from 8 to 10 are selected to continue for 2 more years in the *B* and *C* classes.

The *A* class is formed from members of the testing department who have been with the company only a short time. Entrance is competitive and selection is made from among the applicants on the basis of an examination, school records, and personal interviews. Personality and ability to coöperate with others are carefully considered, as well as technical ability.

Those selected remain in the testing department and obtain the same experience there as those not taking the course. In addition, they spend a half day a week in class on company time.

The work during the first year consists of a study of the application of the fundamentals of engineering to the solution of problems involving mechanics, thermodynamics, heat transfer, electricity, and magnetism. The specific objects are:

1. To show that the same fundamental laws, such as the law of the conservation of energy, apply in all of these fields.

2. To train the men to think out problems for themselves by using these fundamental laws.

3. To teach them to select the pertinent data necessary to a particular problem from a miscellaneous mass of known facts.

4. To extend their grasp of mathematics as required in the study of problems in these various fields of engineering.

5. To show them how to use common sense engineering ideas in the simplification of mathematics.

6. To engender the conviction that there is an answer to every problem, which can and must be reached even if laborious step by step methods are required.

7. To teach them to criticize their own answers, and to determine with certainty by judgment and common sense comparison with other known solutions whether the answer is right.

8. To train them to present ideas clearly, concisely, and attractively.

These objects are carried out by a program of classroom lectures and by assigning engineering problems each week which the students solve at home and turn in at the following class. As far as possible the problems selected are ones which have actually arisen in the engineering departments of the company. In many cases unsolved problems have been assigned, and the classes have thus been given the chance to be of assistance in useful engineering work. These problems differ from most textbook problems in that the students are expected to select from a group of facts those which are necessary for the solution. Another important aspect is that usually it is necessary for the students to make a number of simplifying assumptions in order to bring the problem within the range of practical mathematics.

The assignments usually consist of only one major problem rather than a group of miscellaneous shorter ones. This method is used because the problems which can be assigned approach more closely the type which the men will encounter in their future engineering work.

The solutions of these problems are written up as engineering reports so that the students will become proficient in presenting the results of their work in this form. These reports are constructively criticized on the basis of both the technical work and the quality of presentation, and are given numerical grades.

In addition to the technical lectures, informative talks are given on various phases of engineering and company activities by members of many departments, and instruction in public speaking is given by a member of the faculty of Union College.

Since the organization of the course, the students have entered into this program with great enthusiasm, putting an average of about 15 to 20 hours outside time each week on their home work. The class really sets its own pace. A few men fall by the wayside, but nearly all those entering the *A* class complete it.

Conduct of *B* and *C* Classes

By the end of the first year, the men have received a thorough grounding in the basic methods of solving engineering problems and have sufficient mathematics for most engineering purposes. They are well qualified to enter design engineering departments, and most of those not selected for the *B* class do this soon after graduating. Those continuing with the *B* class leave the testing department and are taken directly on to the payroll of the advanced course. While on this payroll, the men are placed in engineering departments on assignments lasting 3 to 4 months each, in which they do real engineering work and obtain a good insight of the work of the department. As many as possible of the men are assigned for several months to a district office engineering department, with the idea of giving them the customer's viewpoint.

A knowledge of factory processes, and a real appreciation of the factors affecting cost, are of prime importance to designers, and this phase of engineering is receiving more and more emphasis in the course. As many as possible of the second and third year men are assigned to the factory for periods of about 6 months in order to obtain this type of training.

Meanwhile the classroom work of a half day a week is continued. Some of the *B* class men enter the electrical engineering section while others enter the thermal engineering section. In the first a further study is made of the fundamentals of flux distribution, after which transformers, induction motors, and synchronous and d-c machines are taken up, followed by a fundamental study of electron tubes, rectifiers, and inverters. Those entering the second make a further study of thermodynamics, heat transfer, and fluid flow, with the application of these to the design of refrigerators, air conditioning apparatus, and turbines.

In the last year, or *C* class, the men recombine in the mechanical engineering section. In this section elasticity, dynamics, hydrodynamics, and heat transmission are studied and applied to the analysis of stresses and vibrations in machines, cooling problems, and lubrication. During part of the year the class divides and those who previously took the electrical engineering section study heat transfer with the thermal engineering section, while those who previously took the thermal engineering section study the more elementary theory of electrical machinery.

During these last 2 years the men continue to put in considerable time on their home work which still consists mainly of the solution of problems. The problems assigned of course become more difficult and complex, and less and less detailed guidance is given the students in making the necessary assumptions and deciding on methods of attack.

Each section of the course has an individual supervisor who is either a graduate or a member of the course. He devotes the majority of his time directly to the work, but also spends considerable time on engineering. This latter activity is considered quite important since it serves to help keep the course in direct contact with the regular engineering work of the company, and gives the supervisor a broader experience. No individual supervises a section for more than one year.

The technical lectures in all sections are given by a great many men from many different departments. In this way, the subjects are presented from many different points of view and there is little danger of the course becoming "inbred."

Under this program, by the end of the 3 years the men have received a very thorough training in all of the more important theoretical aspects of machine analysis and design, and have had considerable varied engineering experience. They are well equipped to solve problems in stresses, machine vibration, lubrication, and cooling as well as those of a purely electrical nature. The men who will go into electrical engineering departments spend about $^2/_3$ of the time in the course studying mechanical engineering subjects. Those expecting to take up more purely mechanical engineering work receive a very similar training with a little less emphasis on the electrical work.

Results Achieved by the Course

The course has been operating about 11 years, and a total of 309 men have been graduated from it (at present there are 31 men in *A* class, 10 in the *B* class, and 8 in the *C* class). Of this number 185 or 60 per cent are still with the company.

Seventy men have been graduated from the complete 3 years of the course and of these 56 or 80 per cent are still with the company. This high percentage remaining after several years of depression is a significant indication of the excellent work these men are doing. It is particularly significant because of the 14 men who have left, all but one left entirely voluntarily to accept other positions.

Graduates of the course have contributed considerably to the technical literature. Some of the more notable of these contributions have been L. V. Bewley's many papers on traveling waves and lightning phenomena, culminating in his multivelocity theory. R. H. Park greatly advanced the theoretical analysis of synchronous machines and power system stability in his papers on these subjects. W. J. King has published many basic papers on heat transmission, including a comprehensive series of 6 articles in *Mechanical Engineering*. A paper by F. M. Starr on equivalent circuits

won the Alfred Noble prize award in 1932. As a whole, the advanced course graduates have contributed more than 85 national society papers and *General Electric Review* articles, and in addition they have presented numerous discussions and have written a large number of articles for the trade journals.

Within the company the graduates have contributed much to its engineering and have assumed relatively great responsibilities, considering their comparatively short experience. Several have been given responsible charge of the design work in their departments, and several have had their work recognized by a Coffin Award (a company award "for the most signal contributions towards increase of efficiency or progress in the electrical art").

The course has, it is believed, definitely proved its fundamental value through the outstanding accomplishments of its graduates, and it consequently has been actively maintained throughout the past few years of depression.

Similarity Relations in Electrical Engineering

The application of dimensional analysis to various types of problems in electrical engineering is discussed in this paper for the purpose of stimulating the use of model experiments in solving these problems. The authors hold that this method can be applied to many electrical engineering problems that are difficult of solution otherwise. Criterions for determining whether or not dimensional analysis and model experiments can be used are given.

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THE widespread use of model experiments by mechanical and civil engineers has found a much smaller counterpart in electrical engineering. This may be because opportunity is not at hand, but the relative lack of discussion of such tests in electrical engineering journals and the almost complete absence of any reference to them in college textbooks for electrical engineering students make it appear possible that dimensional analysis—the theory on which model experiments are based—is not widely recognized as a tool for investigation in the field.[1] By model experiment is meant one such that the results of tests on one object (the model) can be applied to an entire class of similar objects according to definite rules (similarity relations) deduced by use of dimensional analysis. The term dimensional analysis is a broad one covering changing of units, checking of equations dimensionally, and development of similarity relations, of which only the last is considered in this paper. Certain devices, for example power system calculating boards, are not models in the sense the word is used here.

As an illustration of a model experiment consider the work of Forbes and Gorman[2] who measured the resistance of certain conductors at high frequencies, and by a similarity relationship applied the result of their measurements to bus bars at low frequencies. The advantage of a model experiment in this case was that the frequency at which the measurements were made was chosen to suit experimental conditions. To have determined skin effect directly in the bus bars at the frequency at which the result was desired would have been a far more difficult task. Dwight[3] has referred to similar experiments.

In place of a second example, there may be listed a number of important problems in which model experiments, if possible, might prove helpful: lightning investigations, some radio transmission problems, electric furnace design,[4] determination of current distribution in the earth due to ground return circuits, cable problems, etc. Indeed there seem to have been few technical problems investigated from this point of view and the list of the potentialities could be expanded greatly. (In many cases, however, model experiments would not be worth using even if they could be utilized.)

To take a particular case, in recent years extensive lightning investigations have been conducted. These have been expensive and laborious. Would it not have been possible to obtain by model experiments much of the information needed? An answer to this cannot be given here—a thorough acquaintance with the field of application is usually necessary for the use of dimensional analysis. But the problem does not seem on the surface to be more difficult than the aerodynamical one in which models are tested in wind tunnels, and until a negative answer can be proved, there is no reason to believe that model experiments in the lighting case are not possible and, incidently, probably far cheaper.

A Theorem of Dimensional Analysis

It is the purpose here to deduce some similarity relations using different methods to illustrate several ways of applying dimensional theory. As a preliminary it will be necessary to introduce some defini-

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1. For all numbered references, see list at end of paper.

tions and a theorem which need not be proved in this paper.[5]

a. A fundamental quantity is any quantity such as mass M, length L, time T, etc., in terms of which the dimensions of a given quantity can be expressed. Thus the dimensions of resistance are LT^{-1} in electromagnetic units. All quantities of interest here have dimensional formulas which can be expressed as products of powers of fundamental quantities.

b. An equation is said to be *complete* when its form is not changed by any change in the size of fundamental units. Dimensional analysis can be used only in problems governed by an equation of this type.

c. If there are n quantities entering into a complete equation and m fundamental units, there are $n-m$ independent dimensionless products of some or all of the quantities, and there exists an equation of the form

$$F(\pi_1, \pi_2, \ldots\ldots, \pi_{n-m}) = 0 \tag{1}$$

where π's are the $n-m$ dimensionless products. (This is the so-called π Theorem.)

An Application of the Theorem

As an illustration of one method of dimensional analysis the formula used by Forbes and Gorman may be deduced. It is desired to determine the total resistance per unit length (r_{a-c}) of a bus bar of given shape and area A of cross section, carrying a current of frequency f. Assume that r_{a-c} depends upon A, f, and the specific resistivity of the material ρ. Then by (a) and (c) above, since the dimensional formula of resistance is LT^{-1} (in electromagnetic units) and that of resistance per unit length is T^{-1}

$$T^{-1} = (L^{2p})(T^{-q})(L^{2s}T^{-s}) = A^p f^q \rho^s \tag{2}$$

the left-hand side of the first equality being the dimensions of r_{a-c} and the right hand side those of A, f and ρ raised to powers p, q, s, respectively. Here there are 4 quantities, r_{a-c}, A, f, and ρ, entering and 2 fundamental quantities L and T. Hence $n=4$, $m=2$, and by (c) there are 2 dimensionless products, one of which is $TL^{2p}T^{-q}L^{2s}T^{-s}$ obtained by multiplying both sides of equation 2 by T. For equation 2 to be consistent, the powers of each fundamental quantity must be equal on the 2 sides of the equation. Hence

$$0 = 2p + 2s; \qquad -1 = -q - s$$
$$s = 1 - q; \qquad p = -1 + q$$

whence

$$T^{-1} = A^p f^q \rho^s = A^{-1+q} f^q \rho^{1-q} = \rho A^{-1}[A^q f^q \rho^{-q}]$$
$$= \rho A^{-1}\left[\frac{Af}{\rho}\right]^q \tag{3}$$

Therefore r_{a-c} is a sum of terms of the form $\rho A^{-1} \times (Af/\rho)^q$. Since no other condition exists from which q can be determined, q is entirely arbitrary and r_{a-c} may be written

$$r_{a-c} = \frac{\rho}{A}\,\phi\left(\frac{Af}{\rho}\right)$$

where φ denotes an arbitrary function. But ρA^{-1} is the d-c resistance per unit length r_{d-c}, hence finally

$$\frac{r_{a-c}}{r_{d-c}} = \phi\left(\frac{Af}{\rho}\right) \tag{4}$$

This equation states that so long as the product Af/ρ remains constant, the quantities A, f, and ρ can take on any values, without altering the left-hand side. Thus in the case of the bus bar, a rod of similar cross sectional shape but different area A' and of different resistivity ρ' has the same ratio of a-c to d-c resistance at a frequency f' as the bus bar with A, ρ, f parameters provided

$$\frac{A'f'}{\rho'} = \frac{Af}{\rho} \tag{5}$$

There are several points to be noticed in the above example:

1. It was only by a judicious choice of quantities involved that equation 2 could be written. This emphasizes the point that it requires a background of knowledge in a given field to use dimensional analysis for the derivation of similarity relations in that field.

2. Only one of the 2 possible dimensionless products was used, but equation 4 shows that the other one is r_{a-c}/r_{d-c}. An equation corresponding to equation 1 thus exists.

3. The advantages of dimensional analysis are illustrated: solving the differential equations applicable to the problem has been avoided (these equations are intractable in any save the simplest cases) and a very simple mathematical process substituted; model experiments are shown to be possible.

Equation 4 is a special case of a much more general relationship and it is the purpose of the next paragraphs to prove this. To illustrate another method of deducing similarity relations, the more general relationship will be derived in a different manner which is particularly applicable when differential equations are given.

Example of a Different Method of Deducing Similarity Relations

There are many problems which depend upon the distribution of currents, and electric and magnetic fields. Among these are problems of inductance, resistance, skin effect, proximity effect, radio transmission, eddy currents, etc. All of these problems are governed by the fundamental equations of electromagnetism (see appendix A) from which can be derived

$$\frac{4\pi}{c^2}(j\mu\gamma\omega - \mu k\omega^2)H_x' = \nabla^2 H_x' \tag{6}$$

where $j = \sqrt{-1}$, μ is the magnetic permeability, γ the specific conductivity k the dielectric permeability, c is a constant with dimensions of velocity ($c = 3 \times 10^{10}$ centimeters per second), ω is 2π times the frequency of the varying field, and H_x is the X component of the space vector $\boldsymbol{H}'$ representing this field which can be either a field of magnetic intensity, or of magnetic flux density $\boldsymbol{B}'$, or of electric field strength $\boldsymbol{E}'$ or of current density $\boldsymbol{J}'$. Similar equations exist for the Y and Z components. The term $\nabla^2 H_x'$ (see appendix B) may be considered for the present purpose simply as a second derivative of H_x' with respect to distance.

Equation 6 indicates that model experiments are possible. To prove this the following procedure may be used. Let A be any area "characteristic of" the original sample and of a group of models of this sample to which equation 6 applies. A varies among the members of the group. For convenience A may be taken perpendicular to the Z axis of a set of rec-

tangular axes XYZ and for simplicity the problem may be restricted to 2 dimensions. Write

$$x = c_x\sqrt{A}; \quad y = c_y\sqrt{A}$$

and write also

$$H' = c_H H_0; \quad \mu = c_\mu \mu_0; \quad \gamma = c_\gamma \gamma_0; \quad \omega = c_\omega \omega_0; \quad k = c_k k_0.$$

where H_0, μ_0, γ_0, ω_0, and k_0 are constants characteristic of any member of the group but may vary between members. Substituting in equation 6,

$$\frac{4\pi}{c^2}\left(jc_\mu c_\gamma c_\omega \mu_0\gamma_0\omega_0 - c_\mu c_k c_\omega^2 \mu_0 k_0 \omega_0^2\right) c_H H_{0_x} = \frac{H_{0_x}}{A}\left(\frac{\partial^2 c_H}{\partial c_x^2} + \frac{\partial^2 c_H}{\partial c_y^2}\right) \tag{7}$$

where H_{0_x} is the X component of H_0. A similar equation exists for H_{0_y}. Now if the original and its models are geometrically similar, A may vary from one to the other but c_x and c_y will be the same for all. It is assumed that μ_0, γ_0, ω_0, k_0, H_0 may differ among members of the group, but that c_μ, c_γ, c_ω, c_k, and c_H are the same at corresponding points; that is, the fields set up in the members of a group are geometrically similar (this is usually referred to as dynamical similarity). Then

$$\frac{\partial^2 c_H}{\partial c_x^2} + \frac{\partial^2 c_H}{\partial c_y^2} \tag{8}$$

must be the same for all geometrically similar models of a given original, and consequently

$$\frac{4\pi}{c^2} c_H A\left(jc_\mu c_\gamma c_\omega \mu_0\gamma_0\omega_0 - c_\mu c_k c^2 \omega \mu_0 k_0 \omega_0^2\right)$$

must be the same for this to be true. Hence if c_1 and c_2 are constants, the same for all models of a given sample,

$$\left.\begin{aligned} &\mu\gamma\omega A = c_1 \\ &\text{and} \\ &\mu k\omega^2 A = c_2 \end{aligned}\right\} \tag{9}$$

express the similarity conditions. That is, if equations 9 hold, a distribution of H (or B, J, or E) will be obtained in the model which is exactly similar to that in the original, and quantities depending upon H (or B, J, or E) will be related to corresponding quantities of the model in a definite manner. The 2 similarity conditions expressed by equations 9 cover the general case in which both conduction and displacement currents, or nonradiation and radiation fields, must be considered. If displacement currents and radiation may be neglected,

$$\mu\gamma\omega A = c_1$$

is sufficient. Comparing this with equation 5, it is seen that the 2 are intimately related; indeed the latter follows from the former at once except for the factor μ, accounted for below.

If conduction currents and nonradiation fields may be neglected, then

$$\mu k\omega^2 A = c_2$$

is sufficient for model experiments.

In the intermediate cases in which it is unknown *a priori* which class is concerned, the above conditions might be used in determining the classification. Grover and his students have done some work in this field,[4] not using the present method.

Boundary Conditions

There is one important limitation contained implicitly in the above argument—not only must the fundamental equations be satisfied, but certain boundary conditions also must be considered. This limitation should be borne in mind in determining similarity conditions in general.

Consider for example a cylindrical conductor with its axis parallel to a magnetic field, and let the problem be the investigation of the field in the conductor. The magnetic field may be produced in several ways; for example: (1) By a source outside of and at great distance from the conductor so that the magnetic field is uniform over the surface of the conductor; or (2) by a coil concentric with the conductor and of diameter slightly greater than that of the conductor. In case 2 there is obtained the "magnetic skin effect" and the distribution of the magnetic field is the same as the distribution of the current density in the case of electrical skin effect.

There are here 2 apparently similar problems. The same electromagnetic equations (appendix A) are involved and the physical boundary of the conductor is the same in whichever of the 2 fields the conductor is placed. The point of difference is that at the surface of the conductor different conditions hold:

Case 1: H = constant
Case 2: $H_{T(\text{conductor})} = H_{T(\text{air})}$
and $\mu H_{N(\text{conductor})} = H_{N(\text{air})}$

where H_T is the tangential component and H_N the normal component of H. The low frequency similarity relation $\mu\gamma\omega A = c_1$ holds only in case 1; in case 2 μ cannot be changed, i. e., the model must have the same μ as the original and the similarity relation is reduced to $\gamma\omega A = c_1'$.

Other Model Experiments

Potential model experiments in electrical engineering are by no means limited to those dependent solely upon the electromagnetic field equations. For example, model experiments might be used in studying the stability characteristics of synchronous machines. The well known equation for the oscillation of the rotor of a synchronous motor to which a sudden load is applied is

$$P_I \frac{d^2\theta}{dt^2} + P_d \frac{d\theta}{dt} + P_m \sin\theta = P_L \tag{10}$$

where θ is the phase angle between the terminal potential and the electromotive force induced in the armature; $P_I = KI$ where I is the moment of inertia of the rotor and K a constant; $P_d = V^2/360fr_2$, approximately, where r_2 is the equivalent symmetrical rotor resistance per phase and V the magnitude of the voltage applied to the armature; $P_m = VE_1'/x_s$ where E_1' is the magnitude of the induced electromotive force in the armature due to the d-c field current and x_s is the synchronous reactance; and P_L is the shaft load suddenly applied to the motor.

It is evident that the values of the coefficients P_j, P_m, P_d, and P_L can be reduced considerably if the experiment is performed on a small model. At the same time the equation will remain invariant, hence the oscillations of the small model will give as much information as if the experiment were performed on the full size motor, in so far as equation 10 governs the motion. Moreover, if the measuring scale of time is changed by introducing a new time variable, say $t' = nt$, it is seen that equation 10 will remain invariant if the coefficient P_j is increased in proportion to n^2 and the coefficient P_d in proportion to n. In this way, it is possible to regulate the speed of oscillations without changing their geometrical characteristics; this may be of some interest in experimental work.

Supplementary Note

This paper was written originally to discuss the applications (and lack of applications) of dimensional analysis in electrical engineering in the belief that new uses for model experiments might be uncovered by engineers unacquainted with the basic theory. Between the first writing and the revision of the paper several reports of model experiments in the electrical field have appeared. These are listed in the bibliography.[20–23] They represent an answer to the authors' purpose but since it is only a partial answer the original form of the present paper has been retained.

Appendix A

The fundamental electromagnetic equations are

$$\frac{4\pi}{c}\left(J + \frac{\partial D}{\partial t}\right) = \nabla \times H \tag{11}$$

$$\nabla \cdot D = 4\pi\rho \tag{12}$$

$$-\frac{1}{c}\frac{\partial B}{\partial t} = \nabla \times E \tag{13}$$

$$\nabla \cdot B = 0 \tag{14}$$

$$F = E + \frac{v \times B}{c} \tag{15}$$

where J is the vector conduction current density ($J = \gamma E$ expresses Ohm's law, γ is the specific conductivity); $D = kE$ is the vector electric flux density, k the dielectric permeability and E the vector electric field intensity; $B = \mu H$ is the vector magnetic flux density; μ the magnetic permeability and H the vector magnetic field strength; ρ is the electric charge density (no relation to the ρ used previously for resistivity), and F is the force on a unit charge moving with vector velocity v.

By taking $\nabla \times$ of equation 11, differentiating equation 12 with respect to t and substituting, using equation 13 also, there may be obtained

$$\frac{4\pi}{c^2}\left(\mu\gamma\frac{\partial H}{\partial t} + k\mu\frac{\partial^2 H}{\partial t^2}\right) = \nabla^2 H \tag{16}$$

subject to the assumptions that (Ohm's law) $J = \gamma E$ and that k and μ are constants. Since equation 11 is linear, one term of the Fourier series expansion of H as a function of t may be used $H = H'\epsilon^{j\omega t}$ where H' is a function of the space coördinates only, ω is constant, ϵ the base of the natural logarithms and $j \equiv \sqrt{-1}$.

Then

$$\frac{4\pi}{c^2}(j\mu\gamma\omega - \mu k\omega^2)H' = \nabla^2 H' \tag{17}$$

which gives the magnetic field distribution. Likewise, for the current distribution and for electric field distribution there may be obtained

$$\frac{4\pi}{c^2}(j\mu\gamma\omega - \mu k\omega^2)J' = \nabla^2 J' \tag{18}$$

and

$$\frac{4\pi}{c^2}(j\mu\gamma\omega - \mu k\omega^2)E' = \nabla^2 E' \tag{19}$$

which are similar to equation 17. These equations can be solved only in certain simple cases.

Appendix B

Vector Notation. The Gibbs notation is used. Bold-faced symbols denote vectors, the same symbols in italics and not bold-faced denote the magnitude of the vectors. All vectors are space vectors, not vectors representing the complex numbers of a-c circuit theory. The dot product $\boldsymbol{a} \cdot \boldsymbol{b}$ is the same as the scalar or inner product of $\boldsymbol{a}$ and $\boldsymbol{b}$; the cross product $\boldsymbol{a} \times \boldsymbol{b}$, is the same as the vector or outer product of $\boldsymbol{a}$ and $\boldsymbol{b}$. The quantity

$$\nabla \equiv \boldsymbol{i}\frac{\partial}{\partial x} + \boldsymbol{j}\frac{\partial}{\partial y} + \boldsymbol{k}\frac{\partial}{\partial z}$$

($\boldsymbol{i}$, $\boldsymbol{j}$, $\boldsymbol{k}$, unit vectors parallel to the axes XYZ of a rectangular coordinate system) is both a vector and a differential operator. $\nabla \times \boldsymbol{H}$ is the cross product of ∇ and $\boldsymbol{H}$, sometimes called the curl of $\boldsymbol{H}$; $\nabla \cdot \boldsymbol{D}$ is the dot product of ∇ and $\boldsymbol{D}$, sometimes called the divergence of $\boldsymbol{D}$; $\nabla\phi$ where ϕ is a scalar function of x, y, z, t is sometimes called the gradient of ϕ

$$\nabla^2 \equiv \nabla \cdot \nabla \equiv \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

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The M.I.T. Power Factor Bridge and Oil Cell

Recent developments in a bridge devised at Massachusetts Institute of Technology for obtaining high-precision power-factor measurements on small oil samples, and the associated oil cell, are described in this paper, and the results of measurements on oil samples are discussed. Several conclusions drawn from the work done at M.I.T. on power factor bridges and measurements are given.

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A RESEARCH project on the development of a power factor bridge, test apparatus, and test methods for the power factor measurement of small oil samples has been carried on since June 1930 in the electrical engineering department of the Massachusetts Institute of Technology. This project was conducted with the financial assistance of the Association of Edison Illuminating Companies and the National Electric Light Association, and in coöperation with the cable research subcommittee of the National Electric Light Association, until the dissolution of the National Electric Light Association. While this specific project has been terminated, the study of the general problem of the fundamental properties of insulating oils in particular and insulation in general will be continued in the electrical engineering department of the Massachusetts Institute of Technology.

A previous paper "A Bridge for Precision Power Factor Measurements on Small Oil Samples," by J. C. Balsbaugh and P. H. Moon (A.I.E.E. Trans., v. 52, 1933, p. 528–35), discussed some of the general problems of power-factor bridge design and bridge measurements. The present paper includes further developments in bridge design, design of oil cells, inherent power factor of oil cells and the power factor measurement of oil samples. The general theory of the bridge, operation of the bridge, and the design of the detecting circuit is given in a companion paper,[1] "Comprehensive Theory of a Power Factor Bridge," by J. C. Balsbaugh and Alfred Herzenberg (*Jl. of the Franklin Institute*, v. 218, 1934, p. 49–97).

General Description of Bridge

The type of bridge which is recommended for high-precision power-factor measurements on small oil samples is shown in Fig. 1. This bridge is of the Schering type with symmetrical low voltage measur-

1. This paper includes the general bridge and shield equations, the calculation of the measured bridge power factor and capacitance, calculation of the sensitivity of the bridge expressed in terms of the minimum detectable changes in power factor and capacitance, a study of the factors affecting the precision and accuracy of the power factor measurements, effect of a shield unbalance on the measured power factor and capacitance by bridge measurements, calculation and measurement of the power factor of an oil sample, and the measurement and evaluation of the power factor of air capacitors.

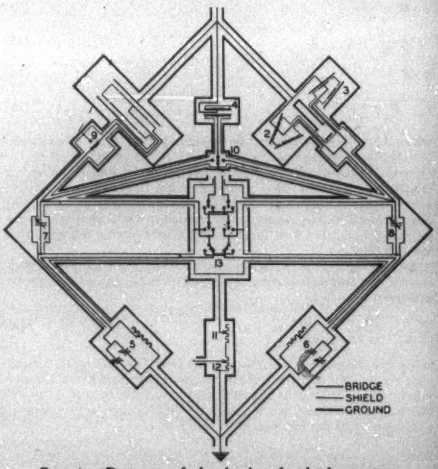

Fig. 1. Diagram of the bridge for high-precision power-factor measurements on small oil samples

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ing bridge arms and a variable capacitance in one of the high voltage bridge arms. The bridge is constructed with a single shield circuit so that the effect of a shield unbalance on the measured power factor and capacitance by the bridge may be minimized through adjustment of the capacitance between the shield and either bridge arm.

The component parts of the bridge are indicated in Fig. 1 and may be described as follows:

Item 1. A fixed cylindrical capacitor having a capacitance approximately equal to that of the oil sample.

Item 2. A variable conical capacitor having a maximum capacitance approximately equal to that of the fixed capacitor. This capacitor should be designed so that changes in capacitance of the order of 10^{-4} of the fixed capacitance may be easily obtained.

Item 3. A variable conical capacitor having a total capacitance of the order of 1 to 2 (10^{-12}) farad, a total change in capacitance of approximately 5 (10^{-4}) of the fixed capacitance and designed so that changes in capacitance of the order of 10^{-7} of the fixed capacitance may be obtained.

Item 4. An oil cell for testing an oil sample. The capacitance of this sample with oil should be of approximately the same capacitance as the fixed capacitor. An oil cell having a volume of approximately 50 cu cm of oil and a capacitance of approximately 25 (10^{-12}) farads with oil has been found satisfactory. However, it is possible to decrease these values and still obtain satisfactory measurements.

Items 5 *and* 6. Similar measuring arms consisting of resistance in parallel with variable capacitors. The resistance consists of 1,000, 100, 10, 1, and 0.1-ohm units and has a total resistance of 9,999.9 ohms. The variable capacitors consist of: (1) a variable, $1{,}500(10^{-12})$-farads precision air capacitor through which changes in capacitance of the order of $0.3(10^{-12})$ farad can be obtained; and (2) variable mica capacitors having a total range of approximately $300{,}000(10^{-12})$ farads through which changes in capacitance of approximately $1{,}500(10^{-12})$ farads can be obtained.

Items 7 *and* 8. Variable capacitors with a range in capacitance of approximately $2{,}000(10^{-12})$ farads and which may be easily adjusted through a range of approximately 25 (10^{-12}) farads. These capacitors are used for obtaining approximate equality of the capacitances between bridge and shield on the 2 sides of the bridge.

Item 9. Switching arrangement so that the fixed capacitor may be connected to either bridge or to shield.

Item 10. Switching arrangement so that the oil cell may be substituted for the fixed capacitor, connected in parallel with variable capacitors (items 2 and 3) or connected to shield.

Item 11. Resistance for balancing shield. This resistance gives principally magnitude balancing for the shield circuit and should be similar to resistances in the low voltage measuring bridge arms (items 5 and 6).

Item 12. Resistance for phase balancing of the shield circuit. This resistance is approximately 5 ohms, adjustable through 0.1-ohm steps and is connected to give a component of the applied bridge voltage.

Item 13. Switch box consisting of: (1) a switch for reversing the arms of the bridge, that is, to permit item 5 or 6 to be connected to either item 1 or item 2; (2) a switch for connecting the detecting circuit between the bridge arms for bridge balancing and between either bridge arm and shield for shield balancing; (3) a switch enabling the detecting circuit to be reversed.

The switches referred to in the foregoing should be constructed so that the circuit is not broken in making a change in the circuit connections. When a bridge is to be operated with a relatively high applied voltage it is advisable to protect the operator from high voltages on the circuits having normally low voltages and which may be produced by either an open circuit or by a mechanical failure of one of the capacitors (items 1, 2, and 3 in Fig. 1). This may be conveniently accomplished through the use of a voltage regulator type of vacuum tube which breaks down at a relatively low voltage. Two of these tubes may be connected in parallel (back to back) to limit the voltage for each half-cycle. Complete protection of the bridge and shield circuits may be obtained by placing such tubes between each bridge arm and shield and between shield and ground. For a bridge with relatively low capacitances in the high voltage arms, these tubes will carry for a sufficient length of time the full short-circuit current of a power transformer having the required volt-ampere rating to energize the bridge.

The bridge shown in Fig. 1 is shielded at both shield and ground potentials. The use of a shield permits obtaining an approximately uniform gradient over the bridge sections of the oil cell and high voltage capacitors, and also permits power factor and capacitance measurements to be obtained in terms of constants which may be accurately determined. The use of a shield at ground potential for the shield circuit effectively eliminates electrostatic pick-up in the shield circuit and thereby gives a more steady shield balance.

Fixed and Variable High Voltage Capacitors

The design of the fixed capacitor is shown in Fig. 2. This capacitor is of the cylindrical type and consists of high-voltage, bridge, shield, and ground sections supported by a hollow shaft. The component parts of this capacitor are also indicated and explained in Fig. 2.

In this capacitor, insulation is placed between the high voltage section and ground, between shield and

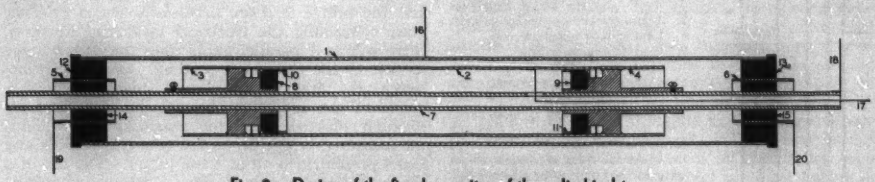


Fig. 2. Design of the fixed capacitor of the cylindrical type

1. High voltage section
2. Bridge section
3, 4. Shield sections
5, 6. Ground sections
7. Shield supporting shaft
8, 9. Insulation between bridge and shield section
10, 11. Spacers for 3, 4 and 8, 9
12, 13. Insulation between high voltage section and ground
14, 15. Insulation between shield and ground
16. High voltage lead
17. Bridge lead
18. Shield lead
19, 20. Ground leads

ground, and between the shield and measuring sections. Placing the ground section between the high voltage section and shield prevents variable surface leakage and conduction currents through the insulating support of the high voltage section from giving an unsteady shield balance. It is important that the insulation between bridge and shield sections be shielded from the high voltage section to prevent any loss entering the bridge from this source. Since for bridge and shield balance, the bridge and shield potentials are adjusted to be very closely equal (within the sensitivity of the bridge), the loss in the insulation between bridge and shield will be negligible. It can be shown theoretically that even if the insulation between bridge and shield has a relatively high power factor, the shield may be easily balanced sufficiently closely to prevent any inaccuracies (in the desired range) in the bridge measurements. This fact may also be checked experimentally by balancing the bridge and shield with and without a definite resistance connected between bridge and shield. The insulation used in the construction of this capacitor may be fiber, hard rubber, bakelite, or other similar materials.

The design of the variable capacitors (items 2 and 3 in Fig. 1) is, in general, similar in principle to the fixed capacitor (Fig. 2) but they are conical in shape instead of cylindrical.

Tests have shown that air capacitors may have inherent power factors which may be relatively high in the 0.000001 range. Since a bridge in general measures the difference in power factor of the 2 impedances in the high voltage bridge arms, the measurement of the power factor of an oil sample in one of the bridge arms to a power factor precision of 0.000001 requires either the evaluation of the power factor of the air capacitors, if they are significant in this power factor range, or a capacitor which has an inherent power factor which is negligible in this power factor range. Power factor tests of air capacitors have shown that the power factor of a capacitor designed similarly to Fig. 2 and constructed with brass surfaces may be made negligible in the 0.000001 range by thoroughly cleaning (removing the surface oxide and cleaning with carbon tetrachloride) the measuring surfaces and by operating the capacitors at a gradient of the order of 1,000 volts per inch.

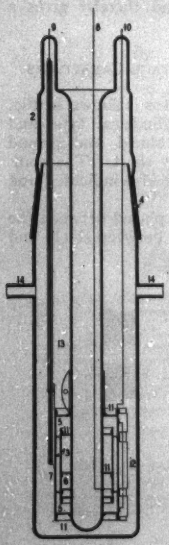
A capacitor of the design shown in Fig. 2 may be constructed from standard tubing. The advantages of this design are: (1) simplicity, (2) the ease of obtaining a shielded lead from measuring section, (3) the ease of disassembling capacitor for purpose of cleaning measuring surfaces, (4) the possibility of using inexpensive types of insulation, and (5) the inexpensive type of construction. Capacitors of the design shown in Fig. 2 have been found satisfactory for high-precision power-factor measurements of small oil samples.

It has been found important to have good connections (the equivalent of soldered connections) for the leads to the high-voltage, bridge, shield, and ground sections of the capacitors. Due to the relatively small currents flowing through these contacts, a poor contact may give a relatively high resistance in addition to producing an unsteady balance.

Oil Cells

An assembly of one of the types of oil cell which may be used for the measurement of the power factor of a small oil sample is shown in Fig. 3. This cell consists essentially of a pyrex glass container for the oil sample, a pyrex glass cap with supporting tube for the electrical measuring surfaces of the cell and the electrical measuring surfaces consisting of high-voltage, shield, and measuring section nickel cylinders.

Another type of cell that has been used for power factor measurements of oil samples is shown in Fig. 4. This cell is, in principle, essentially the same electrically as the cell shown in Fig. 3 with the exception that it has a copper tube sealed into the glass tube through which the measuring or bridge lead is brought out of the cell. Since the high voltage lead and the bridge lead are necessarily sealed into the glass containing the electrical measuring surfaces, there will be 2 parallel paths from the high voltage section to the measuring section: one directly between the high voltage and measuring-section cylinders and the other through the glass between the high voltage lead and the measuring leads. Thus the measured bridge power factor would include any losses present in both of these paths. The use of a copper tube as shown in Fig. 4 will permit determining the effect of the parallel path through the glass to the measuring lead on the measured power factor by the bridge. The effect of any loss in the glass may be completely eliminated from the measured bridge power factor by connecting the copper



1. Pyrex glass container for oil sample
2. Pyrex glass cap and supporting tube for cell measuring and shield sections
3. Electrical measuring surfaces of cell
4. Ground joint
5. Shield sections—nickel cylinders
6. High voltage section—nickel cylinder
7. Measuring section—nickel cylinder
8. Lead to high voltage section
9. Lead to bridge section
10. Lead to shield sections
11. Supporting disks—nickel, spot welded to cylinders
12. Supports for 5 and 7—nickel bands and pyrex glass rods
13. Shield for measuring section lead
14. Tubulations for evacuating cell or for permitting sample to be placed in cell. External shield for cell measuring section is placed outside of cell

Fig. 3. Assembly of one type of oil cell for the measurement of the power factor of a small oil sample

1. High voltage section
2, 4, 5. Shield sections
3. Measuring section
6–12. Supporting disks
13–18. Assembly and supports for 2, 3, 4
19. Clamp for fastening assembly of 2, 3, 4
20. Support for 1
21. Lead to high voltage section
22. Lead to shield
23. Lead to measuring section
24. Copper tube sealed in tube for measuring section lead
25. Lead to copper tube shield
26, 27. Shields for lead to measuring section
28. Pyrex glass insulation between measuring section lead and shield
29, 30. Ground shields
31. Insulation, high voltage to ground
32, 33, 34. Tubulations
35, 36. Pyrex glass cylinders
37. Pyrex glass tube for copper tube and measuring lead

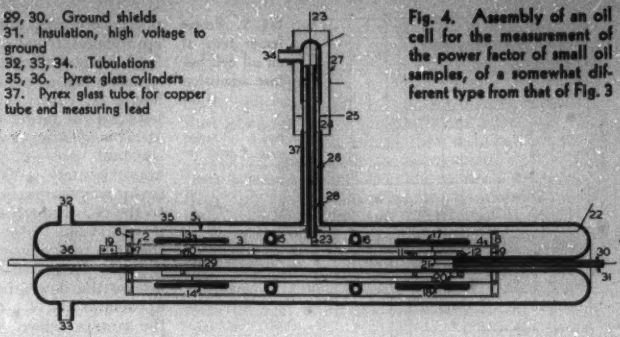


Fig. 4. Assembly of an oil cell for the measurement of the power factor of small oil samples, of a somewhat different type from that of Fig. 3

tube to shield. For this condition any loss in the glass will simply affect the shield circuit balance. With the copper tube connected to the bridge lead a part of the loss in the glass will be measured by the bridge. It has been found that with cell constructions similar to those shown in Figs. 3 and 4, and with a relatively long distance between high voltage and bridge leads, the loss in the glass (with copper tube eliminated from the cell or with the copper tube connected to bridge) will not be significant in the 0.000001 range of measured bridge power factors for temperatures of the cell up to 100 deg C.

The cell shown in Fig. 4 has the bridge section of the cell shielded by means of a nickel cylinder within the cell. For the cell shown in Fig. 3 it is assumed that a satisfactory shield for the bridge section of the cell is provided external to cell. This may conveniently be an external shield at a relatively small distance from the cell with the cell and shield placed in a conducting bath (may be same as heating bath) or a type of shield that may be placed directly on the exterior of the cell (these shields being of sufficient size to shield completely the bottom of cell to a height at least comparable to the interior measuring surfaces).

A cell of the type shown in Fig. 4 may be operated satisfactorily at higher temperatures than the cell shown in Fig. 3 and also may be more easily constructed with a larger capacitance and for larger oil volumes than the cell shown in Fig. 3. Furthermore, a cell of the type shown in Fig. 4 may be completely immersed in an oil bath or placed in an oven (for measurement of power factors at temperatures exceeding room temperatures), whereas the ground joint of the cell in Fig. 3 will limit the permissible cell temperature (particularly so when it is desired to heat the oil under a vacuum), and also will permit only the lower part of the cell to be placed in any oil bath or oven.

The main advantages of the cell construction of Fig. 3 are that the cell may be easily taken apart for effective cleaning following an oil test, and also may be constructed for quite small volumes of oil samples. Where a cell is to be used for testing a number of oil samples, it is desirable to have a relatively simple and effective method of cleaning the cell between tests to prevent contamination of an oil sample from preceding samples. An effective method of cleaning the cell after an oil test has been to remove the cap with the electrical measuring surfaces from the container and thoroughly wash the parts of the cell with carbon tetrachloride and benzene.

A cell of the type of construction indicated in Figs. 3 and 4 also will permit an oil sample to be tested either under a vacuum, that is, excluding air, or in the presence of an inert gas such as carbon-dioxide or nitrogen and thereby prevent contamination of the sample due to contact with air. Testing an oil sample in the presence of an inert gas may also be important in cases where it is desired to test an oil that has been in service, since the testing of the oil under a vacuum may possibly liberate the absorbed gases, thereby producing a change in the oil. The inert gas may be admitted to the cell before the sample is put into the cell, so that any desired pressure comparable to operating conditions may be reproduced for the test sample. Where it is desired to make tests of oil samples from cables in service, the oil may be transferred directly from the cable to the cell in the field, thereby preventing a change in the test sample either due to contact with air or through successive handling of the sample in several containers.

Power Factor Tests of an Oil Cell Before Admission of Oil

Tests have shown that air capacitors may have inherent power factors that may be quite substantial in the 0.000001 range. It is therefore pertinent to investigate the power factor of an oil cell before the admission of oil, and determine the magnitude of this power factor and the methods by which it may be reduced or made negligible in the desired range of power factor measurements. The power factor of the cell before admission of oil to the cell may affect the measured power factor of an oil sample in the cell and the condition producing an inherent power factor may also cause a deterioration of the sample.

Power factor tests on oil cells before the admission of oil are given in Figs. 5 and 6. The cells used for

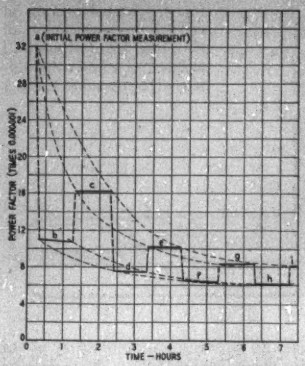


Fig. 5. Power factor tests of an oil cell before admission of oil

a, c, e, g, and i. Power factor measurements at atmospheric pressure (room air)
b, d, f, and h. Power factor measurements at vacuum
All measurements at normal room temperature

these tests were similar in construction to the cell shown in Fig. 4 and as described under the previous heading "Oil Cells." The metal cylinders and disks of the cells were made from a high grade of nickel tubing and nickel strip, respectively, and before assembling in the cells were polished, cleaned with carbon tetrachloride, and then heated in a hydrogen oven at 1,300 deg F for 10 min. Following the construction of the completed cell, the cell was cleaned with carbon tetrachloride and benzene. The tests were made with an average potential gradient of approximately 12,800 volts per inch on the measuring surfaces of the cell and with an applied bridge voltage having a frequency of 55 cycles per second.

Power factor test results are shown in Fig. 5, the measurements being made both at room temperature with room air at atmospheric pressure in the cell and with the cell evacuated (0.0001 to 0.001 mm of mercury). Successive test results in Fig. 5 are indicated by *a*, *b*, etc., to and including *i*, with *a*, *c*, *e*, *g*, and *i* representing measurements with room air at atmospheric pressure and *b*, *d*, *f*, and *h* representing measurements with the cell evacuated. The results given are average values from similar tests made on 6 different cells. Before any power factor measurements were made on a cell it was first sealed to a vacuum system. Following this, the initial power factor of the cell with room air at atmospheric pressure would be either of the order of 0.00003 or impossible to obtain. However, after evacuating the cell no difficulty would be experienced in obtaining a power factor measurement, and the power factor would be from 0.000010 to 0.000012. It is probable that the high or unattainable initial power factor with room air at atmospheric pressure is caused by moisture in the cell, and which the vacuum removes in part, for no further difficulty would be experienced in obtaining power factor measurements with either air or a vacuum. Succeeding power factor measurements with room air at atmospheric pressure and at a vacuum gave the average results given in Fig. 5. It may be noted that for successive evacuations or the admission of room air at atmospheric pressure, both the difference between the power factors and the power factors at atmospheric pressure and at a vacuum decreased until approximately constant values were obtained. The final constant values could also be obtained by maintaining a vacuum in the cell for a sufficient length of time. The magnitude of the difference between the power factors of the cell with room air at atmospheric pressure and at a vacuum, after constant values of power factors were reached, was approximately 0.000002. This difference in power factor was also measured with the room air admitted to the cell through a filter and a liquid-air trap, and it was found to be approximately 25 per cent less than the foregoing value.

An investigation of the effect of temperature of a cell on the power factor of the cell with the cell at a vacuum (0.0001 to 0.001 mm of mercury) gave the results shown in Fig. 6. These temperatures were measured by thermocouples, the thermocouples being located, (*a*) one over the center of the measuring cylinder, (*b*) one under the center of the high voltage cylinder, and (*c*) one between an inner and the outer shield cylinders. The tests shown in Fig. 6 were made on a cell following an evacuation for a sufficient length of time to give the constant sustained values of power factor shown in Fig. 5. Curves *A*, *B*, and *C* in Fig. 6 give power factor against cell temperature for successive heat runs on the cell with the temperatures increased from room temperature to approximately 220 deg C and then decreased. Curve *A′* is a continuation of curve *A*, but due to the rapidity of change in power factor at the higher values, satisfactory measurements could not be obtained. It is interesting to note that for successive heat runs the power factors decrease (below 180 deg C) for corresponding temperatures. Also the temperature difference at a given power factor, for the loop representing increasing and decreasing temperatures of the heat cycle, decreases for successive heat runs. The loop effect of the curves cannot be due to inaccurate temperature measurements, since the maximum difference in temperature between the thermocouples on opposite sides of the space between measuring surfaces was approxi-

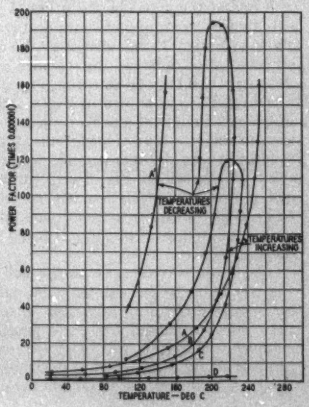


Fig. 6. Power factor tests of an oil cell before admission of oil

Cell under a vacuum

mately 4 deg C. The rate of temperature rise for each of the curves was approximately 30 deg C per hour. The difference in power factors at corresponding temperatures (below 180 deg C) decreased for successive heat runs (with temperature increasing) until continued heating had only a very slight effect on the power factors at a given temperature. For this reason only the results of 3 heat runs are given in Fig. 6. Curve *D* in Fig. 6 gives power factor versus cell temperature after the cell (following the aforementioned heat runs) had been heated by induction until the nickel cylinders of the cell came to a red heat without appreciably changing the degree of vacuum. It is interesting to note that the power factor at 20 deg C decreased to approximately 0.0000005 and, furthermore, was approximately constant through the range of temperature up to 220 deg C. Tests similar to the foregoing were made on a number of cells and substantially the same results as given in Fig. 6 were obtained.

Power Factor Tests on Oil Samples

The results of power factor measurements on a low viscosity type of cable oil (oil that had not been in service) are shown in Fig. 7. The oil used in this test was received from the manufacturer in a metal container which had been throughly cleaned and dried and the air displaced by carbon dioxide before the oil was admitted to the container. After the container was nearly filled with oil the space above the oil was filled with carbon dioxide at a pressure slightly greater than atmospheric pressure. Following this, the container was sealed.

The oil to be tested was transferred from the metal container to a thoroughly cleaned, dried, and evacuated glass flask. This may be done by first pouring a part of the oil into a cleaned funnel connected to the flask through a stopcock. A portion of the oil in the funnel may then be allowed to flow into the evacuated flask. This procedure may be followed until the desired quantity of oil is contained in the flask. The only time that the oil was in contact with air was during the short time of transferring the oil from the metal container to the glass flask.

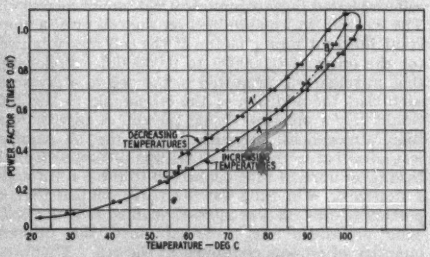


Fig. 7. Power factor measurements on a sample of a low viscosity type of cable oil before being placed in service

Solid dots indicate temperature readings of thermocouple placed directly over center of measuring section
Circles indicate temperature readings of thermocouple placed directly under center of high voltage section

A vacuum was held over the oil in the flask for a period of approximately 3 hr. Then the oil was allowed to flow into another thoroughly cleaned, dried, and evacuated glass flask through a stopcock, the rate of flow of oil being adjusted so that approximately 100 cu cm of oil flowed into the second evacuated glass flask in approximately 6 hr. A vacuum was also held over the oil in the second glass flask. From this flask the oil was allowed to flow into the evacuated oil cell. The foregoing method of treating the oil should permit removing the greater part of the absorbed carbon dioxide from the oil that is admitted to the cell. The stopcocks that were a part of the oil-containing or transfer apparatus were lubricated by the same kind of oil as under test.

The cell used for this test was similar to the cell shown in Fig. 4 with the exception that a copper seal was not used. Oil temperatures were measured by means of thermocouples, one placed directly over the center of the measuring section, another directly under the center of the high voltage section, and another between the inner and outer shield sections. This method permits temperature measurements being obtained inside and outside of the oil under test (that is, the oil between the measuring and high voltage sections). Before the oil was admitted to the cell, the cell was cleaned, evacuated, and heated by induction similarly as for the cell giving curve *D* in Fig. 6 and as explained under the previous heading "Power Factor Tests of an Oil Cell Before Admission of Oil." The power factor of the cell (under vacuum at room temperature) before admission of oil was less than 0.000001 (see Fig. 6).

Measurements on the Oil Sample

After the oil was admitted to the evacuated cell, power factor and temperature measurements were first made at room temperature. All power factor tests given in connection with this group of tests on oil samples were made at a frequency of 55 cycles per second and at an average voltage gradient of approximately 12,800 volts per inch. Then the sample was heated to 100 deg C, first at a rate of approximately 20 deg C per hour from room temperature to 80 deg C, and then at successively lower rates until a constant temperature of 100 deg C was obtained. The sample was maintained at approximately 100 deg C for a period of 2 hr and then was allowed to return to room temperature. This cycle was repeated on one sample 45 times. The results of this series of tests showed that the power factor of the sample (at corresponding temperatures for successive heat runs) decreased at room temperature (approximately 20 deg C) and 100 deg C for the first and second runs, but from the third run on, the power factor of the sample showed no significant average change. The initial power factor at 20 deg C was 0.000875 and the average power factor at 20 deg C for the third and succeeding runs was 0.000562 with a maximum deviation from this value of 0.00005 power factor. The initial power factor at 100 deg C was 0.01125 and the average

power factor at 100 deg C for the third and succeeding runs was 0.01034 with a maximum deviation from this value of 0.00006 power factor. These results were checked with 2 other cells of the same construction using other samples of the same type of oil and with the same test procedure, and gave results substantially the same as the foregoing.

In Fig. 7, curves *A* and *A'* give the power factor of an oil sample for various temperatures from approximately 20 deg C to approximately 100 deg C for increasing and decreasing temperatures. The temperature readings of the thermocouple placed directly over the center of the measuring section and of the thermocouple placed directly under the center of the high voltage section are plotted. Since these thermocouples are symmetrically located with respect to the oil being measured, obviously the average temperature of the oil being measured must closely approximate the average temperature of these 2 thermocouples. This test was made on a sample following the initial decrease in power factor described in the foregoing. The rate of temperature change was approximately 20 deg C per hour for both increasing and decreasing temperatures. It is interesting to note that the power factor of the oil for corresponding temperatures is greater for decreasing temperatures than for increasing temperatures. Furthermore, this phenomenon cannot be explained by erroneous temperature readings, since the difference in average temperature for a given power factor is as large as approximately 8 deg C, whereas the maximum difference between the temperature readings of the 2 thermocouples at any time is approximately 1.5 deg C. Also the power factor at the conclusion of the decreasing temperature part of the cycle returns to the initial reading at room temperature and therefore shows that no progressive deterioration has taken place as a result of the heating cycle. Similar results were obtained on 3 samples of the same kind of oil with similar test conditions.

Curves *A* and *B* give power factor of the sample against temperature, in which the sample is heated to 80 deg C at the same rate as for the foregoing cycle and then the rate is successively decreased until a constant temperature of 100 deg C is reached. It is interesting to note that the power factor for a given temperature changes with a change in the rate of temperature rise and the power factor for a constant temperature of 100 deg C is approximately on the median line of the loop representing the power factors for the increasing-decreasing temperature cycle. Curves *A* and *C* give similar results for a constant temperature of approximately 57 deg C.

Tests on Related Factors

Tests were also made on oil samples to determine the effect of an inherent cell power factor on the measured power factor of an oil sample. For these tests 2 similar cells were used (as shown in Fig. 4 and as described for the preceding tests), one cell being thoroughly cleaned, evacuated, and heated by induction so that the inherent power factor of the cell was negligible in the 0.000001 range of power factor (see Fig. 6, curve *D*), and the other cell being only thoroughly cleaned and evacuated until a constant inherent power factor, 0.000006, was obtained (see Fig. 5, line *h*). These cells were then simultaneously filled with the same type of oil, in a manner similar to the method as given previously. Following this, power factor tests on these samples were made at both room temperature (approximately 20 deg C) and at 100 deg C to determine the difference in power factor of the 2 samples. The kind of oil used for these samples was the same as that used in the preceding tests and gave results substantially the same as those previously given, and also the power factors checked very closely with the values given in Fig. 7. The initial difference in power factor of the 2 samples at room temperature was 0.000017, which decreased to 0.000006 (the same as the initial difference in the inherent power factors of the cell before the admission of oil) after constant power factors at room temperature were reached for both samples. The difference in power factor of the 2 samples at 100 deg C was approximately 0.00058, and this difference was approximately constant and did not change as the power factors of the 2 samples decreased slightly until constant values were obtained (as described previously for the same kind of oil in similar cells). These results show that the inherent power factor of a cell does have an effect on the measured power factor of an oil sample in the cell, but this inherent power factor may be made negligible in the 0.000001 range of power factor.

For the application of an oil cell of the type shown in Fig. 3 for the routine testing of laboratory oil samples or oil samples extracted from cables in service, it is advisable to determine the effectiveness of cleaning the cell following the power-factor measurement of a sample. For this purpose, power factor measurements were made on a number of service-aged oils, the power factor of which varied between 0.0005 and 0.2 at 25 deg C, and between 0.03 and 0.75 at 65 deg C. The cell was cleaned initially and following an oil test, by thoroughly washing the cell with carbon tetrachloride and benzene. Then the cell was connected to a vacuum system and the cell evacuated (approximately 0.001 mm of mercury). The vacuum was maintained on the cell until a constant inherent power factor of the cell was obtained (of the order of 0.000005 to 0.000006). Following this, nitrogen was admitted to the cell to a pressure such that the addition of the oil sample to the cell would give a pressure within the cell of slightly less than atmospheric pressure. Then the oil sample was admitted to the cell. This was accomplished by having an upright tube connected to the cell through a stopcock. The tube was filled with oil and then a portion of this oil was allowed to flow into the cell. This procedure was followed until the desired quantity of oil was contained in the cell. The foregoing method permits heating the oil with air excluded from the cell and also prevents the oil test sample from being injected into a vacuum. The test procedure consisted of first measuring the power factor of the sample at room temperature, then heating the oil to 65 deg C and taking power factor

measurements at this temperature and at intermediate temperatures, and then allowing the temperature of the sample to return to room temperature, and measuring the power factor at room temperature again. The results of these tests showed that for every sample the power factor of the sample at room temperature, following a heat cycle, checked very closely the power factor at the corresponding temperature on the increasing-temperature part of the heat cycle. This indicates that no deterioration of the sample had taken place during the heat cycle. The effectiveness of cleaning the cell was determined by retesting a sample following testing of samples of different oils. In each case it was found that the power factor at both room temperatures and at higher temperatures checked very closely. It is interesting to note that for these service-aged oil samples the power factor at room temperatures did not show the decrease in power factor following a heat cycle as described previously for a different type of oil sample.

Temperature measurements for an oil cell of the type shown in Fig. 3 may be made either by thermocouples located within the cell, or by thermometers located external to the cell. When thermometers are used they may be located, one in the center tube of the cell and filling this tube with oil, and the other external to the cell.

It should be appreciated that in the measurement of the power factor of an oil sample at a given temperature, the precision of power factor measurement may be limited by the precision of temperature measurement. This is, of course, particularly true of power factor measurements made at relatively high temperatures.

Results of Experiences

The following comments are based upon experiences obtained in the development of the apparatus and its use in power factor measurements.

1. Air capacitors may have inherent power factors substantially higher than 0.000001. The magnitude of the power factor depends principally upon the condition of the surfaces and the surface voltage gradients.

2. The air capacitors may be constructed with ordinary insulations. In general the inherent power factor of a correctly designed capacitor will be independent of the power factor of the insulation used in the construction of the capacitor.

3. The use of a bridge with a single shield circuit will permit the bridge and shield balances to be made relatively independent.

4. The measured bridge power factors should be determined in terms of differences in capacitances of the measuring capacitors (items 5 and 6, Fig. 1) for different settings. Such differences may be directly determined from the dimensions of a correctly designed capacitor (conical-type capacitor similar to items 2 and 3, Fig. 1) and correctly connected into the bridge and shield circuits.

5. For high-precision power-factor measurements it is desirable to balance both the bridge and shield to the same precision for both components of balance.

6. The equivalent of soldered or welded connections should be made for leads to the electrical measuring surface of air capacitors and oil cells.

7. An oil test cell may have an inherent power factor which may significantly affect the power factor of a sample measured in the cell, but this inherent power factor may be made negligible in the 0.000001 range by effective cleaning and evacuation.

A Wattmeter for Communication Circuits

An attempt has been made to devise a different type of wattmeter for measuring power and power factor in a-c circuits such as those found in communication service. An adjustable network has been constructed in such a manner that when it is balanced in 3 operations the power factor is indicated directly and the power can be obtained by a short and simple slide-rule calculation.

By
KENNETH R. ELDREDGE*

THERE is a need for a better method of measuring power and power factor in communication circuits, particularly in the laboratory where diversified studies must be made. Ordinary wattmeters are useless because their power requirements are too great. Of course, power measurements can be made with an impedance bridge and thermocouple, or measurements can be made in a given circuit with a power level indicator. Also several vacuum tube wattmeters have been devised. Measurements by these methods are, however, not entirely satisfactory. The impedance bridge method is slow, requires expensive apparatus, and absorbs considerable power from the circuit. The power level indicator must be used in circuits of known constants; then too, frequency changes must be considered. The vacuum tube wattmeters employ special equipment and are somewhat limited in application.

The instrument discussed in this paper has several marked advantages: First, the apparatus comprising the network is inexpensive; second, the measurements are simple compared with existing methods; third, the power factor can be determined without calculation; and last, the power absorption of the wattmeter is small compared with the power levels in the circuit in which it operates. This last is very important. In its present state, however, this instrument also has some disadvantages: (1) There is an appreciable, but not large, frequency error; and (2) The accuracy becomes less at low

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power factors. The range of the instrument is great. With slight modifications it can be adapted to any a-c circuit in which a vacuum tube voltmeter can be made to operate.

In a strict sense, the apparatus is a network in which the elements are balanced with a vacuum tube voltmeter. The connections are such that the phase angle between the voltage and current vectors is readily and directly obtainable; numerical values for the current and voltage are obtained at the same time, and hence the power can be determined by simply computing the product of these 3 measurements.

Method of Making Measurements

In figure 1 are shown the connections of the network used in measuring the power consumed by the load. All the resistors are as purely resistive as possible. Resistor A is a high resistance potentiometer, B is a low resistance potentiometer, and R is a small variable resistor. The voltmeter V is a vacuum tube instrument.

The operation of the circuit is as follows: The contact on A is moved to O and the one on B to M, the electrical center of the potentiometer. The contact on R then is moved to give some arbitrary deflection, e_1, on the voltmeter. After this has been done the contact on B is moved to O, and the one on A is adjusted to give the same voltage, e_2, on the voltmeter. Without disturbing any previous adjustments, the contact on B is moved toward K until the voltmeter again reads the same, e_3. The network now is balanced, and the following theory applies:

If the load voltage be taken as the base, the voltage e_1 (which is half that across potentiometer B) will be at some angle θ as in figure 2. In the second operation the voltage e_2 is made equal to e_1, and it is as shown in figure 2 since it is a portion of the load voltage. In the third operation, by adjusting the contact on B, that is, changing e_1 to some new value e_4, the voltage e_4 measured across the extremities of e_4 and e_2 is made equal to e_3. The vector relations are now as shown in figure 3.

Potentiometer A is calibrated so that its setting a, multiplied by the voltmeter reading e_1, gives the potential in volts across the load. That is,

$$E = ae_1 \tag{1}$$

The load current is measured by the potential drop in the calibrated circuit O-K, consisting of R and B in parallel. Since the

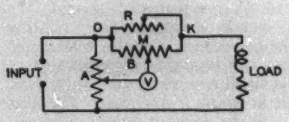


Fig. 1. Schematic diagram of wattmeter circuit

contact on B was set at the electrical center of B, the voltage e_2 is $^1/_2$ of the total voltage drop across the parallel combination, that is $e_2 = Ir/2$, where r represents the resistance in ohms of the parallel resistors R and B. Hence

$$I = \frac{2e_2}{r} \tag{2}$$

The setting, b, of potentiometer B obtained in the third operation gives the load power factor directly as will now be proved. Using figure 3 as a basis, figure 4 has been drawn. Here NP equals PS since the voltages e_3 and e_2 were made equal by adjustment as explained. Let QP be a perpendicular disector of NS. Then angle NQP is a right angle, and NQ is the in-phase component of e_3, or,

$$NP \cos\theta = NQ$$

and

$$\cos\theta = NQ/NP \tag{3}$$

But, NQ equals setting b, divided by 2, that is,

$$NQ = b/2 \tag{4}$$

Also NP equals e_2 which is a constant, or,

$$NP = C \tag{5}$$

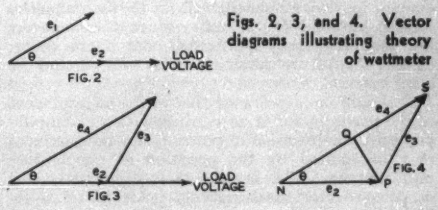
Substituting equations 4 and 5 in 3,

$$\cos\theta = \frac{b/2}{C}$$

and

$$b = C' \cos\theta \tag{6}$$

This last expression is the equation of a straight line, and the power factor is therefore a function of the linear distance along potentiometer B which was calibrated from zero to unity.



Figs. 2, 3, and 4. Vector diagrams illustrating theory of wattmeter

After the separate components of the equation $P = EI \cos\theta$ have been determined, it is only necessary to substitute them in the equation. Thus,

$$P = EI \cos\theta \tag{7}$$

$$P = ae_1 . 2e_2/r . b$$

and

$$P = \frac{2abe_1 e_2}{r} \text{ watts} \tag{8}$$

In actual operation, the values of e_1 and of e_2 were made 10^{-6} volts in all cases. The equation then becomes

$$P = \frac{2ab}{r} 10^{-6} \text{ watts}$$

or

$$P = \frac{2ab}{r} \text{ microwatts} \tag{9}$$

From equation 9 the following factors become available:

1. The power in microwatts is equal to $2ab/r$.
2. The power factor is equal to b.
3. The microvoltamperes are equal to $2a/r$.

From equation 7, other useful factors can be derived. Thus,

$$P = I^2R$$

$$P = IE \cos\theta \tag{7}$$

Then

$$P = I^2 \frac{E \cos\theta}{I}$$

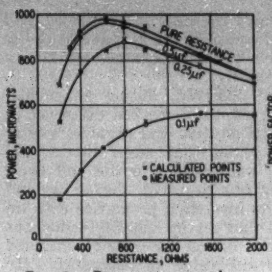


Fig. 5. Power curves with varying resistance and capacitance in series

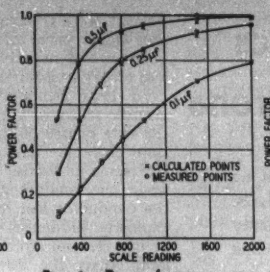


Fig. 6. Power factor curves with varying resistance and capacitance in series

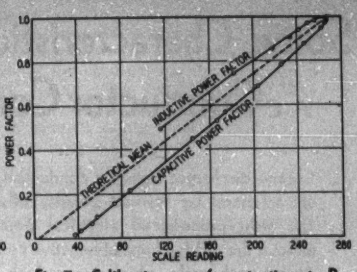


Fig. 7. Calibration curve for potentiometer B

All curves in figures 5, 6, and 7 are for a frequency of 1,000 cyles per second

and therefore,

$$R = \frac{E \cos \theta}{I} \tag{10}$$

Substituting in equation 10 the equations 1, 2, and 6,

$$R = \frac{ae_1br}{2e_3}$$

or, since e_1 equals e_4,

$$R = \frac{arb}{2} \tag{11}$$

Equation 11 then may be broken up as follows:

4. The effective resistance of the load in ohms is equal to $arb/2$.
5. The impedance of the load in ohms is equal to $ar/2$.

These 5 separate terms have been segregated here to show some of the possible applications of the network for determining the specific values of some of the frequently used factors in a-c circuits.

Construction of the Apparatus

For the particular range of currents and voltages that were to be measured in this test, that is, from 10^{-2} to 10^{-4} amperes, and from 0.5 to 2.0 volts at frequencies of from 200 to 3,000 cycles per second, the following apparatus was found to be satisfactory:

1. For the high resistance potentiometer A, a combination of a fixed, noninductive resistor of 200,000 ohms in series with a potentiometer of 600 ohms was used.

2. For B, a small noninductive continuously variable potentiometer of 12 ohms was used.

3. For R, a noninductive continuously variable resistor of about 15 ohms was used. The resistor was calibrated in ohms of resistance while in parallel with the potentiometer B.

4. The vacuum tube voltmeter used was a Western Electric laboratory type instrument with a range of from 3.16×10^{-4} volts to 3.16 volts.

Operating Characteristics

In figures 5 and 6, the data plotted are those of the calculated values of power and power factor and of the measured values of power and power factor. For the most part a very good agreement was obtained. The accuracy is within less than one per cent for high power factors, that is, power factors higher than 0.3. With small power factors, the errors became increasingly greater. This is true for several reasons. As the readings are taken from a calibrated scale, the percentage error of reading increases rapidly at the lower values on the scale. A second reason is that in figure 3, as the power factor angle θ approaches 90 degrees, and e_3 tends toward coincidence with e_2, the precision of setting is smaller as it takes a greater change of e_4 (which is the factor governing b, the power factor setting) to produce a given change of e_3. Satisfactory readings for ordinary purposes, within about 5 per cent can be made with the network at a power factor of 0.1, and for lower power factors approximations down to a power factor of 0.01 are possible.

For some reason the actual power factor of the instrument and the calculated power factor did not agree, that is, the power factor was not exactly a straight line function of the distance along the scale of potentiometer B as theory predicted. On the power factor calibration curve, figure 7, it can be seen that capacitive and inductive power factors fall a slight distance on either side of the theoretical mean. This caused no particular difficulty, but merely necessitated using calibration curves rather than a calculated curve, which, of course, is no limitation.

The apparatus also was tested for frequency error. It was found that calibrations at 1,000 cycles per second were not appreciably in error up to 3,000 cycles per second. At frequencies of less than 500 cycles per second there was an increasing error. This is believed to be caused by 2 factors. At the lower frequencies the probable error of the vacuum tube voltmeter used increases to about 5 per cent. Also, there apparently is among the resistors used, some stray capacitance and inductance which could cause an appreciable frequency error. A second reason for believing this last to be true is that, as already explained, the power factor calibration changes when the load is shifted from capacitive to inductive or *vice versa*.

In operating the instrument for these tests, the power absorption of the wattmeter from the circuit was about 5 microwatts. This loss can be reduced to a small fraction of this value by the use of a higher resistance for A.

Some Characteristics of A-C Conductor Corona

Corona discharges from a-c conductors are characterized by marked polarity effects. The most pronounced electrical polarity effect is the sudden burst of negative corona current each cycle, which sets up high frequency oscillations that produce electromagnetic radiation throughout the radio frequency spectrum. Polished and smooth weathered cables produce such radiation only during negative half cycles; mutilated and contaminated conductors produce it during both positive and negative half cycles under some conditions. An experimental investigation of these effects is described in this paper.

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CERTAIN polarity effects, associated with a-c corona on conductors, have been observed by investigators for many years. Until very recently these polarity phenomena have been of interest almost exclusively because of their fundamental scientific value. Activity in corona research has centered largely about the important problems of determining the laws governing the initial formation of corona and those controlling the power loss resulting from corona. Corona polarity phenomena have not yet been found to be very important factors in either corona formation or power loss; therefore, they have not been investigated actively.

By the use of the synchronous stroboscope Peek[1] observed, during his investigations reported in 1912, a marked difference in the appearance of the positive and negative corona discharges from conductors in a-c corona. He found that the corona discharges around a conductor during a positive half cycle formed a uniform bluish white glow extending to a distance from the conductor which depended on the voltage gradient, curvature of the conductor surface, and the air density. He found the discharges during a negative half cycle to be reddish in color and grouped in tufts or beads that were quite uniform in spacing. These observations quickly were confirmed by other investigators, and now the physical difference in the appearance of the positive and negative corona discharges are known and recognized universally.

In 1913 Bennett[2] observed, during an oscillographic study of a-c corona, a marked difference in the rate of rise of the positive and negative ionization currents. He found that when the critical ionization potential was reached in the half cycle when the conductor was negative, the air around the conductor lost its insulating properties with an explosive suddeness that set up violent oscillations in the electric circuit, unless the circuit contained more than the critical value of resistance. He found the rate of ionization to be much lower, and the tendency to produce electrical oscillations in the circuit very much less in the half cycle when the conductor was positive. Whitehead[3] also has observed that negative corona occurs very abruptly from what he has termed a kind of supersaturated condition. Because of the great difference in the visible appearance of the positive and negative a-c corona on conductors, some distinct and characteristic polarity differences in the electrical phenomena, such as those observed by Bennett and Whitehead, are to be expected.

This paper describes the marked polarity characteristics found during some studies made with the low voltage cathode ray oscillograph of a-c corona on polished, weathered, mutilated, and contaminated conductors, and observations of the electromagnetic radiation produced by the corona discharges in the radio broadcast band of frequencies. A very pronounced electrical polarity effect has been found in a-c corona, which is characterized by a much greater initial rate of change of current during the cyclic bursts of corona current when the conductor is negative than when it is positive. This phenomenon was found to occur on both polished and weathered conductors. This very abrupt burst of negative corona current each cycle initiates high frequency oscillations that produce electromagnetic radiation, or interference, throughout the radio frequency spectrum. The positive corona current, which increases at a much lower rate than the negative, does not produce radio frequency oscillations except under special conditions of conductor contamination or abnormal mutilation.

Bridge for Measuring Corona Current

It can be demonstrated that the dielectric field between 2 identical parallel conductors is undisturbed by the introduction of an infinite conducting plane midway between them if the potential from each conductor to the plane is maintained at half the potential between conductors. Therefore, the dielectric field between a conductor and an infinite conducting plane at a distance $S/2$ from the conductor is exactly similar to half of the field between 2 parallel conductors distance S apart. When the voltage from the conductor to the plane is equal to half the voltage between the parallel conductors, the voltage gradients in the 2 fields are identical. When

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1. For all numbered references see bibliography at end of paper.

a plane of practical dimensions is used, the field is distorted somewhat, and the total flux is slightly decreased because of the limited area of the plane. The greatest flux distortion occurs near the edges of a limited plane; therefore the use of shielding plates makes it possible to obtain an area near the center of the plane in which the flux distribution is practically the same as in an infinite plane, and when the total neutral plane including the shielding is made large the decrease in the total conductor flux is reduced to a small value.

These fundamental relationships were used to devise a bridge circuit for investigating the corona current on conductors independent of the charging current. The circuit uses the same general principles applied in the bridge circuit developed to study insulator corona and described in a previous paper.[4] The high voltage bridge is shown in Fig. 1. The complete circuit diagram for the bridge with the high voltage testing transformer, the low voltage cathode ray oscillograph, the synchronized sweeping oscillator, and other auxiliary equipment are shown in Fig. 2.

The fundamental principles of operation of the high voltage bridge for measuring corona current are as follows: When capacitances C_1 and C_2 and resistances R_1 and R_2 in Fig. 2 are adjusted to make the potential difference between points A and B zero for some value of voltage less than that required to form corona on the conductor under test, the voltage difference between A and B will remain zero for every other voltage less than the critical corona value. Thus, the charging current is completely balanced out of the cathode ray oscillograph deflection. However, when the voltage on the bridge is increased above the critical corona voltage for the conductor under observation, the current in R_2 is increased by the amount of the corona current, and the voltage drop across R_2 is greater than that across R_1 by the amount of the corona-current voltage drop in R_3. From the value of the resistance R_3 and the voltage sensitivity of the cathode ray oscillograph the corona current calibration readily is calculated for the cathode ray oscillograph deflection. In this investigation the voltage sensitivity of the cathode ray oscillograph was determined, and the resistance R_3 was adjusted to make the current sensitivity 100 μa per centimeter of oscillograph deflection.

In the use of the bridge it was impractical to reduce to a negligible value the stray capacitance to ground of the cathode ray oscillograph with its sweeping oscillator and the necessary batteries. This stray capacitance was between point A of Fig. 2 and ground. In order to balance the bridge perfectly it was necessary to connect a small variable air capacitor C_3 between point B and ground to neutralize the stray capacitance effect.

The high voltage arms of the bridge consisted of the capacitances of 2 conductors 22 ft long to 2 special sheet metal planes. The spacing between each conductor and its plane was made adjustable and entirely independent of the other. The conductor used on the corona-free arm of the bridge was a polished $^1/_2$-in. galvanized iron pipe that had an outside diameter of 0.835 in. after polishing. This conductor was entirely free of corona over the range of spacings and voltages used. The other high voltage arm of the bridge consisted of the capacitance of the conductor under investigation to its neutral plane. The conductors investigated ranged in size from No. 10 A.W.G. copper wire to No. 4/0 aluminum cable steel reinforced. Data for the conductors used are given in detail in Table I.

Each neutral plane was composed of 5 24-gage galvanized-iron plates on $^3/_8$-in. galvanized-iron-pipe frames. The arrangement of plates in the neutral plane for the conductor under investigation is shown in Fig. 1. The neutral plane for the corona-free conductor is directly back of the one shown and identical with it. The plates were supported on oil impregnated maple strips that in turn were supported on lacquered Douglas fir frames. These supports provided excellent insulation for the active sections of the planes and eliminated errors that might otherwise occur in the bridge circuit because of poor insulation. The end plates and the top and bottom plates of the center sections were grounded to form parts of the neutral planes and to shield the active center plates. The flux distribution on these shielded active plates had to approximate that on a segment of an infinite plane having the same size and location, because they are connected to the resistance arms of the bridge as shown in Fig. 2, and because if the dielectric flux distortion is very great the accuracy of the quantitative corona current measurements is reduced.

The effectiveness of the shielding in obtaining the proper flux distribution on the active plates was determined by calculation and experimental measurement. The derivations of the equations are given in the Appendix and the data are tabulated in Table II. Cyclograms were taken of the line voltage and the charging current to the active plates, and the flux terminating on them was calculated from the cyclograms. These experimental data show that, for a spacing of 24 in. from conductor to plane, the active plates intercepted 6.7 per cent more flux than would terminate on a corresponding segment of an infinite neutral plane. These data

Fig. 1. A high voltage bridge for investigating corona

Table 1—Data for Conductors Tested

Conductor	Nominal A.W.G. Size	Number of Strands	Diameter of Strands, Inches	Maximum Diameter, Inches	Condition
Copper wire	10	1	0.099	0.099	Polished
Copper cable	6	7	0.065	0.191	Polished
Copper cable	2/0	7	0.140	0.422	Polished
Copper cable	2/0	7	0.139	0.421	Weathered
Aluminum cable steel reinforced	4/0	7	0.188	0.560	Polished
Aluminum cable steel reinforced	4/0	7	0.189	0.575	Weathered

also show that for this spacing the active plates intercepted 36.1 per cent of the total dielectric flux from the length of conductor opposite them. For the 36-in. conductor-to-plane spacing the flux intercepted by each of the active plates was 11.8 per cent more than that for an equal segment in an infinite plane, and it was equal to 26.7 per cent of the total conductor flux. These experimental data show that the active plates, in the neutral planes that were used, approximate very well the same area in a hypothetical neutral plane midway between 2 parallel conductors, and that by the use of the experimentally determined correction factors, the values of the corona current on conductors can be measured accurately.

The effectiveness of the complete neutral planes, including the active plates, in approximating the conductor flux conditions obtained with 2 parallel conductors spaced distance S apart, was checked by determining the visual critical corona voltage for polished wires when they were spaced distance $S/2$ from the neutral planes. The experimental values checked the calculated values very accurately at all spacings, which showed that the neutral planes were satisfactory.

The 2 resistance arms of the bridge were made of identical resistance boxes equipped with wire wound resistance units that could be adjusted for any value of resistance between 0 and 2 megohms. The resistance boxes were specially designed and constructed to secure high insulation and constant resistance with a small time constant.

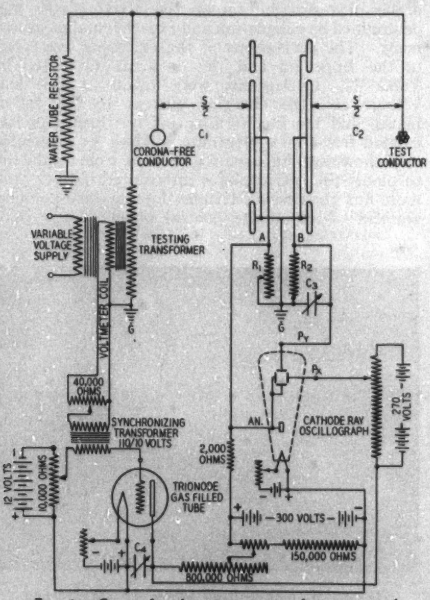

Fig. 2. Circuit for detecting corona formation and measuring corona current on a conductor

Voltage Wave Form Correction

When the conductor under test is in corona the initial very high rate of change of corona current each half cycle causes a large instantaneous voltage drop in the transformer reactance and results in an undesirable distortion of wave form in the high voltage output. The most effective way to eliminate this type of distortion is by adding parallel capacitance in the high voltage circuit. Unfortunately, in this investigation it was necessary for the capacitance to be free of corona to avoid extraneous electromagnetic radiation and such a capacitance was not available. Therefore, it was necessary to load the transformer to the point where the instantaneous impedance voltage drop due to corona current was a small part of the total voltage drop in the transformer. The high voltage load was provided by means of a water-tube resistor made up of 2 sections of garden hose connected in parallel electrically and with water circulated through them in series to maintain a constant temperature and a load resistance of one megohm. The point at which the water tube resistance was connected in the circuit is shown in Fig. 2.

Experimental Procedure

Laboratory procedure followed was to string the test conductor in place and then adjust both it and the corona-free conductor to the proper tension and spacing in front of their respective neutral planes. The polished conductors then were treated by first removing all dents and major irregularities with No. 7/0 sandpaper; this operation was followed by the necessary number of applications of a commercial liquid metal polish and vigorous rubbing with cloths and brushing in the case of stranded conductors to give the conductor a high polish. These preliminary operations were followed by polishing with tissue paper and finally with chamois skin to remove all lint and foreign matter from the conductor surface. Special care was exercised to avoid touching or contaminating a conductor in any way after it was polished. Obviously, these polished conductors do not represent a practical service condition, because a few hours' exposure in the laboratory was sufficient to change the corona characteristics to some extent; however, they do establish a standard of comparison for weathered, mutilated, or contaminated conductors. The weathered conductors were not prepared

in any way except that it was necessary to remove from one conductor one or 2 sharp projections caused by abrasion received in rough handling and not in any way related to weathering.

After a conductor was strung in place and prepared for test, the visual critical corona voltage was determined by observation in a darkened room. This voltage was quite definite and critical for polished conductors, but not for the weathered conductors. On weathered conductors corona first appeared in local spots, then distributed along the conductor, and finally developed into general corona.

At a voltage slightly less than the visual critical corona formation value the resistances and capacitances of the bridge were adjusted to balance out the conductor charging current. After the balancing adjustments were made, a series of cathode ray oscillograms and one of cyclograms were taken of the conductor corona current over a range of voltage from slightly less than the visual critical corona value to 110 kv at intervals of 5 or 10 kv as the conditions required.

After the cathode ray oscillograms and cyclograms of the corona current were completed, the conditions were kept the same and a series of Duddell type oscillograms were taken. These oscillograms recorded simultaneously the voltage between the conductor and plane and the audio frequency output of the superheterodyne radio receiver in a field strength measuring set picking up the 1000-kc electromagnetic radiation produced by the conductor corona. The receiver loop was kept in a fixed relation to the high voltage circuit, and the gain in the receiver was maintained constant for all of the tests to make the results comparable.

During the investigation 2 conductor-to-plane spacings, 24 and 36 in., were used. These spacings correspond with conductor-to-conductor spacings of 48 and 72 in., respectively. The apparatus and experimental methods used made it possible to observe visually the characteristics of conductor corona phenomena and the radio frequency electromagnetic radiations caused by corona, and to record them photographically in the form of oscillograms and cyclograms.

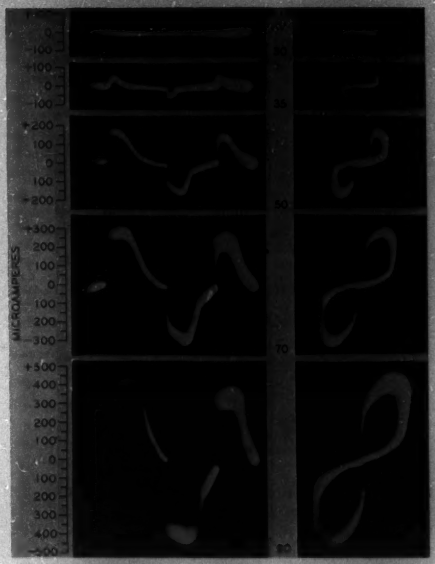

Fig. 3. Cathode ray oscillograms and cyclograms of corona current for a No. 10 polished copper wire

Spacing of conductor from neutral plane, 24 in. Barometric pressure, 751.8 mm of mercury. Temperature: dry bulb 21.7 deg C, wet bulb 15.5 deg C. Humidity: relative, 52 per cent; absolute, 10.25 g per cu m

Polished Conductors

The cathode ray oscillograms and cyclograms in Fig. 3 show the 60-cycle corona current for a No. 10 polished copper wire spaced 24 in. from a grounded plane at various conductor-to-plane voltages ranging from 30 to 90 kv, inclusive. As indicated on the

Table II—Corona Current Correction Factor Data

Conductor				Conductor Capacitance, $\mu\mu$ F per Foot Calculated From Dimensions				
Size								
A.W.G.	Diameter, Inches	Material	Spacing to Plane, Inches	To Infinite Plane	To Infinite Plane Segment Equal to Active Section of Test Plane	Calculated Per Cent of Total Flux That Would Terminate on Infinite Plane Segment	Actual Conductor Capacitance $\mu\mu$ F per Foot From Experimental Data	Actual Per Cent of Total Flux That Terminated on Active Section of Test Plane
10	0.099	Copper	24	2.46	0.834	33.96	0.882	35.9
6	0.191	Copper	24	2.72	0.921	33.85	0.974	35.8
00	0.422	Copper	24	3.12	1.057	33.88	1.139	36.5
0000	0.565	Aluminum	24	3.30	1.116	33.82	1.197	36.3
								Avg. 36.1
10	0.099	Copper	36	2.32	0.554	23.9	0.628	27.1
6	0.191	Copper	36	2.56	0.609	23.8	0.687	26.8
00	0.422	Copper	36	2.88	0.687	23.8	0.755	26.2
0000	0.565	Aluminum	36	3.06	0.728	23.8	0.814	26.6
								Avg. 26.7

Correction factor for converting the total corona current indicated by the oscillograph to current per foot of conductor = 0.417 for $S/2$ = 24 in.; for $S/2$ = 36 in., correction factor = 0.564.

Fig. 4. Oscillograms of conductor-to-plane voltage and radio interference produced by conductor corona on No. 10 polished copper wire

Spacing of conductor from neutral plane, 24 in. Barometric pressure, 750.8 mm of mercury. Temperature: dry bulb 22.2 deg C, wet bulb 15.5 deg C, Humidity: relative. 49 per cent, absolute, 9.55 g per cu m

figure, the deflections above zero are produced by the corona current that flows when the conductor is positive and those below zero when it is negative with respect to the plane. The oscillograms on the left side of the figure have a time scale that was produced by the "trionode" oscillator.[5] The circuit for this oscillator and the method used for holding it in synchronism with the conductor voltage is shown in Fig. 2. The cyclograms on the right side of Fig. 3 were made by applying a voltage proportional to the instantaneous conductor-to-plane voltage on the plates that produced the horizontal deflections,[6,7] and a voltage from the bridge circuit proportional to the instantaneous corona current on the deflector plates that produced the vertical deflections. The horizontal deflections to the right of the center of the cyclograms were produced by positive and those to the left by negative conductor potentials. Zero conductor-to-plane voltage is shown at the center of the cyclogram, and maximum positive and maximum negative voltages are shown at the extreme right and extreme left, respectively. The corona current calibration and the polarity were kept the same for both the oscillograms and cyclograms. The polarities used on the cathode ray oscillograph deflector plates caused the cathode beam to trace the cyclograms in a clockwise direction. Oscillograms and cyclograms both furnish important data that are needed in the study of the characteristics of corona. Oscillograms show the wave form of the corona current directly in rectangular coördinates, and the cyclograms show the phase relation between the conductor-to-plane voltage and the corona current.

An examination of the oscillograms in Fig. 3 shows that the initial corona current increase is very sudden when the corona forms each half cycle because the fronts of the corona current waves are practically vertical. A closer examination shows that the front of the negative corona current wave is much more abrupt than the front of the positive wave. This is shown quite well in both the oscillograms and cyclograms by the fact that the negative corona current rises so rapidly that it does not record on the photographic film until it reaches a considerable value, while the positive current makes a faint trace in practically every instance. This indicates a large difference in the initial rate of change of corona current for the positive and negative waves.

Visual observation of the corona current waves on the fluorescent screen of the oscillograph showed much more detail than could be photographed. These observations showed that the positive corona current wave was quite smooth and free from oscillations, while the negative wave was irregular because of small-amplitude high-frequency oscillations. The photographic records indicate the very abrupt wave front of the negative current, but they do not show the oscillations. These photographic images are in reality smoothed curves for even when the high frequency oscillations were quite pronounced they did not show photographically because approximately $^1/_2$-sec exposure was required and because the nature of corona is such that successive waves are not identical; therefore, the composite image formed by superimposing approximately 30 cycles with small random irregularities was a smoothed curve.

The marked difference observed in the positive and negative corona current is in agreement with the findings of Bennett[3] and Whitehead,[4] and it is further very definitely confirmed by the electromagnetic radiation from the circuit. A series of Duddell oscillograms of the conductor-to-plane

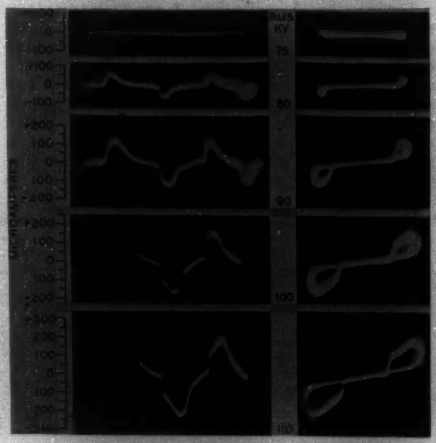

Fig. 5. Cathode ray oscillograms and cyclograms of corona current for a No. 2/0 7-strand polished copper cable

Spacing of conductor from neutral plane, 36 in. Barometric pressure, 757.5 mm of mercury. Temperature: dry bulb, 21.1 deg C, wet bulb 13.9 deg C. Humidity: relative, 44 per cent, absolute, 8.01 g per cu m

voltage and the audio frequency output of the superheterodyne receiver in the field strength measuring set, tuned for 1,000 kc, are shown in Fig. 4. These oscillograms are for the No. 10 polished copper wire, and the conditions are the same as they were when the cathode ray oscillograms and cyclograms of Fig. 3 were taken. The oscillograms in Fig. 4 show that positive corona on the conductor did not produce any 1,000-kc radiation, but that the negative corona produced radiation every negative half cycle when the conductor voltage was above the visual critical corona value. It may be observed that the interference from negative corona starts at the first burst of corona each negative half cycle and stops quite abruptly when the crest of the voltage wave on the conductor is reached.

The cyclograms in Fig. 3 and the oscillograms in Fig. 4 show very clearly how the instantaneous corona formation voltage decreases and passes through zero as the effective value of voltage on the conductor is increased above the visual critical value. At 35 kv (rms) corona occurred practically at the crests of the voltage waves, at 70 kv, the instantaneous corona formation voltage was almost zero; and at 90 kv, the instantaneous conductor voltage had not reversed when corona formed for the succeeding half cycle. This is conclusive evidence that at voltages in excess of the corona value, powerful space charges are produced that are large enough to cause ionizing gradients about conductors when the instantaneous conductor voltage is zero or even in opposition.

The oscillograms and cyclograms in Figs. 5 and 6 are for a No. 2/0 7-strand polished copper cable spaced 36 in. from the grounded plane. A study of these oscillograms shows that the fundamental characteristics are very much the same as those observed on the No. 10 polished copper wire. Voltage

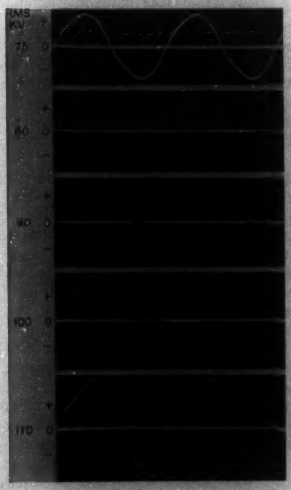

Fig. 6. Oscillograms of conductor-to-plane voltage and radio interference produced by conductor corona on a No. 2/0 7-strand polished copper cable

Spacing of conductor from neutral plane, 36 in. Barometric pressure, 759.6 mm of mercury. Temperature: dry bulb 19.7 deg C, wet bulb 12.8 deg C. Humidity: relative, 43 per cent; absolute, 7.22 g per cu m

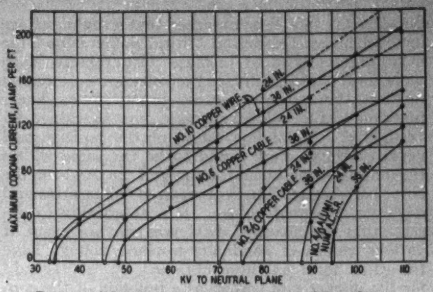

Fig. 7. Maximum corona current per foot of conductor, all conductors polished

Designations on curves indicate conductor-to-neutral spacing in inches

limitations of the testing transformer prevented carrying the tests on the large conductors to twice the visual critical corona voltage, as was done with the No. 10 conductor; however, the tests were carried to voltages far in excess of any practical operating condition in every instance. Cyclograms and Duddell oscillograms for both copper and steel-reinforced aluminum cables show the characteristic decrease in the instantaneous voltage at which corona forms each half cycle as the effective voltage is increased above the visual critical value. Cathode ray oscillograms and cyclograms show that the initial bursts of corona current are much more abrupt on the negative waves than they are on the positive, and visual observation with the cathode ray oscillograph showed superimposed oscillations on the negative waves while the positive waves were smooth. Duddell oscillograms of the radio interference produced by the conductor corona show that interference occurs only when polished cables are negative. These observations on the cables all agree qualitatively with those made on the No. 10 polished copper wire.

Because the fundamental characteristics for all the polished conductors were so much alike, it was thought that the experimental results could be shown clearly by the use of a few typical series of oscillograms and cyclograms on different conductors at the same spacing and by the use of graphs to show some characteristic data for all the conductor sizes and spacings studied. The data selected for graphical presentation were the maximum corona current per foot of conductor as a function of the conductor voltage to neutral. These data were obtained from the cathode ray oscillograms and cyclograms and converted to microamperes per foot of conductor by applying the experimentally determined calibration factors given in Table II.

Maximum corona current per foot of polished conductor as a function of the conductor to plane voltage is shown in Fig. 7 for 24- and 36-in. conductor-to-plane spacings and several different sizes and types of conductors. The intercepts of the curves on the voltage axis are the voltages at which the first visible corona appeared on the various con-

ductors. It should be observed that a slight voltage increase above this initial critical value caused the maximum current to increase very rapidly, then more slowly, and finally, as the voltage was increased further, the current became practically a linear function of the voltage increase over the range investigated. Maximum values of the positive and negative waves were found to be the same within the limits of experimental error, and the points on the curves are the arithmetical mean of the positive and negative measured values. It is interesting to observe that the curves of maximum corona current at various values of conductor-to-plane voltage have the same form as those obtained by Whitehead,[8] for the diameter of corona as a function of the conductor voltage.

The initial abrupt rise of negative corona current per foot of polished conductor as a function of the conductor-to-plane voltage was measured for both the 24- and 36-in. conductor-to-plane spacings and several sizes and types of conductors. These data were found to be more erratic than the maximum corona current shown in Fig. 7; however, they showed the same general relationship to the conductor voltage. This initial abrupt rise, which occurs in the negative corona current and does not occur in the positive, is very significant and important because the very sudden and abrupt change in the circuit stored energy associated with this sudden current change is undoubtedly responsible for setting up local high frequency oscillations that radiate energy at radio frequencies. Data obtained from the oscillograms and cyclograms showed that the magnitude of the initial abrupt rise in the negative corona current increased very rapidly for slight increases in voltage above the visual critical corona value and then became practically a linear function of the voltage for higher values. These data also showed that the initial abrupt increase in negative current is greater for small than for large conductor spacings.

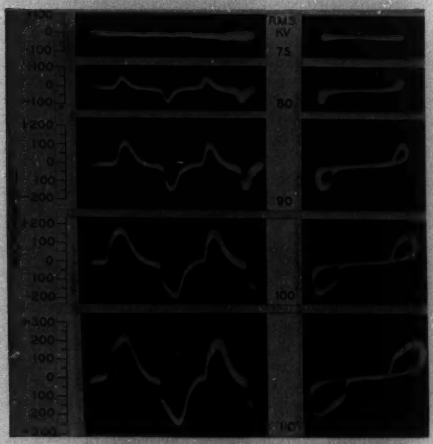

Fig. 8. Cathode ray oscillograms and cyclograms of corona current for a No. 2/0 7-strand weathered copper cable

Spacing of conductor from neutral plane, 36 in. Barometric pressure, 761 mm of mercury. Temperature: dry bulb 20.4 deg C; wet bulb 14.6 deg C. Humidity: relative, 53 per cent; absolute, 9.22 g per cu m

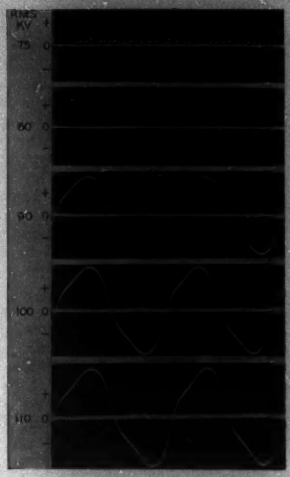

Fig. 9. Oscillograms of conductor-to-plane voltage and radio interference produced by conductor corona on a No. 2/0 7-strand weathered copper cable

Spacing of conductor from neutral plane, 36 in. Barometric pressure 751.7 mm of mercury. Temperature: dry bulb 23.2 deg C; wet bulb 16.6 deg C. Humidity: relative, 50 per cent; absolute, 10.25 g per cu m

Weathered Conductors

Corona characteristics of weathered conductors are of particular interest because the weathered surface represents the usual condition in service. There are all degrees of weathering, and exposure to the elements in different localities may produce quite varied results because of local conditions. For these reasons, the weathered conductors selected for this investigation were taken from lines that had been in service several years in locations where no abnormal atmospheric contamination, such as smoke, gas, or chemical fumes, existed. The conductors used were free from abnormal abrasions or irregularities because it was desired to determine the influence of weathering alone as far as practicable. Oscillograms and cyclograms were taken for a No. 2/0 7-strand copper conductor and a No. 4/0 aluminum cable steel reinforced to make the data comparable with those taken on polished conductors of the same sizes and materials.

Cathode ray oscillograms and cyclograms of the corona current on the No. 2/0 weathered copper cable are shown in Fig. 8. These oscillograms and cyclograms and those taken for No. 4/0 aluminum cable steel reinforced are practically identical in general shape and character with those shown in Fig. 5 for the No. 2/0 polished copper conductor. All of these oscillographic records show the same characteristic very sudden rise in the negative corona current that was observed for the polished

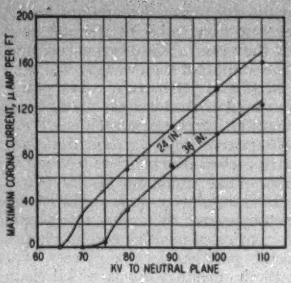

Fig. 10. Maximum corona current per foot of conductor for No. 2/0 weathered copper cable

Designations on curves indicate conductor-to-neutral spacing in inches

conductors, proving that this phenomenon is not attributable entirely to the condition of the conductor surface.

Visual observation in a dark room showed that the corona started on the weathered copper conductor at from 92 to 93 per cent of the voltage required to initiate corona on polished conductor of the same size. These percentages were the same for both the 24- and 36-in. conductor-to-plane spacings.

Dark room observations showed that the corona started on the No. 4/0 weathered aluminum conductor at from 85 to 86 per cent of the voltage required to initiate corona on polished conductor of the same size. These percentages held for both the 24- and 36-in. spacings. The fact that the corona formation voltages on weathered aluminum cable are a smaller percentage of the values for polished cable than were obtained for copper cable should not be considered to indicate any difference in weathering characteristics of copper and aluminum. The weathering results are not comparable, because the weathering conditions to which the cables were subjected were not the same.

On both the copper and aluminum weathered cables the corona first formed in local spots that increased in number as the voltage was increased until the conductors were in general corona. Because of this process of corona formation, the maximum corona current increased very gradually for small increments of voltage above the initial value, then quite rapidly for an interval as general corona was reached, and finally the current became practically a linear function of the voltage. Maximum corona current per foot of conductor as a function of the conductor to plane voltage is shown graphically in Fig. 10 for weathered copper and in Fig. 11 for weathered aluminum cable. For all values of voltage investigated, the maximum corona current for weathered copper cable was somewhat larger than for polished copper; however, on the linear portions of the curves the increase in maximum current was only of the order of 3 to 10 per cent.

Curves of the maximum corona current per foot of conductor for No. 4/0 weathered aluminum cable are shown in Fig. 11. In general, these curves are similar to those obtained for the copper cable if account be taken of the fact that they are for a larger conductor, and that therefore the current will become a linear function of the voltage at a higher conductor-to-plane voltage. Over the range of voltage investigated, the maximum values of corona current for weathered aluminum cable were larger than those for polished cable, except at 110 kv for the 36-in. conductor-to-plane spacing where the current for the polished conductor was slightly larger.

Duddell oscillograms of the voltage and the 1,000-kc electromagnetic radiation or radio interference from the weathered copper conductor are shown in Fig. 9. The oscillograms for both copper and aluminum weathered cables show that in general the characteristics of the radiation are the same as those for polished conductors. The high frequency radiation occurs when the conductor is negative and does not occur when it is positive. Measurements of the field strength of this radiation show that, notwithstanding the fact that the high frequency radiation starts at a lower value of voltage on a weathered conductor than on a polished one, the radiation is greater from the polished conductor, for corresponding values of voltage above the critical corona voltage, than from the weathered conductor. This difference in the intensity of the radiation from polished and weathered conductors shows that, even though the cathode ray oscillograms and cyclograms were not swept at a velocity high enough to show the difference in the rate of rise of the cyclic bursts of negative corona current, the rate of current rise is considerably more rapid for polished than for weathered conductors.

Mutilated Conductors

A study was made of the influence of the surface roughness of conductors on corona and the resulting high frequency electromagnetic radiation. During this work it was found that corona on mutilated conductors having sharp projecting irregularities produced high frequency radiation or radio interference when the conductor was both positive and negative instead of only when the conductor was negative as was found for polished and weathered conductors without abrasions. The positive radiation or interference occurred at a voltage much higher than the visual critical corona voltage, and the voltage at which it appeared decreased as the roughness of the conductor was increased. Radio interference produced by the positive corona on roughened conductors was entirely different from that produced by negative corona. The positive corona produced a single violent impulse in the radio receiver apparently produced by the radiation from a single

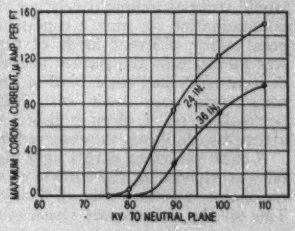

Fig. 11. Maximum corona current per foot of conductor for No. 4/0 weathered aluminum cable steel reinforced

Designations on curves indicate conductor-to-neutral spacing in inches

high frequency wave train. Near the voltage at which the positive interference first occurred, there was only an occasional impulse of positive interference; at higher voltage they became regular and one impulse occurred each positive half cycle. At very high voltages relative to the visual critical corona voltage, sometimes 2 or more positive impulses occurred per half cycle; however, they were always distinct impulses with considerable separation. The negative interference always was made up of a rapid succession of impulses that continued from the first burst of negative corona until the crest of the negative voltage wave was reached every negative half cycle, just as had been observed previously for polished and weathered conductors. The only apparent change in the positive corona current wave form during the occurrence of positive interference was the appearance of a superimposed high frequency that could be detected only by visual observation on the fluorescent screen of the cathode ray oscillograph. Photographic records of the cathode ray oscillograms did not show this change.

It was noticed during the study of positive corona interference that when positive interference was occurring only occasionally was there a distinctly audible corona snap coincident with the radio interference observed visually with the Duddell oscillograph. Observation of the conductor with the room darkened, under these conditions, revealed that the positive radio interference was produced by discharges consisting of a small intensely ionized path, extending out a considerable distance from the conductor and terminating in a plume of ionization beyond the normal corona envelope. These plume discharges were of very short duration as shown by their characteristic sharp snap and the character of the radio interference produced.

Contaminated Conductors

New conductors usually have some grease and other foreign matter on them when they leave the factory, and during shipment and erection they may be subjected to further contamination. The influence of this foreign matter on corona formation[9,10] and radio interference is, therefore, of importance during the early life of a transmission line until the contamination is washed or weathered away.

During the early part of the investigation on polished conductors, it was observed, that when potential was applied on a new conductor before it was cleaned and polished, negative followed by positive high-frequency radiation due to corona would occur at comparatively low voltages. Surface contamination on such a conductor may include a great many different kinds of foreign matter. It was known that the surface material on these conductors contained some kind of grease. Therefore, some tests were made with lubricating oil and petrolatum on a clean polished conductor in an attempt to duplicate the observed results.

A cloth saturated with a light high-grade machine oil was wiped over the surface of a polished copper conductor to form a thin oil film over $^1/_2$ its length. This oil film reduced the visual critical corona voltage below that for the dry polished conductor, but it did not produce any positive radio interference even at more than twice the visual critical corona voltage. The other half of the conductor then was greased with a heavy irregular coating of petrolatum. The petrolatum lowered the visual critical corona voltage and produced positive radio interference at a very low voltage. Visual observation with the room darkened showed that positive corona plumes were forming in very large numbers. The thickness of the petrolatum film and the irregularity were reduced by wiping the conductor several successive times, and the effect on the formation of positive corona plumes was observed. Some positive corona plumes continued to form until the conductor was wiped clean with a dry cloth.

Correlation of Results With Corona Theory

In a previous paper[4] a theory was proposed for the phenomena associated with a-c corona formation. This theory has been found to explain in a satisfactory manner the observed positive and negative corona effects and accounts for the experimental fact, revealed by this investigation, that normally only the negative half-wave of a-c conductor corona produces high frequency electromagnetic radiation.

The theory of a-c corona proposed is based upon Townsend's[11] theory of the ionization of gases by collision and the influence of the difference in mobility of the positive and negative ions on the space charges[12,13] surrounding a conductor in a-c corona. The theory is summarized briefly here to show the correlation with experimental observations.

When the instantaneous conductor polarity is positive, ionization starts when the critical ionization voltage gradient is produced by the resultant field of the positive conductor and the positive residual space charge, and continues to the crest of the positive voltage wave. The highly mobile negative electrons and ions are swept from the field and absorbed by the positive conductor leaving in their paths the relatively immobile positive ions that are formed as a result of ionization by collision. These positive ions have on the average a relatively long life, because the negative ions are removed from the field in large numbers by the positive conductor; this reduces the positive ion loss due to recombination, and the low mobility of the positive ions limits their loss by diffusion. The preponderance of positive ions surrounding the conductor produces a positive space charge. This positive space charge persists after the conductor potential reverses to negative polarity, and it plays a very important part in determining the voltage gradient around the conductor during the initial part of the half cycle following its formation.

The most conclusive evidence of the existence of large space charges surrounding conductors in a-c corona is the fact that at effective voltages slightly in excess of twice the visual critical corona voltage the large space charges prevailing will produce ionizing voltage gradients around a conductor when the instantaneous conductor voltage is passing through zero or is in actual opposition to the corona forma-

tion.[14] See the 70- and 90-kv corona-current cyclograms in Fig. 3 for examples of this phenomenon.

When the conductor potential changes to negative polarity, ionization starts when the critical ionization voltage gradient is produced by the resultant field of the negative conductor and the positive residual space charge and continues to the crest of the negative voltage wave. The highly mobile negative electrons and ions are repelled from the negative conductor, leaving in their wakes the relatively immobile positive ions that result from ionization by collision. These positive ions form a positive space charge about the conductor.

It should be observed that a positive space charge is formed adjacent to the conductor regardless of whether the ionization is caused by a positive or negative half cycle of voltage. However, a larger positive space charge is established during a positive half cycle than is produced by a corresponding negative half cycle of voltage. This is because when the conductor is positive the positive space charge flux adds to the conductor field and extends the ionizing gradient, but when the conductor is negative the positive space charge flux subtracts from the conductor field and limits the extent of both the ionizing gradient and the outside corona boundary.

When the conductor voltage reverses and becomes negative following the establishment of a large positive space charge in the manner just described, a very high voltage gradient is produced between the negative conductor and the residual positive space charge because of the very short distance between them. When this voltage gradient reaches the critical ionizing value (which may occur before the voltage actually becomes negative) breakdown occurs probably in the form of minute arcs that neutralize the space charge. These corona arcs produce extremely sudden changes in the energy conditions of the circuit and produce high frequency oscillations of a violent character. When the conductor is positive the positive space charge has the same polarity as the conductor, and there is no opportunity for an extremely sudden energy change to take place that will cause high frequency oscillations. Therefore, when normal polished or weathered surface conditions exist on a conductor that is in a-c corona, high frequency electromagnetic radiation or radio interference will occur only when the instantaneous conductor potential is negative. This theoretical conclusion is in agreement with the experimental results of this investigation.

Summary

1. Some polarity effects in a-c corona have been known and recognized for many years.

2. The most pronounced visible polarity effect is the marked difference in the appearance of the positive and negative corona discharge around a conductor when it is in a-c corona.

3. The most pronounced electrical polarity effect in a-c corona is the very much greater rate at which the corona current increases when the conductor is negative than when it is positive.

4. The sudden burst of negative corona current each cycle sets up high frequency oscillations that produce electromagnetic radiation or interference throughout the radio frequency spectrum.

5. The positive corona current does not produce radio frequency oscillations except under special conditions.

6. Polished conductors in a-c corona radiate radio interference only during the half cycle when the conductor is negative.

7. Smooth weathered conductors in a-c corona radiate radio interference only during the half cycle when the conductor is negative.

8. Mutilated conductors with sharp projections radiate radio interference under some conditions both when the conductor is positive and when it is negative.

9. Petrolatum contamination on conductors causes them to radiate radio interference under some conditions both when the conductor is positive and when it is negative.

10. When electromagnetic radiation occurs from a conductor in a-c corona on both polarities, there is a distinct difference in the positive and negative radiation.

Appendix—Derivation of Equations for Calculating Capacitance Between Conductor and Neutral Plane

Symbols

C = capacitance
ψ = dielectric flux
D = dielectric flux density
A = area
v = velocity of light = 3×10^{10} cm per second
g = potential gradient
k = relative permittivity
x = distance, along neutral plane at right angles to a perpendicular from conductor to neutral plane
a = distance from conductor to point in dielectric field
S = spacing from conductor to image of conductor such that the neutral plane is at distance $S/2$ from conductor
r = radius of conductor
e = voltage (maximum)
e_n = voltage to neutral (maximum)

Equations

The capacitance in any circuit is given by the equation

$$C = \frac{\psi}{e} \tag{1}$$

For any equipotential surface

$$\psi = DA \tag{2}$$

$$= g\,\frac{10^9 k}{4\pi v^2}\,A \tag{2a}$$

For 1 cm of line the flux through an area of elemental width, dx, is

$$d\psi = g\,\frac{10^9 k\,dx(1)}{4\pi v^2} \tag{3}$$

It can be shown that when S is large compared with r (see "Dielectric Phenomena in High Voltage Engineering," by F. W. Peek, p. 339) in the neutral plane

$$g = \frac{1}{a^2}\left[\frac{Se_n}{\log_e\left(\frac{S}{r}\right)}\right] \tag{4}$$

when

$$a^2 = \sqrt{\left(\frac{S}{2}\right)^2 + x^2} \tag{5}$$

Then from eqs 4 and 5

$$g = \left[\frac{Se_n}{\log_e \frac{S}{r}}\right]\frac{1}{\left(\frac{S}{2}\right)^2 + x^2} \tag{6}$$

and from eqs 3 and 6

$$d\psi = \left(\frac{10^9 k}{4\pi v^2}\,\frac{Se_n}{\log_e \frac{S}{r}}\right)\frac{dx}{\left(\frac{S}{2}\right)^2 + x^2} \tag{7}$$

Integrating

$$\psi\Big]_{x_1}^{x_2} = \frac{10^9 k S e_n}{4\pi v^2 \log_e \frac{S}{r}} \int_{x_1}^{x_2} \frac{dx}{\left(\frac{S}{2}\right)^2 + x^2}$$

$$= \frac{10^9 k e_n}{4\pi v^2 \log_e \frac{S}{r}} \left[\tan^{-1} \frac{2x_2}{S} - \tan^{-1} \frac{2x_1}{S} \right] \tag{8}$$

From eqs 1 and 8 the capacitance to the neutral plane, between x_1 and x_2

$$C = \frac{10^9 k}{2\pi v^2 \log_e \frac{S}{r}} \left[\tan^{-1} \frac{2x_2}{S} - \tan^{-1} \frac{2x_1}{S} \right] \tag{9}$$

The capacitance between an infinite neutral plane and conductor of radius r at distance $S/2$ from the neutral plane, $x_1 = 0$ and $x_2 = \infty$

$$C = \frac{(2)10^9 k}{2\pi v^2 \log_e \frac{S}{r}} \left(\frac{\pi}{2} - 0 \right) = \frac{10^9 k}{2v^2 \log_e \frac{S}{r}} \text{ farads per centimeter of conductor} \tag{10}$$

Substituting dimensions of test circuit and conversion factors in eq 10 for infinite neutral plane ($k = 1.0$)

$$C = \frac{(2.54)(12)(10^9)(1)}{(2)(9 \times 10^{20})(2.303) \log_{10} \frac{S}{r}}$$

$$= \frac{7.35 \times 10^{-12}}{\log_{10} \frac{S}{r}} \text{ farads per foot of line} \tag{11}$$

For test plate 71.8 cm wide, 24 in. (60.95 cm) from conductor, $x_1 = 0$, and $x_2 = 35.9$ cm, from eq 9

$$C = \frac{(2)(10^9)k}{2\pi v^2 \log_e \frac{S}{r}} \left[\tan^{-1} \frac{71.8}{121.9} - \tan^{-1} 0 \right]$$

$$= \frac{(2)(10^9)k}{2\pi v^2 \log_e \frac{S}{r}} (0.169\pi)$$

$$= \frac{(0.169)(10^9)k}{v^2 \log_e \frac{S}{r}} \text{ farads per centimeter} \tag{12}$$

In air, from eq 12

$$C = \frac{(0.169)(10^9)(12)(2.54)}{9(10^{20})(2.303) \log_{10} \frac{S}{r}}$$

$$= \frac{2.49 \times 10^{-12}}{\log_{10} \frac{S}{r}} \text{ farads per foot of plate} \tag{13}$$

For test plate 71.8 cm wide, 36 in. (91.4 cm) from conductor, $x_1 = 0$, and $x_2 = 35.9$ cm, from eq 9

$$C = \frac{(2)(10^9)k}{2\pi v^2 \log_e \frac{S}{r}} \left[\tan^{-1} \frac{71.8}{182.8} - \tan^{-1} 0 \right]$$

$$= \frac{(0.1192)\pi(10^9)k}{\pi v^2 \log_e \frac{S}{r}} \text{ farads per centimeter of plate} \tag{14}$$

In air, from eq 14

$$C = \frac{(0.1192)(12)(2.54)(10^9)}{(9)(10^{20})(2.303) \log_{10} \frac{S}{r}}$$

$$= \frac{1.754 \times 10^{-13}}{\log_{10} \frac{S}{r}} \text{ farads per foot of plate} \tag{15}$$

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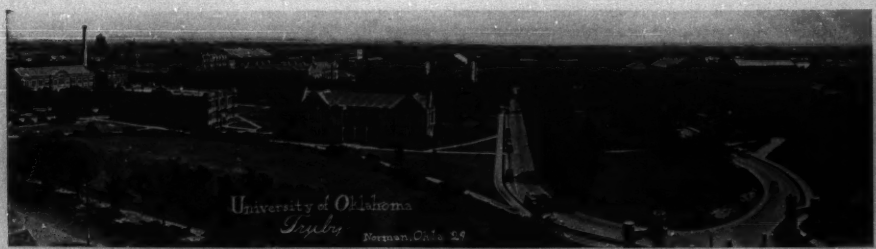

Campus of the University of Oklahoma, Norman, 18 miles south of Oklahoma City where the forthcoming A.I.E.E. South West District meeting will be held. Those attending the inspection trip to be made to the university during the meeting will find of particular interest its petroleum engineering laboratory which contains a complete oil refinery

Methods of Electrical Prospecting

Electrical methods of prospecting are becoming increasingly important as the search for hidden deposits of ore extends deeper and deeper below the surface of the earth. Electrical prospecting is not limited to this use, however; it has found many valuable applications in engineering and in geology. The 4 general methods of electrical prospecting are described briefly in this paper.

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EVER SINCE man has known that mineral wealth lies hidden in the earth, he has been devising schemes for unearthing that wealth with the least possible effort. The search for a divining rod is, in fact, older than the equally dubious arts of alchemy. Only in comparatively recent years, however, have successful, and therefore accredited, schemes for divining the earth been developed. The success of these newer methods would not account for the high interest shown in them were it not for the real need that exists for some reliable method of subsurface exploration. This need is made only too clear by the fact that rocks that can be seen from the surface constitute only 1 per cent of the total area of mining districts. Since by now this easily available 1 per cent has been thoroughly exploited, the attention of prospectors has been turned to the remaining 99 per cent which lies hidden beneath the surface—a portion none the less valuable, but vastly harder to explore. In the search for these hidden deposits, electrical methods are beginning to play an important part, and the importance of electricity in this field may be expected to increase. It is the purpose of this paper to review briefly the more important methods of electrical prospecting and to emphasize their possibilities and limitations.

All Methods Fundamentally Similar

One general statement may be made at the outset. All methods of geophysical prospecting, which is the general name for prospecting by gravitational, seismic, and electrical methods, are carried out in the same fundamental way, that is, by measurement of the response of rocks and ore bodies to various types of physical fields, such as the field of gravity, electric and magnetic fields, and seismic shocks. The study of electrical prospecting is, therefore, the study of the appropriate electric fields, the appropriate methods of response measurement, and, finally, the interpretation of the response. A field fitted to the particular problem at hand should be used, so that the response will be not only of maximum intensity, but also of a unique character. If this be done, the reactions of the ore may be distinguished from those of the other geological elements, and, in addition, reliable indications as to its size, shape, and depth may be obtained.

The various types of electric fields used are 4 in number; these give rise to 4 different types of electrical prospecting. It is convenient to discuss them in 2 groups, the "natural field" methods and the "artificial field" methods. The natural fields are provided by the earth itself; the artificial fields are produced by the prospector.

Magnetic Surveying

Magnetic surveying, the method to be described first, makes use of a natural field, that of the earth's magnetism. It is well known that the magnetic field of the earth is greatly intensified in the presence of certain magnetic ores. Hence, this type of ore may be located simply by measuring the field intensity at various points over the area to be explored. A pocket magnetic dip needle, which is nothing more than a compass needle mounted on a horizontal shaft, is the simplest and commonest method of doing this; but refined magnetic balances have been developed which are much more sensitive. The usual field magnetometer, for example, will detect changes in the earth's magnetic field intensity of as small an order as 3 parts in 10,000.

Important iron ores, such as magnetite, and some nickel ores, may be detected in this way. Iron pyrites, however, better known as "fool's gold," are magnetically inert. Magnetically inert ores cannot be explored by this method, of course, but this fact is at once a disadvantage and an advantage. Magnetite, a strongly magnetic ore, is distributed so widely that it may be used as an index for the discovery of other types of deposit. Quarry rock has been discovered in New England by this method, simply because it contained $^1/_2$ per cent of magnetite. The magnetic method has had many such commercial successes.

Self-Potential Method

The second natural earth field that is used is less obvious than the magnetic one. This field is known as the "self-potential" field. It arises from the fact that many ores, particularly the sulphides, are chemically active. Differences in the degree of oxidation give rise to a difference of electric potential between various parts of the ore. A current flow

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thus is established which creates a potential distribution throughout the ground. The intensity of this potential field on the surface may be measured by placing 2 electrodes, in the form of porous cups filled with copper sulphate, on the ground and measuring whatever potential appears between them with an ordinary potentiometer. The electrodes are moved

Fig. 1. A group of instruments used in geophysical prospecting by the department of geology at Massachusetts Institute of Technology

At the lower left is a portable gasoline-engine-driven alternator used in the inductive method of prospecting. On the tripods, from left to right: a Helmholtz balance for magnetic surveying; receiving coil and amplifier for inductive prospecting; complete apparatus for commutated direct current surveying; and a magnetic balance

from one location to another, and the process of measuring the potential difference between them is repeated at each location. By covering the terrain in this manner, a map of the existing surface potential may be made. The singularities or distortions in the map indicate the source of the current. The interpretation of the map is difficult, since it is complicated by numerous chemical reactions occurring in the ground independent of the ore body. This method is used extensively, however, because the field is localized about the ore, and because the method is cheap and rapid and may be carried out easily in conjunction with other methods.

These natural fields, the magnetic and the self-potential, have the advantage that they are provided free of charge; there is an attendant disadvantage in the fact that the excitation of the ore is not under the control of the prospector. The artificial fields offer a much more fertile field for the exercise of engineering ingenuity. By their use the prospector may choose the particular type of field, or combination of fields, best suited to his problem, and he may use it under control. Moreover, the use of artificial fields is suited particularly to exploration for deposits having high electrical conductivity, and it is a significant fact that many commercially valuable ores do possess this property. Hence the methods about to be described are of considerable commercial importance, but the results are often misleading and they must be used with skill and judgment.

Inductive Method

The first of the artificial field methods, the so-called inductive method, makes use of a sinusoidally varying magnetic field. The frequency of oscillations used depends upon the type of ore it is desired to locate, and, equally, upon the surrounding rocks. Usually a frequency of from 500 to 1,000 cycles per second is used. The field is produced by a large loop antenna, energized by a gasoline-engine-driven alternator of the correct frequency. One type of loop is triangular in shape, about 25 ft on a side, and set up in a vertical plane. Other systems use a horizontal loop of greater extent.

The theory of the measurement is this: The lines of force in the magnetic field at a distance from the loop lie, in general, in a plane perpendicular to the plane of the loop; but if an ore body interferes with this field, eddy currents are set up in the ore body, and these eddy currents in turn set up a secondary field. The original field and the secondary field combine in a resultant field the direction of which at the point in question is changed from the direction of the original field. The situation is closely analogous to that of armature reaction in d-c machines. By means of locating the changes in field direction caused by such reactions, the ore body may be located. It becomes necessary, then, to measure the direction of field intensity at many different points.

To measure the field direction, a receiving coil, to which an amplifier and a pair of headphones are attached, is mounted on a tripod in gimbals, so that the plane of the coil can assume any position relative to the ground plane. The plane of the receiving coil then is rotated about its vertical axis until the sound in the headphones is minimum; the plane of the coil then coincides with the horizontal component of the field intensity; knowing this direction, the direction of the resultant field may be determined by rotating the coil about its horizontal axis until the sound is minimum. By making a systematic series of such observations over the area, the magnetic field may be mapped, and the distortions caused by ore bodies discovered. However, it remains for a skillful interpreter to locate the ore bodies accurately.

Surface Potential Method

The method to be described last is called the surface potential method. In this method, an electric field is set up by sending a commutated direct current through the ground. To establish this field 2 power electrodes are driven into the ground above the suspected ore body, separated by as large a distance as is practicable, often several thousand feet or more. These power electrodes then are connected to a source of direct current, such as a battery

or a gasoline-engine-driven generator, but they are connected through a commutating mechanism. Usually ordinary ring commutators are used. As the commutator turns, a reversing voltage is applied to the electrodes, and as a result a reversing current flows through the ground, thereby creating a potential field the polarity of which reverses with each commutation.

Two pick-up electrodes, entirely independent of the power electrodes then are placed at any 2 locations in the area. These pick-up electrodes are connected to a second commutator, which turns on the same shaft as that of the power commutator. Thus, as the power circuit is commutated, the pick-up circuit is commutated in synchronism. The reversing potential that appears between the pick-up electrodes thereby is "rectified" back to d-c pulses, which can be measured on a potentiometer. The potentiometer is connected only during the steady state part of each pulse, so that the inductive effects during each build-up and build-down period will not affect the measurement. In other words the measurement is essentially a d-c one, and as such it is easier to carry out accurately than the a-c measurements of the inductive method.

The aim of the commutation is this: Contact potentials and potentials arising from chemical reactions are often of the same magnitude as the potentials to be measured. These stray potentials, therefore, must be eliminated. The commutation performs this task by averaging out to zero all potentials except those produced by the power circuit.

By choosing a sufficient number of points and by measuring the potential that appears between any 2 of them, a map of the surface potential may be made. Any distortions in this map indicate, through proper interpretation, the presence of conducting bodies.

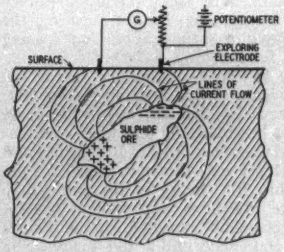

Fig. 2. An idealized view of the self-potential method

Current flow between parts of the sulphide ore sets up a potential gradient at the surface which can be measured with a potentiometer

Surprisingly accurate maps may be made by this method, but it remains for proper interpretation to locate correctly whatever conducting ore bodies may be present.

An Application to Geological Research

This description of the 4 most important methods of electrical prospecting must not lead one to believe that they are restricted to the vulgar purpose of revealing rich ore deposits. They have also many valuable applications in general engineering such as locating the depth to bed rock and faults in foundation problems, locating underground water supplies, and many others. In pure geology electrical prospecting is a tool of no mean significance. One such application to a problem in geological research with which the author had the pleasure of being associated

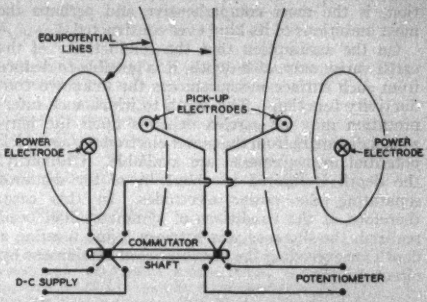

Fig. 3. The commutated d-c method, shown in plan view

The equipotential lines set up by the current flow are explored by the pick-up electrodes. Ore or other conducting material is indicated by distortions of the equipotential lines. Simultaneous commutation of power and pick-up circuits eliminates extraneous potentials

will be described; this work was carried out under the direction of Professor L. B. Slichter of the geology department of Massachusetts Institute of Technology. The purpose of this initial research was to develop experimental technique in the study of the electrical properties of the earth's crust at great depths. The method adopted was the commutated direct current method just described.

In this method it is clear that the greater the distance between the electrodes, the deeper into the earth will go the bulk of the current. Hence to find the conductivity of the earth at great depths, the electrodes must be separated by a great distance. In this project, the separation was about 30 miles. The electrodes used were power substation grounds located at Clinton and West Roxbury, Mass. The return circuit for the current was a 66-kv transmission line, used through the coöperation of the New England Power Association and the Edison Electric Illuminating Company. A maximum current of 25 amp was sent through this circuit (transmission line and ground return) and this current was commutated once every second. The engineering difficulties encountered in commutating this current in a circuit of more than $^1/_4$ h inductance, quickly enough so that the steady state period could exist for a large percentage of each reversal, were overcome by the use of a specially designed progressive suppressor circuit. The resulting commutation with this suppressor in

use was accompanied by only barely visible arcing.

Pick-up electrodes in the form of 3-ft iron rods were placed at more than 60 locations throughout the eastern half of the state, an area of some 2,500 square miles. By connecting these rods with telephone lines loaned by the New England Telephone Company, the potentials appearing between them were led to the central measuring station at Clinton. By using grounds in telephone central offices, the total number of potential measurements was increased to 92. The resulting map, now in process of construction, is the most comprehensive and perhaps the most ambitious of its kind ever constructed.

On the assumption that the conductivity of the earth varies only with depth, it is possible to deduce from such surface measurements the unknown conductivity function. The depth to which such interpretation may be carried depends upon the horizontal distances from the power electrodes over which potential measurements are available. Ordinarily, the depth is limited to about $^1/_5$ of the distance separating the power electrodes. In this case, therefore, if the conditions of symmetry had been realized, the distance was between 5 and 6 miles, a depth far exceeding the possibilities of attainment by direct drilling.

Interpretation of Maps Difficult

Little has been said about the specific methods of interpretation applied to the different types of maps that may be constructed by these methods, because the potential theory involved is difficult, and also because experience and judgment play so large a part in it. Often the problem is reproduced on a small scale in the laboratory, and an attempt made to reproduce the given map from different configurations of conductors.

In general, the problem of interpretation may be stated in this way: "Given a definite type of distortion in a geophysical prospecting map, is it possible to predict definitely the type, the size, the location, and the depth of ore body that caused that distortion?" Generally speaking it is not possible to do so; but with experience, and by using all the information mining engineers and geologists are able to supply, and by using all possible methods of geophysical prospecting, enough information may be amassed so that the resulting conclusions are not far from the geological truth.

It is, of course, a great deal to expect that any one type of exploration will indicate any more than one property of the deposit; and even though all the electrical and physical properties of the deposit could be determined, whether or not the ore were worth mining still would remain an open question. It is well to remember, therefore, that the results of electrical prospecting are not a law unto themselves but rather must be used as an aid, very often a very valuable aid, to the methods of prospecting that have been in existence since mining began. It is well to remember also that the urgency of finding a successful electrical divining rod has led to many abuses of the methods here described which in no way detract from their essential value.

Inductance of Steel Reënforced Aluminum Cable

Calculated values of inductance of steel reënforced aluminum cable, presented in this paper, show that previously published values of inductance obtained experimentally are in error by amounts ranging up to 5 per cent. Furthermore, all these errors are on the low side, that is, the unsafe side from the standpoint of the design engineer.

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WHEN theory and experiment fail to agree, usually the theory must be amended. Therefore the writer at first regarded with much suspicion his own calculated values of the inductance of aluminum cable, steel reënforced (A.C.S.R.) when he found rather important discrepancies between them and the corresponding experimental values that have formed the basis for extensive published tables.[1,2] Careful and repeated checks of the theoretical work, however, revealed no errors. The method and difficulty of obtaining the experimental results that formed the basis for tables referred to will be examined.

Inductance values were based upon laboratory tests made at one-foot spacing; for other spacings the values were calculated from those at one-foot spacing by means of the fundamental inductance formula. Apparently, there has been no publication of the actual test data or a description of the method of test, but inquiry has revealed that the tests were made on short specimens, less than 100 feet long. The inductance measured was of the order of 10^{-5} henry, and a limit of error of 1 per cent therefore would require measurement within 10^{-7} henry of the true value. This presents some difficulties, and perhaps the results were as good as could be expected, especially since the correction for end effects still would remain to be made before the test results would be ready for use in applying to long lines. On such short specimens the end effects easily might amount to several per cent of the total. On the basis of these experimental difficulties, and the soundness of the theoretical attack, it can be stated positively that the experimental results are in error by amounts ranging up to 5 per cent in the determination of the inductance, which is the

A paper recommended for publication by the A.I.E.E. committee on power transmission and distribution. Manuscript submitted Oct. 9, 1933; released for publication Aug. 3, 1934.

1. For all numbered references see list at end of paper.

constant most effective in determining the power capacity and voltage regulation of a transmission line. Further, all these errors are on the low side, that is, the unsafe side from the standpoint of the design engineer.

It is shown in the Appendix that a *lower limit* for the value of inductance of A.C.S.R. may be calculated accurately, based upon the assumption of zero current in the steel reënforcement. Table I shows the comparison of the computed lower limit with the test results for one-foot spacing.

Table I—Comparison of Test and Calculated Values of Inductance of A.C.S.R.

Circular Mils (Aluminum)	No. of Strands Aluminum	No. of Strands Steel	Inductance in Mh per Mile of Each Conductor (1 Ft Spacing) Test[2]	Computed Lower Limit	Difference = Minimum Error in Test Value	Percentage Difference
1,590,000	54	7	0.906	0.9509	0.0449	4.7
1,510,500	54	7	0.912	0.9592	0.0472	4.9
1,431,000	54	7	0.920	0.9679	0.0479	4.9
1,351,500	54	7	0.928	0.9771	0.0491	5.0
1,272,000	54	7	0.938	0.9868	0.0488	4.9
1,192,500	54	7	0.948	0.9972	0.0492	4.9
1,113,000	54	7	0.957	1.008	0.051	5.1
1,033,500	54	7	0.968	1.020	0.052	5.1
954,000	54	7	0.981	1.033	0.052	5.0
900,000	54	7	0.990	1.043	0.053	5.1
874,500	54	7	0.994	1.047	0.053	5.1
795,000	54	7	1.01	1.062	0.052	4.9
715,500	54	7	1.03	1.079	0.049	4.5
666,600	54	7	1.04	1.091	0.051	4.7
636,000	54	7	1.05	1.098	0.048	4.4
605,000	54	7	1.05	1.106	0.056	5.3
556,500	30	7	1.05	1.100	0.050	4.5
500,000	30	7	1.07	1.117	0.047	4.2
477,000	30	7	1.08	1.124	0.044	3.9
397,500	30	7	1.11	1.154	0.044	3.8
336,400	30	7	1.14	1.181	0.041	3.5
300,000	30	7	1.16	1.199	0.039	3.3

Percentages tabulated in the last column of table I represent a *lower limit* to the percentage errors in the previously published tables, and not the actual errors. An approximation will be made to allow for the effect of the current in the steel strands. This effect is small. Table II presents values of reactance at a frequency of 60 cycles per second for various spacings, with allowance made for the effect of the steel reënforcement. It is believed that this table is accurate to within ± 0.5 per cent.

Conclusions

Errors up to 5 per cent have been pointed out in existing A.C.S.R. tables. A more accurate table is presented. It is recommended, however, that precise tests be made on one specimen of each stranding, that is, one cable of 54 + 7 strands, one of 30 + 7 strands, etc. Rational methods, pointed out in this paper, may be used to extend the results to other sizes having the same stranding. End effects may be handled in several ways—for example, by testing 2 different lengths of loop having identical end arrangements, and taking the difference of their inductances. The loops should be at least 200 or 300 feet long in order to provide accurate results.

While the theory suffices to show indisputably that large errors exist in the present tables, nevertheless certain assumptions have had to be made in the theoretical analysis. All these assumptions have been considered carefully, and their effects calculated or at least estimated. Table II is an improvement over the previously published tables, but the matter cannot be considered as settled satisfactorily until agreement between experimental and theoretical results has been reached.

Appendix

The inductance of A.C.S.R. conductors is affected by the following considerations:

1. Stranding of aluminum.
2. Spiraling of aluminum strands.
3. Skin effect.
4. Proximity effect.
5. Effect of steel core.

These effects will be considered in the order listed.

Stranding of Aluminum

This effect may be taken into account precisely by computing the geometric mean distance of the aluminum cross section to itself. (This sometimes is called geometric mean radius. However, it is not in any sense a radius, so this term is somewhat deceptive.) There are 4 well established theorems that will be used in the computation, namely:

a. Self geometric mean distance of a circular area is $re^{-1/4}$ where r = radius and $e = 2.718\ldots$.

b. Geometric mean distance between 2 circular areas external to each other is equal to the distance between their centers.

c. Geometric mean distance from a circular line to any point, line, or area wholly enclosed by the circular line is equal to its radius.

d. If a circular line of radius r has on it n equally spaced points, the geometric mean distance among them[3] is $r\sqrt[n-1]{n}$.

Self Geometric Mean Distance of 54 Aluminum Strands. All strands are the same size (see figure 1) and are arranged in circular layers of 6, 12, 18, and 24 about the central strand. The 3 outer layers are aluminum. If the radius of a single strand be designated by ρ, the radii of the circles through the centers of successive layers will be 2ρ, 4ρ, 6ρ, and 8ρ. The self geometric mean distance of the entire aluminum area to itself, which will be called D_s, is

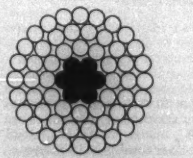

Fig. 1. A.C.S.R. with 54 aluminum and 7 steel strands

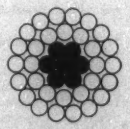

Fig. 2. A.C.S.R. with 30 aluminum and 7 steel strands

$$D_s = \sqrt[54^2]{(8\rho\sqrt[12]{24})^{24\times24}(6\rho\sqrt[12]{18})^{18\times18}(4\rho\sqrt[12]{12})^{12\times12}(8\rho)^{8\times8\times8}(6\rho)^{6\times6\times6}(\rho e^{-1/4})^{54}}$$

$$= \rho\sqrt[36]{6^{819}\,4^{1161}\,e^{-54/4}} = 7.28883\,\rho = 0.495942\sqrt{A}$$

where A is the total area of aluminum expressed in circular measure, equal to $54(2\rho)^2$. In the large radical above, the first parenthesis is the geometric mean distance between strands in the outside layer;

Table II—Inductive Reactance of A.C.S.R. in Ohms per Mile at 60 Cycles per Second for One Conductor of a Single Phase or Equilateral 3-Phase Transmission Line

Circular Mils (Aluminum)	No. of Strands Alum.	No. of Strands Steel	Interaxial Spacing in Feet 1	2	3	4	6	8	10	12	14	16	18	20	24	28	32	36	40
1,590,000	54	7	0.360	0.444	0.493	0.528	0.577	0.612	0.639	0.661	0.680	0.696	0.710	0.723	0.745	0.764	0.780	0.794	0.807
1,510,500	54	7	0.363	0.447	0.496	0.531	0.580	0.615	0.642	0.664	0.683	0.699	0.713	0.726	0.748	0.767	0.783	0.798	0.810
1,431,000	54	7	0.366	0.450	0.499	0.534	0.583	0.618	0.645	0.668	0.686	0.702	0.717	0.730	0.752	0.770	0.787	0.801	0.814
1,351,500	54	7	0.369	0.454	0.503	0.538	0.587	0.622	0.649	0.671	0.690	0.706	0.720	0.733	0.755	0.774	0.790	0.804	0.817
1,272,000	54	7	0.373	0.457	0.506	0.541	0.591	0.625	0.653	0.675	0.693	0.710	0.724	0.737	0.759	0.777	0.794	0.808	0.821
1,192,500	54	7	0.377	0.461	0.510	0.545	0.594	0.629	0.656	0.679	0.697	0.713	0.728	0.741	0.763	0.781	0.798	0.812	0.825
1,113,000	54	7	0.381	0.465	0.515	0.549	0.599	0.634	0.661	0.683	0.701	0.718	0.732	0.745	0.767	0.786	0.802	0.816	0.829
1,033,500	54	7	0.386	0.470	0.519	0.554	0.603	0.638	0.665	0.687	0.706	0.722	0.736	0.749	0.771	0.790	0.806	0.821	0.833
954,000	54	7	0.391	0.475	0.524	0.559	0.608	0.643	0.670	0.692	0.711	0.727	0.741	0.754	0.776	0.795	0.811	0.825	0.838
900,000	54	7	0.394	0.478	0.527	0.562	0.612	0.646	0.674	0.696	0.714	0.731	0.745	0.758	0.780	0.798	0.815	0.829	0.842
874,500	54	7	0.396	0.480	0.529	0.564	0.613	0.648	0.675	0.697	0.716	0.732	0.747	0.759	0.781	0.800	0.816	0.831	0.843
795,000	54	7	0.402	0.486	0.535	0.570	0.619	0.654	0.681	0.703	0.722	0.738	0.752	0.765	0.787	0.806	0.822	0.836	0.849
715,500	54	7	0.408	0.492	0.541	0.576	0.625	0.660	0.687	0.710	0.728	0.744	0.759	0.772	0.794	0.812	0.829	0.843	0.856
666,000	54	7	0.412	0.496	0.546	0.581	0.630	0.665	0.692	0.714	0.733	0.749	0.763	0.776	0.798	0.817	0.833	0.847	0.860
636,000	54	7	0.415	0.499	0.548	0.583	0.633	0.668	0.695	0.717	0.735	0.752	0.766	0.779	0.801	0.820	0.836	0.850	0.863
605,000	54	7	0.418	0.502	0.552	0.586	0.636	0.671	0.698	0.720	0.738	0.755	0.769	0.782	0.804	0.823	0.839	0.853	0.866
556,500	30	7	0.418	0.501	0.550	0.585	0.634	0.669	0.696	0.718	0.737	0.753	0.767	0.780	0.802	0.821	0.837	0.851	0.864
500,000	30	7	0.423	0.507	0.556	0.591	0.640	0.675	0.702	0.724	0.743	0.759	0.774	0.786	0.809	0.827	0.843	0.858	0.871
477,000	30	7	0.426	0.510	0.559	0.594	0.643	0.678	0.705	0.727	0.746	0.762	0.777	0.789	0.811	0.830	0.846	0.861	0.873
397,500	30	7	0.437	0.521	0.570	0.605	0.654	0.689	0.716	0.738	0.757	0.773	0.788	0.800	0.822	0.841	0.857	0.872	0.884
336,400	30	7	0.447	0.531	0.580	0.615	0.664	0.699	0.726	0.749	0.767	0.783	0.798	0.811	0.833	0.851	0.868	0.882	0.895
300,000	30	7	0.454	0.538	0.587	0.622	0.671	0.706	0.733	0.755	0.774	0.790	0.805	0.817	0.840	0.858	0.874	0.889	0.902

the second is that between strands in the second outer layer; the third, between strands in the third or inner layer of aluminum; the fourth, from the outer layer to all aluminum strands inside it; the fifth, between the strands of the second and third layers; and the last parenthesis is the geometric mean distance of each strand to itself.

Self Geometric Mean Distance of 30 Aluminum Strands. Similarly, for the 30 aluminum strands of figure 2,

$$D_s = \sqrt[30\times29]{(6\rho\sqrt[12]{18})^{12\times18}\,(4\rho\sqrt[12]{12}^{\,12\times12})\,(6\rho)^{18\times12\times12}\,(\rho e^{-1/4})^{30}}$$

$$= \rho\,\sqrt[900]{6^{288}\,4^{139}\,e^{-30/4}} = 5.78446\,\rho = 0.528045\sqrt{A}$$

where A for this design is $30\,(2\rho)^2$, the total area of aluminum in the cross section.

The inductance calculated on the basis of the aluminum strands only may now readily be obtained, assuming uniform current density over the aluminum. For the 556,500 circular mil 30 + 7 strand A.C.S.R. at 12 inch interaxial spacing, it is

$$0.74113\,\log_{10}\frac{D_M}{D_s} = 0.74113\,\log_{10}\frac{12}{0.5280\sqrt{0.5565}} = 1.100 \text{ millihenry}$$

per mile of conductor.

Spiraling of Aluminum Strands

The spiraled strands of aluminum comprise long concentric solenoids with some compensation from the alternate directions of twist in the successive layers. The magnitude of the inductance contributed by spiraling in the 556,500 circular mil 30 + 7 strand A.C.S.R. will be discussed. The outer layer consists of 18 strands of aluminum with a lay of one revolution in about 12 inches. The second layer consists of 12 strands of aluminum, and has a reverse lay of one revolution in about 8 inches. The axial magnetomotive forces of the 2 layers, therefore, will very nearly cancel inside the second layer. The main solenoid flux, therefore, will be confined between the outer and second layers, and will have a magnetomotive force of about 18/30 ampere turn per foot for each ampere of total current since the steel carries very little current, as will be shown later. The annular area of cross section of the flux path is 0.292 square inch. The return path will be outside the cable, so each line of solenoidal flux will link only the outer layer, carrying 18/30 of the current. The inductance contributed by this spiraling, therefore, will be $(5280\times\frac{18}{30}\times\frac{18}{30}\times4\pi\times6.45\times0.292)\div(30.5\times10^6) =$ 0.0115 millihenry per mile of each conductor.

The effect is of the order of $^1/_{10}$ of one per cent. It may be noticed that the effect of spiraling always will be to *increase* the inductance, and so the effect is in the wrong direction to account for any part of the large discrepancy of several per cent.

Skin Effect

Skin effect in a solid round wire of radius r reduces that portion of the total inductance due to flux inside the wire by a factor equal to[4] the difference between unity and the real part of $\frac{4}{nr}\,\frac{J_0(nr)}{J_1(nr)}$ where $n = \sqrt{-j\,4\pi\mu\omega\gamma}$ and J_0 and J_1 indicate Bessel functions of the first kind and of zero and first order, respectively, μ is the permeability, ω is the angular velocity of the current, and γ the conductivity in absolute centimeter-gram-second units. The total effect is small at power frequencies, and it has been shown by Kennelly, Laws, and Pierce[5] that the combination of air and metal in a large stranded conductor has very nearly the same skin effect as the equivalent solid conductor. On this basis, it is found that the correction to be applied because of skin effect amounts to 0.0007 millihenry per mile for the 556,500 circular mil cable at a frequency of 60 cycles per second.

A slightly more accurate figure for the skin effect can be obtained by considering the aluminum strands as a hollow tube having inner and outer radii q and r, respectively. Then the internal inductance is[6] the real part of

$$\frac{2}{nr}\,\frac{J_0(nr) - \dfrac{J_1(nq)}{G_1(nq)}\,G_0(nr)}{J_1(nr) - \dfrac{J_1(nq)}{G_1(nq)}\,G_1(nr)} \text{ abhenries per centimeter}$$

and the correction to be applied becomes 0.0006 millihenry per mile. The correction is negligible, about $^1/_{10}$ of one per cent. The effect is to reduce the inductance, so that there is a partial cancellation between this effect and the small increase in inductance resulting from spiraling.

Proximity Effect

The approximate importance of proximity effect at the one foot spacing used in the tests may be computed from the round wire formula. The effect[7] is to *reduce* the inductance by an amount equal to $2\sum_{1}^{\infty} m\left(\frac{r}{D}\right)^{2m}\phi_{m,o}$ abhenries per centimeter for one conductor. (See reference 7 for definition of $\phi_{m,o}$.)

For the particular size and spacing under consideration, the correction to be applied is a reduction of only 0.000019 millihenry per mile. It is absolutely negligible. If this correction were not so very small it might be desirable to compute the proximity effect on the equivalent aluminum tubes.[6] Proximity effect in a spiraled cable is less than in a solid equivalent conductor because the circular dissymmetry of the current distribution requires leakage across the boundaries of the individual strands as the current progresses in an axial direction; hence the true proximity effect is even smaller than the very small figure just given.

There are 2 or 3 other minor corrections that have a slight effect on the inductance. If the over-all diameter of the cable be increased because of either oxidation or loosening of the strands, a slight decrease in inductance would result. For each per cent increase in diameter the decrease in inductance would be only about $^1/_4$ of one per cent at spacings of about one foot, and less at larger spacings. It seems very unlikely that this could be of any importance in an actual line, under tension, although perhaps this effect was appreciable in the experimental set-up.

If the lay of the strands in all layers, expressed in turns per unit length, were the same, then the strands in the inner layers would be shorter and would tend to carry somewhat more current than the outer ones because of their lower resistance. This would offset somewhat the skin effect, which tends to cause a crowding of current toward the outside. It seems to be the manufacturing practice, however, to give more twist to the inner strands, about in proportion to the diameter of the layer, so that the aluminum strands in different layers actually do have almost identical lengths and resistances.

Total Inductance of Aluminum Strands

Before considering the effect on the inductance of the current and flux in the steel strands, which may involve more uncertainty than the other considerations because of the comparatively high and varying permeability, it is instructive to review all the other effects. It has been shown that the computation involving geometric mean distance gives very nearly the exact inductance for the aluminum. There is a slight positive correction to be added, since the effect of spiraling appears to add about twice as much inductance as the reduction resulting from skin effect and proximity effect combined. At large spacings the proximity effect is even smaller. The net correction is less than $^1/_{10}$ of one per cent. For the very large sizes, the increase in inductance resulting from spiraling and the decrease resulting from skin effect both become somewhat greater, but their difference remains very small.

Current and flux in the steel core necessarily *increase* the inductance over its value for the hollow aluminum portion alone for A.C.S.R. at usual power frequencies. To prove this, consider the effect of transferring part of the current from one layer of aluminum strands to the more central steel. This change would leave unaffected the magnetic field outside the aluminum layer, but would *increase* the strength of the field within it and hence cause more linkages and more inductance.

Therefore, the accurately computed inductance for the aluminum alone constitutes a lower limit to the possible value of inductance. The fact that the existing tables present values considerably lower than this lowest possible value is conclusive evidence that important errors exist in those tables.

Although the error can be shown to exist by neglecting all current in the steel, the lower limit computed in this way is not a satisfactory value to use as the basis for a standard table. A very good approximation of the true effect of the steel core can be made.

Effect of Steel Core

The boundary condition controlling the determination of the relative currents in the aluminum and the steel portions is that at the surface of contact of the 2 metals the current densities are in direct proportion to the respective conductivities. The particular case of the 536,500 circular mil A.C.S.R. at a frequency of 60 cycles per second will be considered. It has been shown already that the skin effect in the aluminum is very small. The skin effect in the steel is unaffected by the tubular aluminum sheath, and so would be the same as for a 7 strand steel cable of the same size. Test data are available[8] on such cables. At 60 cycles per second the skin effect resistance ratio is 1.007 at 10 amperes and 1.013 at 20 amperes for Siemens Martin steel. This indicates that the current density throughout the steel is approximately uniform, since otherwise the resistance ratio would be considerably more than one. The current distribution in the steel is therefore but little affected by the alternating character of the current. The current will divide almost exactly inversely as the d-c resistance of the 2 paths. The resistivity of the steel is about 110 ohms per mil-foot at 20 degrees centigrade, and of aluminum about 17.0 ohms per mil-foot. The aluminum will carry $\frac{30}{7} \times \frac{110}{17.0} = 27.7$ times as much current as the steel. The steel wire will carry 1/28.7 or 3.48 per cent in the cable under consideration. The effect of this core current on the inductance now will be computed and applied as a correction to the calculations already made, in which the effect of core current was neglected. First it is noted that the removal of 3.48 per cent of the current from the aluminum and its flow in the steel has no effect whatever upon the magnetic flux external to the entire cable. It will increase the flux density in the aluminum region by an amount that varies from zero at the outside to a maximum at the inside of the aluminum, where before the flux density was zero. The flux density in the steel is increased also, the value on the basis of assumed zero core current being zero throughout. If now the aluminum be considered as a tube of inside diameter 0.4086 inch and outside diameter 0.9534 inch, the increase in flux linkages per centimeter length resulting from the increased flux in the aluminum is equal to

$$\int_{0.3048}^{0.4767} \frac{4\pi I}{2\pi x}\left(0.0348 + 0.9652\,\frac{x^2 - 0.2043^2}{0.4767^2 - 0.2043^2}\right)^2 dx -$$

$$\int_{0.3048}^{0.4767} \frac{4\pi I}{2\pi x}\left(\frac{x^2 - 0.2043^2}{0.4767^2 - 0.2043^2}\right)^2 dx = 0.378\,I - 0.358\,I =$$

$$0.020\,I \text{ linkage per centimeter}$$

where I is expressed in abamperes. Applying the proper conversion factors this is found to represent an increase in inductance per mile of one conductor amounting to 0.00322 millihenry.

In addition to this there is another increase in inductance resulting from the linkages between the core current and core flux. Experimental results[9] on 7 strand steel cables of the size of the core indicate an internal inductance that varies slightly with the current, but an average value of 1.50 millihenries may be used. In order to make use of this datum for A.C.S.R., it must be multiplied by the square of the fraction of current carried by the steel, or 0.0348. The contribution to the inductance is therefore $0.0348^2 \times 1.50 = 0.00182$ millihenry per mile. The total increase resulting from the presence of the steel in the center instead of a nonconductor is $0.00322 + 0.00182 = 0.00504$ millihenry per mile. The same increase would apply to other A.C.S.R. cables of different size provided they are geometrically similar, i. e., composed of $30 + 7$ strands of aluminum and steel, respectively. For the $54 + 7$ strand A.C.S.R. the corresponding increase works out to be $0.0017 + 0.0006 = 0.0023$ millihenry per mile.

These corrections, added to the computed lower limits of inductance listed in table I, form the basis for the reactance figures presented in table II.

For reënforcement of standard low-carbon steel strand the permeability is higher, and the skin effect resistance ratios are 1.13 and 1.35 at 10 and 20 amperes, respectively. The measured internal inductance is about 4.5 millihenries per mile, an average value over the range of probable current density. The steel core therefore will carry about 25 per cent less current than before. The increase in inductance resulting from additional linkages in the aluminum region will be decreased to 0.0024, and in the steel there will be a total increase of $0.026^2 \times 4.50 = 0.0030$ millihenry per mile. The total change resulting from the steel is 0.0054 compared with 0.0050 for the less permeable steel—a negligible difference.

The question might be raised as to how computations of inductance based upon measurements made on steel cables can pretend to greater accuracy than values obtained by direct measurement on A.C.S.R. cables. The answer of course is that experimental error introduced in the measurements on the steel cable affect only about $^1/_2$ of one per cent of the entire A.C.S.R. inductance, the other 99.5% being computed by well established fundamental methods.

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Saturated Synchronous Reactance

It is well known that the effects of magnetic saturation are important in modifying the operating characteristics of synchronous machines. In this paper is shown a method of accurately taking into account these effects on the balanced steady-state operation of a cylindrical rotor synchronous machine by using a saturated value of the synchronous reactance. The expression for this reactance is derived directly from fundamental principles, and its use in calculating machine characteristics accurately is illustrated on a typical steady state stability problem.

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As is well known, a cylindrical rotor synchronous machine operating without magnetic saturation under balanced polyphase load conditions can be represented by its synchronous impedance in series with its excitation voltage. However, it has long been realized that the effects of saturation should be correctly taken into account. Various empirical schemes[1,2] for adjusting the synchronous reactance have been proposed but, as shown in table I of this paper, these methods may give results which are considerably in error.

In a paper by Crary, March, and Shildneck[3] it is shown that with certain restrictions a saturated synchronous machine can be represented by an "equivalent" unsaturated machine. However, in the cylindrical rotor case, this "equivalent" machine does not have the same load angle as the actual machine which it replaces, and hence the synchronizing power of the "equivalent" machine will not in general be the correct value for the actual saturated machine.[4] This may introduce considerable error, as shown in table II.

In a paper by H. V. Putman a simple expression is derived for the saturated synchronous reactance. This expression is derived directly from basically sound fundamental principles which take into account correctly the most important factors affecting saturation. The correct use of Putman's expression should therefore give accurate results. The difficulty in using Putman's expression arises from the fact that the saturated synchronous reactance is a variable. For example, in calculating the steady-state power-angle characteristics of a synchronous machine, the saturation has a different value for each point on the curve. Hence, a different value of the saturated synchronous reactance should be used in calculating each point, and in any calculations involving differentiation—for example, in calculating the steady state synchronizing power—the saturated synchronous reactance should be treated as a variable. In Putman's paper (equations 24 and 25) this fact is neglected, the saturated synchronous reactances being treated as constants in the differentiation. This may introduce considerable error, as shown in table II of this paper.

The methods of both Putman and Crary, March, and Shildneck require a knowledge of the air gap voltage of the machine in order to calculate its reactance. Many cases may arise in which the data are so stated that it is difficult to calculate the air gap voltage. For example, let the field current, terminal voltage, and power output of a saturated synchronous machine be given. It is necessary to resort to successive approximations in order to calculate the air gap voltage. Hence, the methods of Putman and Crary, March, and Shildneck are, practically speaking, restricted to cases where the terminal operating conditions are explicitly known.

This paper presents a treatment of the cylindrical rotor synchronous machine based upon Putman's expression for the saturated synchronous reactance. It is shown that by means of an auxiliary curve, the appropriate value of the saturated synchronous reactance can be determined in calculating each point on the power-angle characteristics of a typical simple system, and that the effects of saturation on the maximum power of such a system can be readily and accurately taken into account. The paper also shows a comparison of results obtained by tests with those obtained by various methods of calculation.

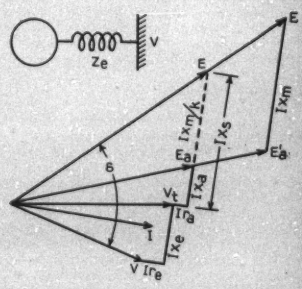

Fig. 1. Cylindrical rotor synchronous generator connected to an infinite bus

Assumptions

The assumptions are those which are commonly made in analyzing the steady-state performance of a

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1. For all numbered references see list at end of paper.

cylindrical rotor synchronous machine.[4] Of these, the most important are:

1. The air gap is uniform. From this assumption, the direct-axis synchronous reactance X_d is equal to the quadrature-axis synchronous reactance X_q.

2. The saturation curve of the machine under load conditions is assumed to be the same as the open-circuit characteristic. According to this assumption the field leakage flux is assumed to have the same effect under load conditions as it has at no-load.

(In reference 3, at the end of the paper, the effects on the saturation of the change in field leakage flux under load conditions are approximately accounted for by using, instead of the open-circuit saturation curve, a family of load saturation curves calculated with the appropriate values of field leakage under load conditions. If deemed advisable, this refinement may be introduced. It is omitted in this paper in order to simplify the presentation of more essential facts.)

Saturated Synchronous Machine

Consider a saturated cylindrical-rotor synchronous machine operating under balanced steady-state conditions, connected through an impedance Z_s of resistance r_s and reactance x_s to an infinite bus of voltage V, as shown in figure 1. On the basis of the foregoing assumptions, the well-known vector diagram shown by the solid lines of figure 1 can be drawn,[3,5] in which

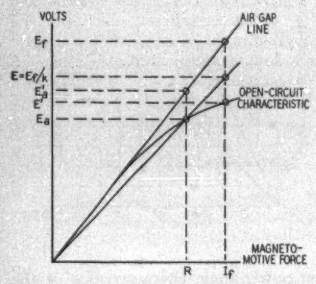

Fig. 2. Open-circuit characteristic

I = armature current
V_t = terminal voltage of the machine
r_a = armature effective resistance
x_a = armature leakage reactance
E_a = voltage generated by the resultant air gap flux
E_a' = voltage which would be generated by the resultant magnetomotive force R if the magnetic circuit were not saturated
E_f = voltage which would be generated by the field excitation I_f if the magnetic circuit were not saturated
X_d = unsaturated value of the synchronous reactance
x_m = $X_d - x_a$ = reactance equivalent to the armature reaction when there is no saturation

Any consistent system of units may be used. The voltages E_f and E_a' are shown in figure 2.

Let

$$k = E_a'/E_a \tag{1}$$

Then k is a measure of the saturation of the machine. (Except for the manner in which field leakage is treated, k as defined above is the same as the saturation factor k of reference 3 at the end of the paper.) Figure 4 shows a typical curve of k as a function of E_a.

By applying equation 1 to figure 1, it can be seen that the saturated value of the synchronous reactance is

$$x_s = x_a + x_m/k \tag{2}$$

and that the saturated value of the excitation voltage is

$$E = E_f/k \tag{3}$$

These results agree with those obtained by Putman.[6] Since k is a function of E_a, both x_s and E are functions of E_a. Figure 4 shows a typical curve of x_s as a function of E_a.

Equations 2 and 3 are derived directly from the fundamental vector diagram of figure 1, and hence take into account correctly the most important effects of saturation. This is an important improvement over any method of empirically adjusting the synchronous reactance.[1,2]

It can readily be seen that the voltage E in figure 2 is equal to the voltage E given by equation 3. (In figure 2, $E_f/E = E_a'/E_a = k$, or $E = E_f/k$). It should be noted that the excitation voltage E is not equal to the voltage E' read from the open-circuit saturation curve, figure 2. The voltage E' would appear at the machine terminals at no-load if the field current were maintained constant. Hence E' is frequently used as the excitation voltage. However, the removal of the load would change the saturation of the machine. The voltage E would appear at the machine terminals if the load were removed and the field current *and saturation* maintained the same as under load conditions. Hence equation 3 determines the excitation voltage at the correct saturation of the machine under load conditions.

Power-Angle Characteristics

Consider the system shown in figure 1. As is well known, the air gap power of the machine P_a is given by

$$P_a = \frac{EV}{Z}\sin(\delta - \alpha) + \frac{E^2 r}{Z^2} \tag{4}$$

and the power P_b delivered to the infinite bus is given by

$$P_b = \frac{EV}{Z}\sin(\delta + \alpha) - \frac{V^2 r}{Z^2} \tag{5}$$

where

r = total series resistance = $r_s + r_a$
x = total series reactance, saturated value = $x_s + x_a$
Z = total impedance = $\sqrt{r^2 + x^2}$
α = $\tan^{-1}(r/x)$
δ = load angle of the machine with respect to the infinite bus, i. e., the angle between the vector voltages E and V, positive when E leads V.

Positive values of P_a and P_b correspond to generator action of the machine. Equations 4 and 5 apply equally well when the machine is operating as a synchronous motor with negative values of δ, P_a, and P_b. Equations 4 and 5 are the well-known relations which are useful in steady state stability studies, written in a form which the author has found convenient.

As is well known, saturation affects the power-

angle characteristics, since it affects x_s and E. The following is an accurate method of calculating these curves, based upon equations 2 and 3 as expressions for x_s and E, which correctly take into account the most important effects of saturation.

Since $E = E_f/k$, equation 3, and is thus dependent upon saturation, it is more convenient to express equations 4 and 5 as follows:

$$P_a = \frac{E_f V}{kZ} \sin(\delta - \alpha) + \frac{E_f^2 r}{(kZ)^2} \tag{6}$$

$$P_b = \frac{E_f V}{kZ} \sin(\delta + \alpha) - \frac{V^2 r}{Z^2} \tag{7}$$

In equations 6 and 7, (kZ), α, and Z^2 are variables dependent upon the saturation. Even if the machine excitation and the bus voltage are constant, the saturation will vary with changes in the load angle δ. Therefore (kZ), α, and Z^2 are variables dependent upon δ. Hence, in order to determine the values of these quantities to use in equations 6 and 7, it is necessary to express the air gap voltage E_a (which determines the saturation) as a function of δ. The following equation is derived in appendix A:

$$(kZE_a)^2 = (E_f Z_a)^2 + (V x_m)^2 + 2E_f V Z_a x_m \cos(\delta - \alpha_a) \tag{8}$$

where

$$Z_a = \sqrt{(r_a + r_a)^2 + (x_a + x_a)^2}$$
$$\alpha_a = \tan^{-1}[(r_a + r_a)/(x_a + x_a)]$$

On the left-hand side of equation 8, both k and Z are functions of E_a, as are the variables (kZ), α, and Z^2 which appear in equations 6 and 7. By assuming various values of E_a, these variables and the quantity $(kZE_a)^2$ which constitutes the left-hand side of equation 8 can be calculated and curves drawn showing (kZ), α, and Z^2 as functions of $(kZE_a)^2$. These auxiliary curves are shown in figure 5 for the case illustrated in example 1 (see below).

Having plotted these auxiliary curves for the system under consideration, the power-angle characteristics can be calculated for any given excitation of the machine and any given voltage of the infinite bus, as outlined in the following:

Assume a value of δ for which the corresponding values of P_a and P_b are to be calculated. From equation 8 calculate the corresponding value of $(kZE_a)^2$. From the auxiliary curves of (kZ), α, and Z^2 as functions of $(kZE_a)^2$, read the corresponding values of these quantities. Substituting these values the given values of E_f and V, and the assumed value of δ in equations 6 and 7, the corresponding values of P_a and P_b now can be readily calculated. By repeating this procedure for other assumed values of δ, the power-angle characteristics can be calculated, accurately taking into account the effects of saturation.

Numerical Example 1

Consider the cylindrical rotor synchronous machine whose open-circuit and short-circuit characteristics are given in figure 3. The armature resistance is $r_a = 0.022$ and the armature leakage reactance is $x_a = 0.105$, both expressed in "per unit" on the machine rating as a base. From the open-circuit characteristic, the saturation factor k can be calculated, equation 1, and plotted as a function of the air gap voltage E_a, as shown in figure 4. From the short-circuit characteristic and the air gap line,

X_d (unsaturated) = 0.970

Hence

$x_m = X_d - x_a = 0.865$

By equation 2,

$$x_s = 0.105 + \frac{0.865}{k}$$

Figure 4 shows x_s plotted as a function of E_a.

Consider this machine supplying power to an infinite bus through a feeder of resistance $r_e = 0.092$ and reactance $x_e = 0.436$, both expressed in per unit on the machine rating as a base. Let it be required

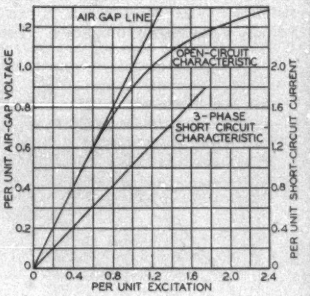

Fig. 3. Open-circuit and short-circuit characteristics of a cylindrical rotor synchronous machine

to calculate the power-angle characteristics of the system at a constant excitation, $E_f = 1.61$, and a constant receiver bus voltage, $V = 1.00$.

It will first be necessary to calculate the auxiliary curves of figure 5. The following calculation for one assumed value of E_a illustrates the method:

$r = r_e + r_a = 0.114$

For $E_a = 1.00$,

$k = 1.19$, $x_s = 0.830$, from figure 4

Hence

$x = x_e + x_s = 1.27$

Since r is small compared with x,

$Z = \sqrt{r^2 + x^2} = x$, very nearly, $= 1.27$
$Z^2 = x^2$, very nearly, $= 1.61$
$kZ = 1.51 \quad (kZE_a)^2 = 2.28$

However, r is sufficiently large so that α cannot be neglected.

$\alpha = \tan^{-1}(r/x) = 5.1$ degrees

By carrying through the above calculations for several other assumed values of E_a, data can be calculated for the auxiliary curves of figure 5.

In connection with these curves, equation 8 must

be used. For the case under consideration, $x_s + x_s = 0.541$. Hence

$$Z_s = \sqrt{(r_s + r_a)^2 + (x_s + x_a)^2} = 0.553$$

$$\alpha_s = \tan^{-1}[(r_s + r_a)/(x_s + x_a)] = 11.9 \text{ degrees}$$

Hence equation 8 becomes:

$$(kZE_a)^2 = 1.54 + 1.54 \cos(\delta - 11.9 \text{ degrees}) \qquad (8a)$$

(It is, of course, pure coincidence that the constant term 1.54 in equation 8a is also the coefficient of the variable term.)

By assuming various values of δ, the corresponding values of P_a and P_b can now be calculated and data obtained from which the power-angle characteristics shown in figure 6 can be plotted. The following calculation for one assumed value of δ illustrates the method:

For $\delta = 60.0$ degrees,
$(kZE_a)^2 = 2.57$, from Equation 8a

Hence

$kZ = 1.54$, $\alpha = 5.2$ degrees, $Z^2 = 1.55$, from figure 5

Hence, from equations 6 and 7 at $\delta = 60.0$ degrees

$P_a = 0.980 \quad P_b = 0.876$

Figure 6 also shows a comparison of calculated with test results. The agreement is well within the accuracy required in most engineering problems, the calculated values of power being, at the worst, about 0.02 per unit below the test results.

Calculation of Maximum Power

Consider the system of figure 1. If in equation 6, (kZ) and α were constants, then under specified conditions of constant excitation and infinite bus voltage, the air-gap power-angle characteristic would be a displaced sinusoid, and the maximum value of P_a would obviously be

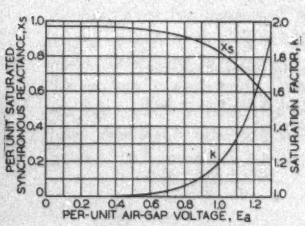

Fig. 4. Saturation factor and saturated synchronous reactance as functions of the air gap voltage

$$\pm P_a \text{ max.} = \pm \frac{E_f V}{kZ} + \frac{E_f^2 r}{(kZ)^2} \qquad (9)$$

and would occur when $(\delta - \alpha) = \pm 90$ degrees, the positive signs being for generator, and the negative signs for synchronous motor action of the machine. However, the saturation varies with changes in δ, and consequently (kZ) and α are variables dependent upon δ. Thus the air-gap power-angle characteristic is not exactly a displaced sinusoid, and the maximum value of the air gap power will not occur exactly when $(\delta - \alpha) = \pm 90$ degrees. However, in all practical cases, near its maximum value, the power-angle characteristic is approximately a displaced sinusoid and very little error will result from assuming that at $(\delta - \alpha) = \pm 90$ degrees, the corresponding value of P_a given by equation 9 is the maximum value. The error will not be over one per cent if the load angle at which the air gap power actually reaches its maximum value is within about 8 degrees of $(\delta - \alpha) = 90$ degrees. In equation 9, (kZ) is dependent upon the saturation. Its value at pull-out can be determined by substituting $\delta = (\pm 90 \text{ degrees} + \alpha)$ in equation 8, and referring to the auxiliary curve of (kZ) as a function of $(kZE_a)^2$, similar to that shown in figure 5.

Table I—Comparison of Results Obtained by Various Methods of Calculating Maximum Power

	Case 1		Case 2		Case 3		Case 4	
Method	$P_a$max.	%error	$P_a$max.	%error	$P_a$max.	%error	$P_a$max.	%error
A	1.24	0	1.32	0	1.56	0	1.92	0
B	1.24	0	1.30	− 2	1.55	−1	1.91	− 1
C	1.29	+ 4	1.50	+14	1.70	+9	1.94	+ 1
D	1.16	− 6	1.26	− 5	1.44	−7	1.71	−11
E	1.45	+17	1.56	+18	1.46	−6	3.04	+58

Similarly, from equation 7, the maximum power which the machine of figure 1 can deliver to the receiver bus under specified conditions of constant excitation and receiver bus voltage is, very nearly,

$$P_b \text{ max.} = \frac{E_f V}{kZ} - \frac{V^2 r}{Z^2} \qquad (10)$$

at a load angle $\delta = 90$ degrees $- \alpha$. The values of (kZ) and Z^2 to be used in equation 10 can be determined by substituting $\delta = 90$ degrees $- \alpha$ in equation 8 and referring to the auxiliary curves of figure 5.

Numerical Example 2

Consider the system of example 1, shown in figure 1. Let it be required to calculate the pull-out power of the generator at a constant voltage of the receiver bus, $V = 1.00$, and a constant excitation, $E_f = 1.61$ (as given in "Example 1").

Pull-out will occur approximately when $\delta = (90$ degrees $+ \alpha)$. The angle α is a variable dependent

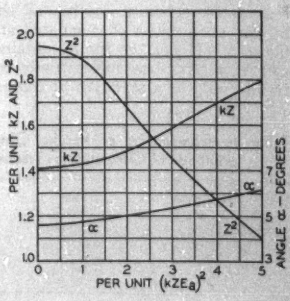

Fig. 5. Auxiliary curves for example 1

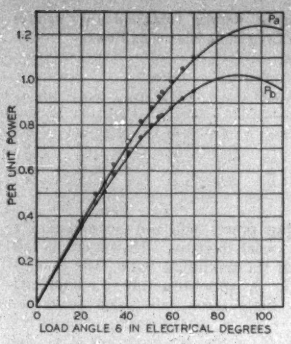

Fig. 6. Calculated power-angle characteristics of the system of example 1

Test points shown by small circles

upon saturation, and hence its exact value is not known. However, α is small and its approximate value will be accurate enough, say $\alpha = 5$ degrees. Hence, at pull-out, $\delta = 95$ degrees. Hence, from equation 8a, $(kZE_a)^2 = 1.73$ and from figure 5, $(kZ) = 1.46$. Hence from equation 9, P_a max. = 1.24. This checks to within slide rule accuracy the maximum value read from the complete air-gap power-angle characteristic shown in figure 6.

Table I shows a comparison of the maximum values of the air gap power calculated for several representative cases by the following methods of calculation:

Method A. From peak value of the air-gap power-angle characteristic calculated as shown in example 1.
Method B. Calculated by equation 9, as shown in example 2.
Method C. Neglecting saturation entirely.
Method D. Adjusted synchronous reactance, as described in reference 1 of the list at the end of the paper.
Method E. Adjusted synchronous reactance, as described in reference 2.

The results are shown for the following cases:

Case 1. System described in example 1.
Case 2. System of figure 1. Machine of example 1
$r_a = 0.482$, $x_a = 0.661$, $V = 1.00$, $E_f = 1.70$ (Large resistance).
Case 3. System of figure 1. Machine of example 1.
$r_a = 0$, $x_a = 0.500$, $V = 1.00$, $E_f = 2.50$ (Large field current).
Case 4. Machine of example 1 directly connected to an infinite bus. $V = 1.04$, $E_f = 1.74$.

Method A is based directly upon the fundamental vector diagram of figure 1, which is known to give reasonably accurate results, as shown for case 1 by the comparison of calculated and test results in figure 6. Hence the results obtained by method A can be accepted as substantially correct, and these results used as a standard of comparison in judging the accuracy of the other methods. On this basis, the errors of the other methods are shown in table I.

Table II—Comparison of Results Obtained by Various Methods of Calculating Synchronizing Power

Method	$dP_a/d\delta$	% error
F	0.653	0
G	0.647	− 1
H	0.741	+13
I	0.549	−16
J	0.749	+15

Table II shows a comparison of the values of the synchronizing power, $dP_a/d\delta$, for the system of example 1 under the following load conditions: Generator delivering its rated kilovoltamperes with its excitation adjusted so that its terminal voltage $V_t = 1.00$. Receiver bus voltage $V = 1.00$. From these data, the following quantities which are required can be calculated: $E_a = 1.03$, $E_f = 1.61$, $P_a = 1.02$, armature current lags terminal voltage by 1.0 degrees.

The results were calculated by the following methods:

Method F. From slope of experimentally-determined air-gap power-angle characteristic, figure 6.
Method G. From slope of air-gap power-angle characteristic calculated as in example 1, figure 6.
Method H. Neglecting saturation entirely.
Method I. Equation 24 of reference 5 of the list at the end of the paper.
Method J. Reference 3.

Summary

It is important to take into account correctly the effects of saturation in calculating the performance of synchronous machines. It is shown in this paper that these effects can be correctly and conveniently taken into account by means of equations 2 and 3 as expressions for the saturated synchronous reactance and excitation voltage of a cylindrical rotor synchronous machine operating under balanced steady-state conditions.

Appendix A—Derivation of Equation 8

From figure 1:

$$\bar{E}_a = \bar{V} + \bar{I}\,\bar{Z}_c \text{ and } \bar{I} = \frac{\bar{E} - \bar{V}}{\bar{Z}}$$

in which all quantities are expressed as vectors.

$$\bar{Z} = r + jx = (r_a + r_a) + j(x_a + x_a + x_m/k)$$
$$\bar{Z}_c = (r_a + r_a) + j(x_a + x_a)$$

Hence

$$\bar{E}_a = \bar{V} + \frac{(\bar{E} - \bar{V})\bar{Z}_c}{\bar{Z}} = \frac{\bar{E}\bar{Z}_c + \bar{V}(\bar{Z} - \bar{Z}_c)}{\bar{Z}}$$

Since

$\bar{E} = \bar{E}_f/k$ (equation 3), and $(\bar{Z} - \bar{Z}_c) = jx_m/k$,

$$\bar{Z}\bar{E}_a = \frac{\bar{E}_f}{k}\bar{Z}_c + j\,\bar{V}\frac{x_m}{k}$$

Hence

$$k\bar{Z}\bar{E}_a = \bar{E}_f\bar{Z}_c + j\bar{V}x_m \tag{11}$$

Let $\bar{V}$ be the reference vector. Then in polar form, $\bar{V} = V\underline{/0}$ degrees and $\bar{E}_f = E_f\underline{/\delta}$, where the symbols V and E_f (without the bars above them) mean the magnitudes of the voltages. In polar form $\bar{Z}_c = Z_c\underline{/90 - \alpha_c}$, where $Z_c = \sqrt{(r_a + r_a)^2 + (x_a + x_a)^2}$ and $\alpha_c = \tan^{-1}[(r_a + r_a)/(x_a + x_a)]$. Then in polar form, equation 11 becomes:

$$k\bar{Z}\bar{E}_a = E_fZ_c\underline{/\delta + 90 \text{ degrees} - \alpha_c} + Vx_m\underline{/90 \text{ degrees}} \tag{12}$$

The right-hand side of equation 12 is the sum of 2 vectors, the angle between them being $(\delta - \alpha_a)$. Their vector sum is the included diagonal of a parallelogram. Hence the magnitude of their resultant is given by:

$$(kZE_a)^2 = (E_f Z_s)^2 + (Vx_m)^2 + 2E_f V Z_s x_m \cos(\delta - \alpha_a)$$

where the symbols Z and E_a (without the bars above them) mean the magnitudes of these quantities. This is equation 8.

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A New Source of "Kilocycle Kilowatts"

Many applications of "kilocycle kilowatts" (electric power at frequencies of 1,000 to 100,000 cycles per second) have not been feasible because of the high cost of equipment for generating such power. In this paper, a new source of kilocycle power employing an electronic tube called the arc tube is described. The cost of the arc tube and its associated equipment is lower than that of other sources of kilocycle power; its frequency is readily adjustable.

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MANUFACTURERS continually are finding that an optimum frequency exists for doing most high frequency jobs. The comparatively high initial cost of equipment for generating kilocycle frequencies (1,000 to 100,000 cycles per second), however, has prevented both industrial use of kilocycle frequency power and experimentation to determine optimum frequencies. This paper reviews a few present-day uses of "kilocycle kilowatts" and suggests the arc oscillator tube as a source of kilocycle frequency power available at lower cost than the usual type of equipment.

The fact that high frequency power is useful industrially and that best frequencies exist for most processes is best established by citation of some present uses: 360 cycle power is used to bake enamel on auto fenders; 1,000 to 2,000 cycle power is used for metal and scrap melting; 900 to 2,000 cycle power excels for certain alloying processes inasmuch as electrical stirring occurs and can be controlled by frequency; 4,800 cycle power is found best in the manufacture of razor blade steel; 5,000 cycle power is used in ozone generators; 30,000 cycle power is optimum for proximity pipe welding; 40,000 to 50,000 cycle power is used in small induction furnaces; and 50,000 cycle power is used to sterilize milk.

Characteristics of Power Sources

There are 3 types of apparatus in common use for securing kilocycle frequency power: (1) rotating equipment, (2) high vacuum tubes and equipment, and (3) gaseous tubes and equipment. The industrial utility of each is governed principally by initial cost, operating cost, efficiency, life, input voltage requirements, size, and weight.

Rotating equipment is expensive, its operating costs are reasonably low, its efficiency is fair, its life good, it can be built for industrial supply voltage, it requires a good foundation, and is rather heavy.

High vacuum tube equipment is expensive, its operating costs are low, its efficiency fair, and its life fair. A rectifier must be built into the unit as high direct voltages usually are required. Complete equipment is rather bulky, but weight is light.

Gaseous tube equipment has moderate initial and operating costs for installations of 1,500 cycles per second or less; above 1,500 cycles costs mount

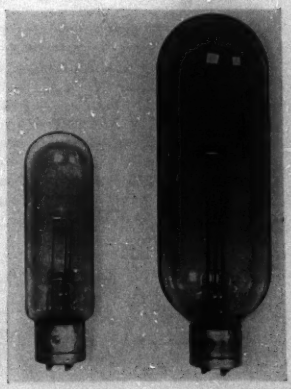

Fig. 1. Two typical arc oscillator tubes: (left) 50 watts and (right) 500 watts output

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with frequency. Efficiency is good, and life is fair. Industrial direct voltages may be used on the newer tubes. Space requirements and weight are moderate.

In any of these systems, operating costs, efficiency, and life are reasonable, but the principal curtailment to general use is high initial cost. However, a fourth source of high frequency power, the arc tube, presents to industries a source of kilocycle frequency power at lower initial cost.

In addition to low initial cost, it is characterized by low operating costs, fair efficiency, fair life, operation on industrial direct voltages, simplicity, small space, and small weight requirements.

Arc Tube Equipment

The arc tube consists essentially of 2 electrodes closely spaced in inert gas under high pressure. Figure 1 shows 2 typical tubes rated at 50 and 500 watts output, respectively. The well designed and built arc tube has 3 outstanding points of superiority over the old open arc, which predict its popularity: (1) an optimum gas pressure may be used to give maximum power; (2) electrodes may be spaced permanently for maximum efficiency at rated output; and (3) oxygen and water vapor may be driven from the tube before inert gas is admitted, thus insuring uniform power, better efficiency, and longer life.

Besides the tube, essential equipment consists of a choke coil, a stabilizing resistor, a capacitor, and an inductor. In high power applications the stabilizing resistor may take the form of the ohmic resistance of the windings of an electromagnetic field.

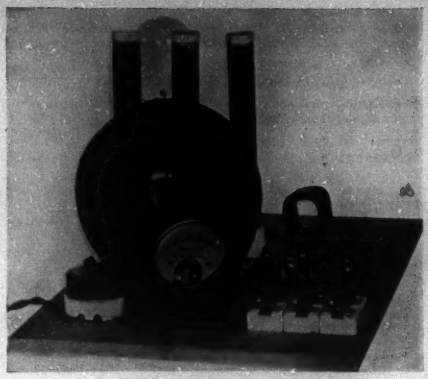

Fig. 4. A 50-watt arc-tube oscillator

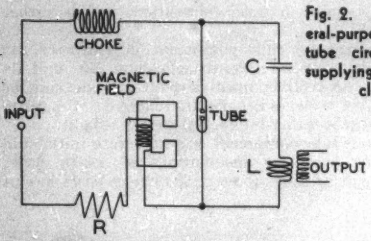

Fig. 2. A general-purpose arc-tube circuit for supplying kilocycle power

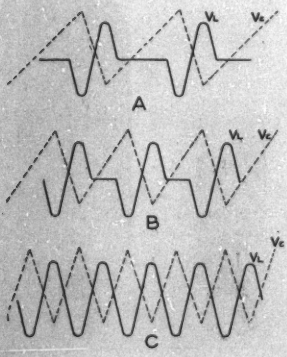

Fig. 3. Wave shape of output of circuit shown in figure 2

V_c—Voltage across capacitor C
V_L—Voltage across conductor L
A—Output for slow charging rate of capacitor C
B—Output for faster charging rate
C—Sine wave output for optimum charging rate

The optimum circuit arrangement depends upon the type of load, the wave shape, and the frequency desired. One general-purpose circuit is illustrated in figure 2. The choke maintains uniform continuous-current input, while high frequency oscillations take place in the branch of the circuit that contains the inductor L and the capacitor C, or the "LC-tube" circuit.

A complete cycle of operation may be described as follows:

1. When voltage is applied, capacitor C is charged through resistor R. (The choke causes a momentary pause in the starting cycle but not thereafter, as it maintains a steady continuous current during operation.)

2. The tube conducts no current until capacitor C is charged to sufficient voltage for breakdown between tube electrodes. At this point the tube ionizes, acts as an instantaneous short circuit, and allows C to discharge through the "LC-tube" circuit. Line current inrush is prevented by the choke.

3. At the instant C is completely discharged, a high current is flowing in the "LC-tube" circuit. The inductor L continues current flow, which overdischarges the capacitor and drives the tube voltage negative, whereupon the arc extinguishes and the tube is again an open circuit.

4. The capacitor C again becomes charged through the resistor R and the cycle is repeated.

Output at any desired voltage may be taken from the secondary of a transformer which constitutes the inductor; or, as in induction heating, output is taken directly from the inductance coil, which is the furnace coil. Output is in the form of sinusoidal pulses caused by each capacitor discharge (see V_L in figure 3). Frequency of these pulses is governed by the capacitor charging rate; the effect of successively decreasing the capacitor charging period is shown in figure 3. Part C of figure 3 shows that if charging periods are made short enough, sinusoidal pulses of voltage appear in uninterrupted sequence, giving sine wave output.

Variable frequency is accomplished by changing

either the period of charge, or the periods of both charge and discharge of the capacitor. A change in the value of either the stabilizing resistance or the voltage alters the period of charge; changes in load or inductance alter the period of discharge; change of capacitance alters both periods. Optimum sine wave operation at different frequencies obviously requires proportionate changes in charging and discharging periods. Sine wave operation may be obtained at any frequency by fixing 2 constants such as, input voltage and inductance, capacitance and inductance, or—the more usual—input voltage and load, and choosing other constants accordingly.

Wider Use of Kilocycle Power Predicted

The arc tube is destined to supply cheaper power for industrial utilization because: First, it is adaptable to varying needs—frequency can be changed conveniently; second, equipment can be made economically in any reasonable size, either to supply only a few watts or to furnish 50 or more kilowatts; third, arc tube equipment operates directly from industrial direct voltages; fourth, there are no moving parts to wear, and operating costs and maintenance are low; fifth, little associated apparatus is required; sixth, tube construction is not complicated, and hence with reasonable production cost should be low.

With "kilocycle kilowatts" available at lower cost, the use of 1,000 to 100,000 cycle power in industry, which has been limited to the few known processes that justify the present cost of such power, should increase. Some new applications that have been awaiting the availability of cheaper kilocycle power can now be put into practice, and doubtless further uses will be found by the experimenter who can use the less expensive equipment.

Precise Speed Control for D-C Machines

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In this paper a circuit is described that holds the average speed of a d-c shunt-wound machine as constant as the standard reference used (for which the most precise standard known can be employed) and holds the instantaneous speed very close to standard speed if there are not sudden changes of load or applied voltage. The machine is positively indexed in phase with respect to the standard. In addition to its precision, the method is characterized by its simplicity and general applicability over a considerable part of the range of d-c machine speed and capacity.

TO MEET a need for supplying several amperes of alternating current of fixed wave form, with amplitude and frequency held constant to 1 part in 2,000 or better, the method of speed control described in this paper was developed; this need arose in connection with a new method for the precise determination of specific heats of metals.[1,2,3,4] The method of speed control devised proved to be so much more precise than is needed for the particular problem at hand, and to be of such simplicity and general applicability that it has been considered worthwhile to report on the scheme apart from the project for which it was developed. In the problem at hand the immediate object was to produce something that would serve the purpose sufficiently well, with a minimum expenditure of time and money. Hence (as is pointed out later) some few refinements that could be added very readily to an installation designed to operate indefinitely have not been incorporated. Many circuits were tried without finding another that operated as satisfactorily as the one described. A complete account of this evolution to the final form cannot be included here, but a record is on file at the Massachusetts Institute of Technology.[5]

Factors Affecting Speed of a Shunt Machine

As a preliminary to explaining the operation of the speed control circuit, it may be advantageous to

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1. For all numbered references see list at end of paper.

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enumerate the factors that tend to cause the speed of a shunt wound machine to change:

1. Those causing gradual change.
   a. Change in temperature of the windings.
   b. Gradual change of applied voltage.
   c. Gradual change of load.
   d. Gradual change of friction (including windage).
2. Those causing sudden change.
   a. Sudden change of applied voltage.
   b. Sudden change of load.
   c. Sudden change of friction (such as might result from axial oscillation).
   d. Poor armature brush contact; erratic sparking.

The method explained in this paper keeps the machine synchronized with a standard in spite of all of the gradual changes however great (within the limits of the design of the machine) with entire success, and likewise for all the sudden changes if they are not large. Large sudden changes of applied voltage or load are permissible if pronounced hunting about the index position is permissible. Factors 2*c* and 2*d* ordinarily are small and largely can be avoided.

The method is such that the machine is positively indexed in phase with a frequency standard (which can be of the utmost precision if desired) so that as long as there are no sudden changes too large for the control to handle, the average speed of the machine is as constant as the frequency of the standard. If sudden changes are absent (as in the particular problem at hand) the speed of the machine is at every instant equal to (or a constant multiple of) the frequency of the standard to an extremely high degree of precision.

Machine Used

The machine for which the circuit was developed is a Roth Brothers Company single-phase synchronous converter the name plate data and resistances of which are as follows:

Power	500	watts
Voltage	115	volts d-c
	75	volts, 60 cycles per second
Current	7.2	amperes a-c
Speed	1,800	rpm
Armature resistance	1.0	ohm between d-c brushes
Field resistance	270	ohms

The converter is operated inverted from a storage battery to supply alternating current at about 62 cycles per second (in order to avoid interference from the 60 cycle supply in the building). It is provided with a flywheel which brings the total moment of inertia of the rotating parts to about 4 pound-(feet).[2] The inductance of the field winding (ignoring external resistance in series) is such that about 0.7 second is required to build up from zero to about 70 per cent of normal current. (What really is of most significance here is the time required to change the flux a small amount near its normal value. These figures are given merely to indicate the order of magnitude of the field response time.) The converter and its speed control circuit are shown diagrammatically in figure 1.

Operation of Circuit

The tuning fork standard F is housed in a thermally-insulated electrically-heated box in which air is circulated by means of a fan, and is kept within several hundredths of a centigrade degree of a fixed temperature by means of a Wheatstone bridge thermostat arrangement not shown. The frequency supplied by the fork can be adjusted over a moderate range in the vicinity of 60 cycles per second by means of sliding weights. The fork is started by tapping key K, thus energizing the fork driving coil. When the fork contact is made, the grid of tube T_1 (a grid-controlled mercury-vapor-filled tube) is made sufficiently positive to "trip" the tube. An instant later, the discharge in T_1 is extinguished by the discharge of condenser C_1. The time constant of the circuit used to change the potential of the grid is so small that in the meanwhile the potential of the grid has dropped below the tripping potential, so that the tube cannot trip again until the fork contact closes again. Thus the action of tube T_1 accomplishes the driving of the fork and the flashing of the neon tube N connected to the secondary of an induction coil S (the vibrator of which is clamped down). The disc D, attached to the converter shaft, when viewed by the light from the flashing neon tube gives visual evidence of the speed of the converter with respect to the frequency of the fork. This stroboscope circuit was adapted from one suggested by Professor H. E. Edgerton, Massachusetts Institute of Technology.

The part of the circuit described thus far is in the main merely auxiliary to the speed control circuit *per se*, which operates as follows: On the converter shaft is mounted also a 2-part commutator C, about 7 inches in diameter. The segments are separated by about $^1/_{16}$ inch of insulation. Two brushes are about 180 degrees apart, and a third brush is midway between them. The potential of the third or middle brush is controlled in a manner similar to that for the grid of tube T_1; it becomes positive at the instant the fork contact is made, but then falls in potential with extreme rapidity. If

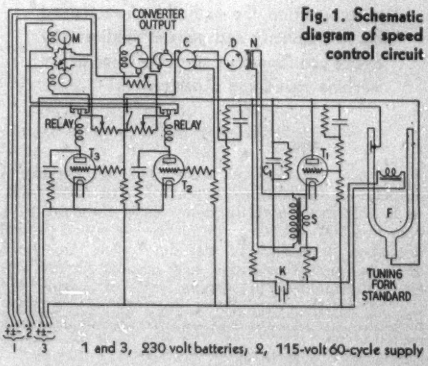

Fig. 1. Schematic diagram of speed control circuit

Table I—Check of Converter Frequency Against Pendulum

Run	Temperature in Fork Box, Degrees C	Total Cycles	Pendulum Beats*	Converter Frequency*
1	36.05	36,000	583.33	61.715
2	36.05	48,600	787.50	61.714
3	36.05	37,800	612.45	61.719
4	36.05	75,600	1,234.80	61.720
5	36.05	73,800	1,195.90	61.711
			Weighted average	61.716

* The pendulum does not beat exactly seconds. However, its calibration in terms of seconds does not enter into the determination of how constant the speed of the converter was held. The only questions entering here as far as the pendulum is concerned are the effects of change in the pull of gravity, the length of the pendulum, the amplitude, and the damping. The total possible effect of these factors under the circumstances of the test can be shown to be negligible within the precision obtained. In order to obtain frequency in cycles per second, the last column must be multiplied by 1.00063 ± 0.00005.

when the middle brush becomes positive it is on the insulation between segments, nothing further happens, and as long as this continues the converter is perfectly synchronized with the fork. If, however, the middle brush is on one segment or the other at the instant it becomes positive, either tube T_2 or T_3 "trips" (both of which are grid-controlled mercury-vapor-filled tubes), thus supplying a small pulse of excitation to the converter in the direction needed to keep the speed correct. The maximum value of the pulse is reached in about 0.005 second whereupon the discharge in the tube (T_2 or T_3) is extinguished by condenser discharge. The pulse then dies out as the extinguishing condenser acquires its charge, and may be succeeded by another pulse the next time the fork contact is made if the rotor has not been returned to the index position.

The scheme as outlined to this point controls the speed of the machine quite satisfactorily for a while; but as the field temperature increases or the supply voltage for the converter drops, the machine tends always to go faster or always to go slower than the standard speed. Hence, if the amount of control that tube T_2 and T_3 exert is initially small enough to produce negligible hunting, the control eventually is lost, while if it is made powerful enough to retain synchronism in spite of large changes of field temperature or of supply voltage, undesirable hunting is produced.

The feature that solved the foregoing difficulty, and that is mainly responsible for making possible the smooth continuous operation of the machine indefinitely in the absence of substantial sudden disturbances, is the motor-driven field rheostat M. As the machine tends to change speed gradually for any reason whatever, one of the tubes T_2 or T_3 is in operation a greater fraction of the time than the other. By means of the relays in series with the respective tubes, the rheostat M is adjusted gradually by one or the other self-starting synchronous clock motors pinned to its shaft. The combination of grid-controlled mercury-vapor-filled tube and automatic rheostat control makes it possible to reduce the tube control to a very small amount and yet keep the machine synchronized. The motor driven rheostat gradually changes the field current so that the machine always is naturally trying to run practically in synchronism with the tuning fork. The control tubes then need only give occasional small quick pulses to keep the field rheostat properly adjusted and to correct for small sudden disturbances. The pointer on the stroboscope disc in fact practically never changes its position by more than 1 mechanical degree, and ordinarily drifts slowly within an angle of about $^1/_2$ a mechanical degree; the control tubes "trip" only at intervals of several seconds after the machine is near temperature equilibrium. Under these circumstances the instantaneous speed may differ from the average speed by 1 part in 10,000 or 20,000.

Converter Frequency Checked

The results of 5 runs checking the frequency of the converter against a pendulum are shown in table I. Since in these runs the rotor always was practically exactly in synchronism with the tuning fork (as indicated by the stroboscope) the runs are in reality checks on the constancy of the frequency of the standard. While it is fully evident to any one who can view the machine in the light of the stroboscope that the machine will not retain so constant a speed over a period of 10 to 20 minutes without the use of the control circuit even if the machine is energized from a large, independent battery, a few tests were made to determine the variation. The results are given in appendix A.

From table I it is found that the maximum deviation from the average is 5 parts in 60,000 of which about 2 parts can be charged against the method of test used. A contact-making synchronous clock motor run from the converter was used to record on the tape of a chronograph the number of cycles through which the converter rotated. The pendulum made a time record on the same tape. This record could not be read closer than 0.01 second, and small irregularity in the gear train of the clock motor probably could account for another 0.01 second. The average deviation of the 5 runs is 3 parts in 60,000, and the probable error of the average is about 1 part in 60,000. The most probable frequency of the converter when run under the conditions of the tests is 61.755 ± 0.003 cycles per second, most of the uncertainty here being attributable to the fact that the pendulum is calibrated to only 1 part in 20,000. Several runs taken with the fork box at lower temperatures indicate that the fork has a temperature coefficient of approximately 0.01 per cent per degree centigrade. Whatever portions of the difference between the results for the various runs are chargeable to actual difference in frequency of the fork most likely are caused by slight differences in amplitude resulting from slight changes of battery voltage, or from a slight change of impedance of the driving coil circuit.

Power Sources Required

The circuit as used and as described requires 2 independent direct current sources. However, the source for the control tubes need not be a battery. It is preferable to have tube T_1 on a steady voltage

to avoid possible change of amplitude of the fork, but its circuit could be operated from the same source as the converter. Neither is it a requisite to have both 115 and 230 volts to supply the tubes. The latter is used on tube T_1 to get a brighter flash from the neon tube. The circuits for tubes T_2 and T_3 are different from the circuit for T_1 because the arrangement saves one filament transformer (none of which is shown) and because the control tubes are of a type slightly different from tube T_1. The only reason for using different types is to use those at hand; either type works at any of the positions, as might other types.

The separate source for the control tubes could be eliminated entirely in one of several possible ways. Instead of passing the tube currents through portions of the resistance in the field circuit, the tubes might operate relays that would respectively insert or short-circuit resistance in the field circuit. However, this scheme might not be as quick acting as the scheme used, and would be limited by the current breaking capacity of contacts. A separate control-field winding might be used. This has the disadvantage of requiring a specially wound machine, but has the advantage of affording quicker response in change of flux than can be expected from the main field winding. Also, there are other schemes, which the authors are developing, whereby the plate supply for the control tubes may be obtained from the alternating current output of the converter (when such load is not objectionable) through an insulating transformer.

It is not vital to have a voltage supply double the normal machine voltage, for the shunt field. The double voltage is used across the field circuit because it is available and has the advantage of making it possible practically to cut in half the time required to build up field flux, and to cut in half the effect of change in resistance of the field winding. Neither is it necessary to have a separate alternating current supply. Unless such load is objectionable, the filament transformers could be energized from the converter output; otherwise filament batteries could be used. Likewise the power for the field rheostat drive could be supplied from the converter output, or from a direct current source.

Self-starting synchronous clock motors are used for the field rheostat drive merely because of their availability, convenient gearing, and adequate torque. The 2 motors are coupled to the same gear train in such a way that one serves for each direction of rotation. A single small reversible motor really should be used. It is conceivable that for small machines, field rheostat motors could be driven directly in series with the control tubes, thus eliminating the relays. The range and speed of control obtainable from this rheostat is very flexible because the rheostat can be extended indefinitely in range and can be operated at any desired rate of change of resistance merely by proper design of the rheostat or an accompanying shunt, and by selection of speed and gearing for the driving motor.

It is conceivable that with a certain amount of study and experiment the design could be carried further to enable the machine to meet larger sudden changes of load or voltage without large swings from the index position, and without continual oscillation about the index position resulting from the increased control necessary to meet these larger changes, when large sudden changes are absent. In the circuit described, the maximum current from the control tubes is about 0.05 ampere, and passes through only about 4 to 20 ohms of the field circuit, while the normal field current is about 0.4 ampere in a circuit of about 600 ohms resistance. Hence it readily is seen that the amount of tube control actually used in comparison with the maximum that could be obtained is extremely small. This aspect of the problem has not been given much attention, however, because of the necessity of pushing along the work for which the particular development serves. A study now has been started with the specific purpose of developing a circuit that will retain the machine in synchronism and give a minimum of hunting trouble in spite of substantial sudden changes of load or voltage. It is emphasized that such claim is not made for the circuit herein described. Some data concerning the performance of this circuit when sudden changes occur is given in appendix *B*.

The commutator is of copper, not particularly carefully machined, but has given very little trouble. Light strips of phosphor bronze were used for brushes at first, but were discarded because they "tore up" the commutator too much. Pencil leads have been used very successfully but the softer leads gradually left a deposit that made it necessary to provide the commutator with wipers in order to prevent short-circuiting of the segments across the insulation. There are other commutator and brush arrangements that will avoid this; however, brushes made from thin 6*H* pencil leads have been in use for some time without wipers with entire success, and look as if they would last a long time. Two leads are used in parallel in each holder. With a wide smoothly-ground commutator, using a row of brushes in each holder, the utmost reliability could be obtained, and the brushes could be replaced without interrupting operation. In fact, in the holders diametrically opposite each other there is no need at all for having the brushes narrow. Provided that the brushes are not made so heavy that a reasonable spring force will not keep them in contact with the commutator, they can be made wide, to reduce the rate of wear. The middle brush must be of such width that it does not short-circuit across the insulation, but allows a little dead space so that if the machine is running at the correct speed, it can drift a very small amount without being alternately accelerated and retarded unnecessarily. The presence of this small dead space adds greatly to the smoothness of operation.

For installations requiring extreme reliability, several control tubes could be used in parallel at each tube position and the design made so that one at each position still would be adequate. This would permit changing tubes without interrupting operation.

Since the precision with which the speed can be controlled depends practically entirely on the precision of the standard, the possible use of such a speed

control scheme to supply synchronous clocks where controlled central-station frequency is not available has been suggested. Various sorts of frequency standards could be utilized to accomplish what the tuning fork does if greater precision is desired, though according to E. Norrman[6] tuning forks can be made that rival quartz crystals as standards. It would be easy of course to avoid having a contact made by the fork itself, by using a magnetic pick-up coil, or a shutter intercepting a beam of light directed upon a photoelectric tube, for examples, and amplifying the output in either case so that another contact could be made to do what the fork contact does.

Probably there are other situations both commercial and experimental in which the scheme may be applicable, since there appears to be no reason why it could not be worked out over a considerable part of the range of speed and capacity of direct current machines.

The writers are indebted to the American Academy of Arts and Sciences for a grant from the Rumford Fund, a small part of which was used for purchase of apparatus for this development.

Appendix A—Tests Made Without Using the Control Circuit

The machine was started cold, synchronized with the tuning fork, and the control circuit then disconnected. The speed was checked during a 40 minute interval. The machine then was synchronized again with the tuning fork, and the control circuit again disconnected. The speed then was checked during a 15 minute interval. The machine then was synchronized again with the tuning fork and operated for more than 2 hours, at the end of which time the speed was checked over a 15 minute interval. The results were as follows:

Time, Minutes	Gain in Speed, Per Cent
0	0.00
10	0.55
20	1.08
30	1.50
40	1.75
41	0.00
56	0.28
172	0.00
187	0.19

These results were obtained with no load on the converter. A second test taken with normal specific-heat-test inductive load of about 0.8 ampere at 0.95 power factor gave substantially the same results. The gains in speed were computed from the apparent speed of the stroboscope disc averaged over 1 minute intervals; instantaneous changes in speed were substantially greater than shown, and in the last 15 minute interval some changes were negative. It is conceivable, of course, that after the machine is warmed up an interval might be selected wherein the number of revolutions lost would equal the number gained and that the average speed therefore would check exactly with standard speed, but such coincidence is extremely unlikely. The total number of revolutions gained were as follows:

Interval, Minutes	Revolutions Gained
0– 40	751
41– 56	24
172–187	18

These tests make it readily evident that through operating the machine from a battery and delivering a constant load, it is futile to hope for as nearly constant speed without the control circuit as with it, even for time intervals of several minutes. The steadiness of the speed, even after a delay of 3 hours was allowed for temperature equilibrium to be practically reached, compares unfavorably with the results obtained when the machine was synchronized with the fork; had a more precise standard been used the comparison would be still less favorable. If the machine were run continuously for a considerable time interval, the departures from standard speed caused by changes in ambient temperature and change in battery voltage between charging periods readily could become enormous in comparison with the tolerances acceptable for precise frequency standards.

Appendix B—Tests Involving Sudden Changes of Load or Voltage

It is emphasized again that the circuit described in this paper is not designed to withstand large sudden changes of load or voltage, but is designed particularly to control the machine with smoothness when operating from a battery supply and delivering a substantially constant load. However, as a matter of interest in order to obtain an idea of what this circuit can do when the load or the voltage is changed suddenly, the following tests were made.

A sudden change in voltage was obtained by suddenly throwing a load across or removing a load from the 230 volt terminals of the supply battery for the converter. This was tried with various loads of various power factors on the converter, with no significant differences. It was found that a sudden change of about 4 volts could be made across the 230 volt supply (giving about 2 volts change across the armature) without the rotor swinging more than 90 mechanical degrees from the index position, after which control is temporarily lost. In order to accomplish this, the control tube current was passed through 100 ohms of the field circuit, this being simpler than to increase the current which is limited by the relay coils. Under these circumstances the rotor oscillated continually about 6 mechanical degrees each side of the index position. It should be borne in mind that by increase of the control tube current it is possible further to strengthen the control excitation enormously without overloading the tubes, and so to withstand greater sudden changes, but the accompanying oscillations of the machine about the index position become objectionable.

With the control circuit the same as described in the preceding paragraph, the machine was operated for about $2^1/_2$ hours directly from the 115-230 volt laboratory supply from the power house (private plant of the Massachusetts Institute of Technology; voltage fluctuations are caused by sudden changes of laboratory or other loads). During this time a recording voltmeter showed maximum variation across the 230-volt lines (in the laboratory) of about 4 volts, with jumps of a few volts every minute or 2. It is likely that some transients were larger than recorded because of the sluggishness of the recorder mechanism. No recording instrument was available for the voltage to neutral. During the run the machine on 6 occasions gained or lost from $^1/_2$ to 5 revolutions before recovering synchronism; the net loss for the entire period was $4^1/_2$ revolutions.

The machine also was operated for several hours as the only load on a 250 kw generator driven from a 325 kva induction motor in the laboratory substation. The control tube current was passed through only 20 ohms of the field circuit (the maximum used for battery operation) and although the operation was not as smooth as for battery supply, synchronism never was lost.

A sudden change of resistance load was made across the output terminals of the converter (the control tube current passing through 100 ohms of the field circuit). It was found that a change of about 10 per cent of rated load could be made suddenly (starting from any or no previous load) without causing the rotor to swing more than 90 mechanical degrees from the index position. The normal specific-heat-test inductive load of about 0.8 ampere at 0.95 power factor could be thrown on or off with practically no disturbance at all, because of its demagnetizing effect, even with the control excitation much smaller. The changes of load taken from the machine were accompanied by changes of 0.5 to 1 volt across the armature terminals.

These tests leave little doubt as to the feasibility of withstanding

larger sudden changes by making the control excitation more powerful. It is necessary to modify the method of control, however, so as to avoid continual large oscillation about the index position.

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Calculations for Coreless Induction Furnaces

Calculations of electrical characteristics of coreless induction furnaces usually are made by means of the penetration formula (equation 18 in this paper); this formula, however, gives only an approximation which is fairly accurate only at relatively high frequencies. As a wide range of frequencies can be used in these furnaces, there is a need for calculations that are good at any frequency; to meet this need, the fundamental calculations upon which the penetration formula is based are presented in this paper.

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A CORELESS induction furnace usually consists of a cylindrical coil wound rather closely on the outside of a crucible holding the molten charge. It is equivalent to a transformer with a solid metal secondary. Several formulas are available for calculating the electrical characteristics of this type of furnace, and it is useful to show the relation between these formulas, and the range for which each is suitable. This work has been taken up in connection with a thesis at Massachusetts Institute of Technology, and in this paper the formulas dealing with the Bessel function solution and the pentration solution for the current and flux in the charge are discussed.

In figure 1, let a be the average outside radius of the charge in centimeters and b the radius of the primary coil. Assume that conditions are uniform in the direction of the axis of the cylinder, that the coil and the charge are of equal axial length, and that the permeability of the charge is unity. If the permeability is not unity, then with alternating current and flux the permeability changes during every cycle, and the accuracy of a solution based upon the assumption of constant permeability is greatly reduced. If such an assumed constant value is adopted, the permeability μ is inserted as a multiplier along side of ω and f.

Let the magnetic flux density between the radii a and b be H_e, produced by the current in the primary coil. Circumferential currents will flow in the charge in the direction opposite of that of the primary current, and so the flux density within the charge will be less than H_e. If H be the flux density, and i the current density in the charge in abamperes per square centimeter, at radius r

$$H_e - H = 4\pi \int_r^a i\,dr \tag{1}$$

Since H_e is constant, by differentiating equation 1

$$\frac{dH}{dr} = 4\pi i \tag{2}$$

The total voltage around any circle of radius r due to resistive potential drop and alternating flux is zero. That is,

$$2\pi r i \rho_1 + j\omega \int_0^r 2\pi r(-H)dr = 0$$

the flux in the direction in which i would drive magnetic flux, being $-H$. The resistivity of the charge in abohms per centimeter cube is ρ_1.

Substituting the value of i given by equation 2, and multiplying by $2/\rho_1$,

$$r\frac{dH}{dr} - j\frac{\omega}{\rho_1}\int_0^r 4\pi r\,H dr = 0$$

Differentiating,

$$r\frac{d^2H}{dr^2} + \frac{dH}{dr} - j\frac{\omega 4\pi r}{\rho_1}H = 0$$

Put

$$p^2 = \frac{-j\omega 4\pi}{\rho_1}$$

$$\frac{d^2H}{dr^2} + \frac{1}{r}\frac{dH}{dr} + p^2H = 0$$

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Let $pr = z$

$$\frac{d^2H}{dz^2} + \frac{1}{z}\frac{dH}{dz} + H = 0 \tag{3}$$

This is the standard form of Bessel's differential equation of order zero. The solution consists of Bessel functions and is

$$H = AI_0(mr\sqrt{j}) + BK_0(mr\sqrt{j}) \tag{4}$$

putting $pr = mrj\sqrt{j}$ where $m^2 = \frac{4\pi\omega}{\rho_1}$

Symbols A and B represent constants to be determined by the boundary conditions. The function K_0 contains log $(mr\sqrt{j})$ and so is infinite when r is zero. As the magnetic flux density cannot be infinite at the center of the metallic charge, the constant B is zero. The equation then becomes

$$\begin{aligned} H &= AI_0(mr\sqrt{j}) \\ &= AJ_0(mrj\sqrt{j}) \\ &= A(\text{ber } mr + j \text{ bei } mr) \text{ by definition} \end{aligned} \tag{5}$$

Constant A is found by putting $r = a$ where $H = H_\varphi$

$$A = \frac{H_\varphi}{\text{ber } ma + j \text{ bei } ma} = \frac{4\pi NI_1}{l(\text{ber } ma + j \text{ bei } ma)} \tag{6}$$

where

I_1 = primary current in abamperes
N = turns in the primary
l = axial length in centimeters

$$H = \frac{4\pi NI_1}{l}\frac{\text{ber } mr + j \text{ bei } mr}{\text{ber } ma + j \text{ bei } ma} \tag{7}$$

The voltage impressed on the primary coil is $I_1R_{ab_1} + j\omega\varphi N$ where R_{ab_1} is the resistance in abohms of the primary coil to alternating current of the given frequency and φ is the total flux in the circle of radius b, neglecting the thickness of the primary winding.

$$\begin{aligned} \phi &= \int_{r=0}^{a} 2\pi r \frac{4\pi NI_1}{l}\frac{\text{ber } mr + j \text{ bei } mr}{\text{ber } ma + j \text{ bei } ma}\,dr + \int_{r=a}^{b} 2\pi r H_\varphi dr \\ &= \frac{8\pi^2 NI_1 a}{lm}\frac{\text{bei}' ma - j \text{ ber}' ma}{\text{ber } ma + j \text{ bei } ma} + \pi(b^2 - a^2)H_\varphi \end{aligned}$$

where the prime (′) denotes differentiation with respect to ma, using the integrals

$$\int mr \text{ ber } mrdmr = mr \text{ bei}' mr$$

and

$$\int mr \text{ bei } mrdmr = -mr \text{ ber}' mr$$

Dividing the voltage by I_1 and noting that $m^2 = \frac{4\pi\omega}{\rho_1}$,

$$Z_{eff} = R_{ab_1} + \frac{2\pi N^2\rho_1 ma}{l}\frac{\text{ber}' ma + j \text{ bei}' ma}{\text{ber } ma + j \text{ bei } ma} + j\frac{\omega 4\pi^2 N^2}{l}(b^2 - a^2) \text{ abohms} \tag{8}$$

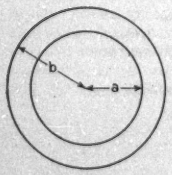


Fig. 1. Cross section of a coreless induction furnace

a = outside radius of charge
b = radius of primary coil

Rationalizing the denominator, and letting R = the a-c resistance of the primary coil in ohms and ρ = the resistivity of the charge in ohms per centimeter cube,

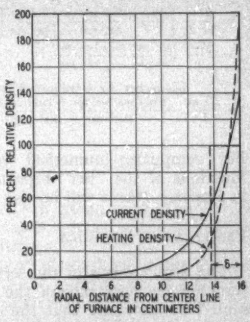
$$R_{eff} = R + \frac{2\pi N^2\rho ma}{l}\frac{\text{ber } ma \text{ ber}' ma + \text{bei } ma \text{ bei}' ma}{\text{ber}^2 ma + \text{bei}^2 ma} \text{ ohms} \tag{9}$$

$$X_{eff} = \frac{2\pi N^2\rho ma}{l}\frac{\text{ber } ma \text{ bei}' ma - \text{bei } ma \text{ ber}' ma}{\text{ber}^2 ma + \text{bei}^2 ma} + \frac{8\pi^2 fN^2}{l}(b^2 - a^2)10^{-9} \text{ ohms} \tag{10}$$

These are in agreement with the expression following equation 37, page 31, of reference 1 (see list at end of paper). Heaviside determined the magnetic field in the metallic core of a solenoid in terms of Bessel functions.[2]

Fig. 2. Relative current and heating densities in a typical coreless induction furnace

Diameter of furnace = 32 centimeters = 12.6 inches
Resistivity of charge = 200 × 10^{-6} ohms per centimeter cube
Frequency = 960 cycles per second
ma = 10
δ = 2.3 cm.



The series for the fractions in Bessel functions in equations 9 and 10 have been published,[3,4] and when they are substituted the following are obtained:

When ma is less than 2,

$$R_{eff} = R + \frac{2\pi N^2\rho}{l}\left(\frac{1}{2}ma\right)^4\left[1 - \frac{11}{24}\left(\frac{1}{2}ma\right)^4 + \frac{473}{2160}\left(\frac{1}{2}ma\right)^8 - \ldots\right] \text{ ohms} \tag{11}$$

$$X_{eff} = \frac{4\pi N^2\rho}{l}\left(\frac{1}{2}ma\right)^2\left[1 - \frac{1}{3}\left(\frac{1}{2}ma\right)^4 + \frac{19}{120}\left(\frac{1}{2}ma\right)^8 - \ldots\right] + \frac{8\pi^2 fN^2}{l}(b^2 - a^2)10^{-9} \text{ ohms} \tag{12}$$

When ma is greater than about 4, for slide-rule accuracy,

$$R_{eff} = R + \frac{\pi N^2\rho ma\sqrt{2}}{l}\left[1 - \frac{1}{ma\sqrt{2}} - \frac{1}{8m^2a^2} + \frac{25}{128m^4a^4} + \ldots\right] \text{ ohms} \tag{13}$$

$$X_{eff} = \frac{\pi N^2\rho ma\sqrt{2}}{l}\left[1 + \frac{1}{8m^2a^2} + \frac{1}{4\sqrt{2}m^3a^3} + \frac{25}{128m^4a^4} - \ldots\right] + \frac{8\pi^2 fN^2}{l}(b^2 - a^2)10^{-9} \text{ ohms} \tag{14}$$

When ma is between 2 and 4, values of the functions of the "ber" type should be taken from tables and used in equations 9 and 10. These tables have been published elsewhere.[5,6,7]

Note that

$$ma = 2\pi a\sqrt{\left(\frac{2f}{\rho \times 10^9}\right)} \tag{15}$$

where a is the radius of the charge in centimeters and ρ is in ohms per centimeter cube.

An accurate experimental check on the first term of equation 14 has been made.[8] Sufficiently high frequencies were used so that terms in $1/m^2a^2$ and higher powers were negligible. Rods of copper and of alloys were used inside the primary coil. The resistivity of these cores was measured precisely with direct current, and the reactance at different frequencies was measured with alternating current. The agreement between measured and computed values was very close.

The current density at radius r in the charge is given by equations 2, 5, and 6, and is

$$i = \frac{1}{4\pi}\frac{d}{dr}\left[\frac{4\pi NI_1}{l}\frac{\text{ber } mr + j \text{ bei } mr}{\text{ber } ma + j \text{ bei } ma}\right]$$

$$= \frac{NI_1 m}{l}\frac{\text{ber}' mr + j \text{ bei}' mr}{\text{ber } ma + j \text{ bei } ma} \tag{16}$$

$$= \frac{NI_1 m}{l}\frac{\text{ber } ma \text{ ber}' mr + \text{bei } ma \text{ bei}' mr + j(\text{ber } ma \text{ bei}' mr - \text{bei } ma \text{ ber}' mr}{\text{ber}^2 ma + \text{bei}^2 ma} \text{ abamperes per square centimeter} \tag{17}$$

For computing numerical values, the tables of functions of the "ber" type may be used. If I_1 is in amperes, then i will be also.

Penetration Formula

The first 2 terms of the series in equation 13 for the effective resistance of the charge can be represented by assuming that the charge is replaced by its outermost shell of thickness

$$\delta = \frac{\sqrt{2}}{m} = \frac{1}{2\pi}\sqrt{\left(\frac{\rho \times 10^9}{f}\right)} = 5030\sqrt{(\rho/f)} \text{ centimeters} \tag{18}$$

where ρ is in ohms per centimeter cube, and by assuming that the current density is uniform throughout the shell. The effective resistance of the secondary then can be computed by the following:

$$R_{eff} = \frac{\rho 2\pi(a - \delta/2)}{\delta l} \text{ ohms} \tag{19}$$

referred to the secondary.

Substituting $\delta = \frac{\sqrt{2}}{m}$ in equation 19 and multiplying by N^2 for resistance referred to the primary, the first 2 terms of the second part of equation 13 are obtained. This gives the resistance with slide-rule accuracy for $ma = 6$ or larger. It is necessary to use $2\pi(a - \delta/2)$ for the perimeter of the shell and not $2\pi a$, or an error as large as 12 per cent will be made when $ma = 6$.

The reactance is not computed by means of the shell of thickness δ, but by the Bessel function calculation; however, it can be expressed in terms of δ, for $ma = 6$ or larger, directly from equation 14, as follows:

$$X_{eff} = \frac{2\pi a\rho N^2}{\delta l} + \frac{8\pi^2 f N^2}{l}(b^2 - a^2)10^{-9} \text{ ohms} \tag{20}$$

The first part of this is not quite equal to the secondary resistance, but is 12 per cent larger when $ma = 6$, and 7 per cent larger when $ma = 10$.

Even where the frequency is high enough for the penetration formula to give the effective resistance with desired accuracy, the coreless induction furnace is not in every way equivalent to a primary coil and a shell of thickness δ. For instance, to assume such a complete equivalence and calculate flux density and exciting current by usual transformer formulas does not seem as safe as to compute these features by the fundamental equations given in this paper. A penetration formula derived for flat plates is not always suitable for cylinders.

The penetration formula is used also in calculations of conductors carrying high frequency current. It is a very useful device and is practically indispensable with irregular cross sections, so long as δ is considerably less than the radius of curvature of any part of the surface and so long as the frequency is sufficiently high. The limited extent of the equivalence of the shell of thickness δ to the actual body of metal, however, should always be kept in mind.

In figure 2 are shown the relative current densities and heating densities at different radii of a sample induction furnace in which $ma = 10$. The density if all the current were uniformly distributed in a shell of thickness δ is taken as 100 per cent.

Example

The following example illustrates the calculations for a typical furnace by the series and by the penetration formula:

Find the electrical characteristics of the following coreless induction furnace:
Average diameter of charge, $2a = 18$ inches
Length of charge, $l = 24$ inches
Resistivity of molten iron charge, $\rho = 200 \times 10^{-9}$ ohms per centimeter cube
Permeability of charge, $\mu = 1$
Diameter of coil, $2b = 25$ inches
Number of turns in coil, $N = 12$
Frequency, 960 cycles per second
Resistance of coil for 960 cycle current, 0.0030 ohms

$$ma = 2\pi \times 9 \times 2.54\sqrt{\left(\frac{1920}{200{,}000}\right)} = 14.1, \text{ by equation 15}$$

$$R_{eff} = 0.0030 + \frac{\pi \times 144 \times 200 \times 10^{-9} \times 14.1 \times \sqrt{2}}{24 \times 2.54}\left[1 - \frac{1}{14.1\sqrt{2}} - \cdots\right]$$

The series in square brackets $= 1 - 0.05 = 0.95$

$R_{eff} = 0.0030 + 0.0281 = 0.0311$ ohms, by equation 13

From this can be computed the first term of X_{eff}, which is

$$\frac{0.0281}{0.95} = 0.0296 \text{ ohms}$$

$$X_{eff} = 0.0296 + \frac{8\pi^2 \times 960 \times 144 \times 3.5 \times 21.5 \times 6.45 \times 10^{-9}}{24 \times 2.54}$$

putting $b^2 - a^2 = (b - a)(b + a)$

$X_{eff} = 0.0296 + 0.273 = 0.303$ ohms, by equation 14

$Z_{eff} = \sqrt{(0.0311^2 + 0.303^2)} = 0.319$ ohms

$$\text{Power factor} = \frac{R_{eff}}{Z_{eff}} = \frac{0.0311}{0.319} = 0.098 \text{ or } 9.8 \text{ per cent}$$

$$\text{Efficiency} = \frac{R_2}{R_1 + R_2} = \frac{0.0281}{0.0311} = 0.90 \text{ or } 90 \text{ per cent}$$

By the penetration formula, equation 18,

$$\delta = \frac{1}{2\pi}\sqrt{\left(\frac{200{,}000}{960}\right)} = 2.30 \text{ centimeters}$$

Resistance of skin depth of charge, by equation 19

$$= R_{sd} = \frac{200 \times 10^{-9} \times 2\pi(9 \times 2.54 - 1.15) \times 144}{2.30 \times 24 \times 2.54}$$

$$= 0.0281 \text{ ohms, referred to the primary side.}$$

It should be noted that all the dimensions in the formulas are in centimeters.

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Sparking Under Brushes of Commutator Machines

Sparking under the brushes of commutating machinery has been investigated in considerable detail, for the purpose of studying and analyzing the various factors which cause sparking. Among the conclusions reached are that in a detailed consideration of sparking phenomena both current density and rate of change of current density must be taken into account.

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During the time interval when any armature coil of a commutator machine is short-circuited by the brush, the current in the coil must be reversed. If it is completely reversed to the exact value of the normal current in the armature coil as the commutator bar leaves the brush, no current has to be interrupted and, consequently, no sparks will be formed at the trailing edge of the brush. Even greater assurance of sparkless operation at the trailing edge can be obtained if the current reversal is accomplished slightly before the segment leaves the brush and if no voltage is induced in the coil for the remainder of the commutating period. At the leading edge of the brush, no sparking is to be expected if no voltage is induced in the coil at the time it is short-circuited.

The trailing-edge type of sparking, when it does occur, is always due to the interruption of a current—that is, to a switching phenomenon. If sparking at the leading edge occurs, it is due to the presence of a voltage induced in the coil as it is short-circuited. The current which passes through the minute points of initial contact at the brush edge in consequence of this voltage is likely to heat the contact points sufficiently to cause sparking. The phenomena at the edges of the brush and various factors affecting them have been dealt with in a previous paper by the authors.[1] In the same paper it was shown that in d-c machines the ideal conditions at the edges, as briefly described in the previous statements, are associated with a flat initial and final portion of the time curve. From these considerations alone, it appeared to be of no consequence how the coil current changes as a function of time during the period between the small initial and final part of the curve.

There is, however, a third type of sparking, namely, that under the brush, which can be observed in quite a number of machines and with regard to which the intermediate course of the current curve may be of importance. It is the purpose of this paper to present the results of experiments which indicate the physical causes of sparking under the brush and to review the factors in design which affect them.

The Basis for Investigation of Sparking Under a Brush

An obvious physical cause for sparking under a brush is the effect of mechanical roughness, which in severe cases might result in complete, though momentary, separation of the brush from the commutator. Although this undoubtedly can be and

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1. For all numbered references, see list at end of paper.

frequently is a cause of sparking under brushes, such sparking can at times be observed even with a high degree of mechanical smoothness, and one is forced to doubt that mechanical roughness is its sole possible cause. High local current densities have frequently been suggested as another likely cause of sparking under brushes. However, certain experiments showing sparkless operation with densities much in excess of those occurring under brushes of machines, indicated that high densities in themselves would not satisfactorily explain all cases of sparking under the brush. Therefore, a further study of the electrical nature of the contact between the brush and a commutator or ring is needed in order to arrive at an explanation of the phenomenon.

A sliding brush contact exhibits the peculiar characteristic that as its current increases its resistance decreases. In figure 1, curve *a*, a static volt-ampere characteristic of such a contact has been plotted. The data for the curve were obtained with a graphite brush (0.1 square inch in area) on a brass ring. The ring was 5 inches in diameter, and was run at 1,200 rpm. The brush was $^3/_{16} \times {}^9/_{16}$ inch, and the spring pressure on it was 15 pounds. Direct current entered the brush, passed to the ring, and was then conducted to a second ring on the same shaft and out through another brush. A third ring on the shaft was also connected to the other 2, and a copper brush was placed in contact with this ring. The contact drop of the tested brush was measured by connecting a voltmeter between this brush and the copper brush. A separate test showed the contact drop of the copper brush, when carrying sufficient current to operate the voltmeter, to be less than 0.05 volt, which is a negligible value. Several minutes elapsed at each current setting before the voltage was read. (In all of the curves in the paper the ohmic drop of the brush itself has been subtracted from the voltage readings.)

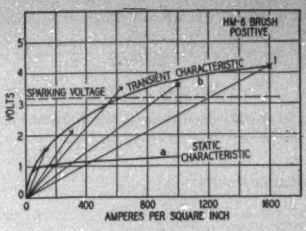
The variable contact resistance shown by curve *a* in figure 1 was, of course, obtained under "steady state" conditions. If the current density in the contact was allowed to change rapidly, an entirely different characteristic was obtained. The transient characteristics of the contact were therefore investigated in the hope of finding an explanation of the sparking under a brush.

The Nature of Dynamic Contact Volt-Ampere Characteristics

An experiment to determine the dynamic contact characteristics was made, again using the apparatus described and with the circuit shown in figure 2. The availability of electronic devices made it possible to establish testing conditions that could not be readily obtained during many of the earlier investigations of contact phenomena. As a consequence, some very interesting results were obtained. A rectifier of the type utilizing an ignitor rod in contact with the mercury to control the starting of the arc was connected in series with the brushes, and during each positive half-cycle the starting of this rectifier was delayed until some time after the voltage had reached its maximum value. In this way, an extremely

Fig. 1. Brush volt-ampere characteristics

a. Static
b. Rapidly increased current



rapidly rising current through the brush was obtained. An oscillogram of the current in the brush and the contact drop of the brush is reproduced in figure 3. A number of such oscillograms were taken, and in each a different peak value of current was obtained by changing the series resistance as each film was recorded. The peak value of current and the peak value of voltage were then obtained from each of the films, and in figure 1, a curve *b* has been plotted using these points. Therefore, the curve represents the voltage obtained with a rapidly increasing current. It will be noted that this curve lies considerably above the static curve, though it has a somewhat similar shape.

Conditions for Sparking Under a Brush

Some of the points on curve *b* represent contact voltages which are several times normal. Sparking under the brush was observed as these points were being obtained. This was the case while the film reproduced in figure 3, for example, was being recorded. The maximum value of the current shown on the film is 160 amperes, corresponding to a current density of 1,600 amperes per square inch. With this same current flowing through the brush continuously no sparking was observed, and as can be seen from figure 1 the contact drop in the case of the continuous current was very much less. These 2 tests were made a few minutes apart and the mechanical conditions were practically identical.

The sparks observed apparently were due to either the production of small incandescent particles, or to the formation of a gaseous discharge, as a result of the abnormal contact voltages. Slepian[2] has shown that a potential of a few volts, when impressed across a diminishing contact area of a material similar to that from which brushes are made, will heat the separating points to a few thousand degrees. Thus a virtual "explosion" of small particles of carbon under the brush might produce the luminous sparks. On the other hand, if the contact voltage becomes sufficient, sparks having the character of a low current arc might be formed and momentarily maintained. Small arcs could be formed easily, due either to the breaking of local points of contact under the brush as the ring revolves, or to the high potential gradient across a local contact point with such local contacts acting as small "ignitor electrodes."[3]

The question then arises as to the value of the voltage which will cause sparking underneath the

brush. A test was made by first using such values of current that sparking was observed, and then by decreasing this current until the sparking just vanished. From the oscillograms it was found that for this particular brush, a value of 3.2 volts was typical of the potential at which sparking began to be noticeable. Referring again to figure 1, it will be seen that at the higher currents the voltages given by the upper curves are considerably in excess of this value, and sparking was continuously observed when all of these points were being obtained. A horizontal line designating the sparking voltage has also been drawn in the figure.

The volt-ampere characteristics in figure 1 will, of course, be expected to vary from one kind of brush to another. Several brushes have been tested in the same way, and with a given current the actual values of voltage do vary. However, for all of the carbon grades tested so far, sparking occurred at about the same value, namely, approximately 3.2 volts.

Effect of the Rate of Current Increase on the Contact Voltage

Instead of increasing the current very rapidly through the brush contact, an experiment was made by using a sinusoidal current-wave of 60 cycle frequency. The brush was cold prior to the initiation of current, and it was positive with respect to the ring during the first half-cycle of current flow.

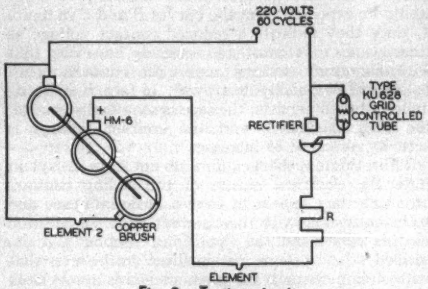


Fig. 2. Testing circuit

A volt-ampere characteristic obtained from this first half-cycle of conduction is plotted in figure 4, curve *A*. The static curve from figure 1 has been reproduced in figure 4 for reference. Although the 60 cycle curve lies above the static curve, the sinusoidal rate of current increase was not sufficient to produce contact voltages high enough for sparking, with a reasonable current.

After 2 cycles of operation the character of the 60 cycle dynamic curve changed, and in figure 4 a second curve *B* has been plotted showing its form. A half-cycle was plotted during which the brush was positive. The contact resistance, according to this curve, is almost constant and the contact voltage for any current is less than that obtained during the first half-cycle of conduction as shown by curve *A*.

As time progressed, a further change took place in the 60 cycle curve. The entire curve fell, and its final form is shown in curve *C*, figure 4. Several seconds must elapse before the curve changes from the form *B* in figure 4 to that of *C* in the same figure. The brush was positive during the half-cycle from which this curve was plotted also.

Theory of the Dynamic Characteristics

In curve *C*, figure 4, the a-c resistance of the contact is seen to be substantially constant. At the point where the static characteristic intersects the 60 cycle curve *C*, the d-c resistance of the contact is, of course, equal to the constant a-c resistance. This point will be seen to correspond closely to the root mean square value of the a-c current; that is, the contact has the same resistance when the direct current and the root mean square alternating currents are equal and when "steady state" conditions have been reached. This fact strongly suggests that the contact resistance is a function of the temperature at the contact region. Thirty-two years ago, Kahn[4] found similar results. Slepian,[2] and later Ludwig and Baker[5] made the same suggestion from other data. Holm[6] has found the contact temperature to be of fundamental importance in explaining the action of stationary contacts. Explanation of the mechanism by which the contact temperature produces the observed variation in contact resistance, have been varied and dissimilar, however. Without attempting to be explicit as to mechanism, it is of interest to discuss the curves that have been presented on the basis of a thermal cause for the variations of contact resistance.

In figure 4 the difference between curves *A* and *B* could be due to the thermal time lag of the contact; that is, about 2 cycles are required before the temperature at the contact might increase sufficiently to cause a generally decreased resistance. Of course, curve *A* itself exhibits the phenomenon of a resistance which is variable with current, but this is to be expected because a cold brush will probably have very small contact regions, which will consequently be heated and cooled very rapidly. In 2 cycles a larger amount of material would be heated, and the number as well as the size of the contact regions may

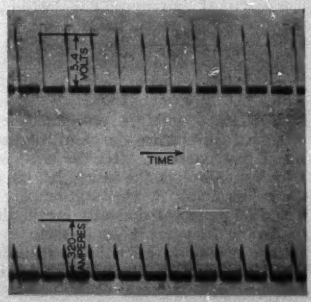


Fig. 3. Oscillogram showing the effect of a rapidly increased current through a brush contact

be considerably increased. As the regions become larger, they will heat and cool more slowly, and curve *B* shows that the resistance no longer changes appreciably as the current varies, as well as the fact that the mean value of the resistance has decreased from the original value associated with curve *A*.

Curve *b* in figure 1 is really the envelope of a number of curves, one for each point through which *b* was drawn. These individual curves can be drawn only by using one point and the origin, because the rapidity with which the current rises precludes the measurement of intermediate values. However, since the oscillograms from which these points were obtained were made under conditions similar to that from which curve *B*, figure 4, was taken except that the current was increased more rapidly, probably the individual curves are also nearly linear. They have been drawn as linear in figure 1, and when plotted they give the appearance of rays extending from the origin to the points on curve *b*. The entire curve *b* is thus seen to be similar to the rising branch of curve *A* in figure 4. Curve *b* is actually higher than curve *A* because of the greater rapidity of current increase, and it becomes evident that if the current in a cold brush were rapidly increased from zero to point 1 on curve *b* in figure 1, the voltampere characteristic would be similar to curve *b*, but it might be higher because the peak value of voltage is not reached after the first cycle, and curve *b* is not the initial curve corresponding exactly to *A* in figure 1. The fall of contact resistance with increased current which is shown by curve *b* may again be ascribed to the increase in temperature of the contact region with the current. The contact voltages represented by curve *b* are considerably greater than those represented by curve *A* in figure 4, however, presumably because the contact temperature will follow the current less closely in time as the rate of current rise is increased. In other words, the

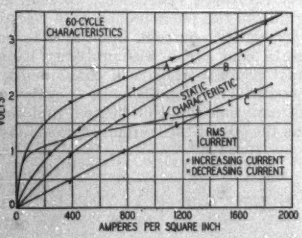


Fig. 4. Brush volt-ampere characteristics on 60 cycles

A. Initial half cycle
B. After 2 cycles
C. After 5 minutes

high contact voltages associated with a rapidly increased current are the result of the thermal time lag of the contact. After the lapse of a cycle or so of current through the brush, having the wave form shown in figure 3, the volt-ampere characteristic would be represented closely by the line drawn from the origin to point 1 on this curve. The contact voltage given by this point is maintained for some time, as shown by the oscillogram in figure 3, because of the wave form of the current. That is, its peak value is $3^1/_2$ times the root mean square value, and if the resistance remains substantially constant and is determined by the root mean square current (as is true with the 60 cycle curves), then the peaked current wave should repeatedly cause abnormal contact voltages.

In figure 4, the difference between curves *B* and *C* may also involve the temperature. Another explanation would be to associate this slow change with the "polishing action" of the current on the contact. Thus, it is known that the passage of current through a contact will reduce the brush friction, probably because of an electrical transfer of material which aids the polishing action. This "smoothing" of the brush surface would be expected to establish more intimate contact with the ring and thus lower the contact drop. This suggestion is supported by the observation of the comparatively long time required for the transition from curve *B* to curve *C*. It is further supported by unpublished results obtained by the late G. M. Little, which showed that if direct current was suddenly passed through a brush contact, the voltage-time curve would fall rapidly just after its initial value had been reached, and then, after a sharp break in the slope of the curve, a very slow decrease would ensue. After the oscillogram in figure 3 was taken, sparking under the brush seemed to increase in intensity with time. This fact at first seems contrary to what would be expected from the curves *B* and *C* in figure 4, since they indicate a reduced contact voltage as time passes. It must be realized, however, that with abnormal voltages across the contact, brush polish will be quickly destroyed; in fact, if sparking under a brush persists, the face is soon badly eroded, the ring blackened, and the contact voltage is actually observed to increase.

Thus, thermal changes alone do not seem to explain fully the electrical nature of the sliding contact, although they appear to have a basic influence and to be consistent with the observations. In addition to this effect and the "polishing" action just described, the authors are inclined to believe that with sliding contacts the phenomenon is appreciably influenced by partly or entirely loose particles coming from the brush, as outlined by Hellmund.[7] There is little doubt that under many, if not all, operating conditions, the segments or portions of rings when leaving the brush carry with them loose particles from the brush in a certain temperature condition. These particles will naturally cool off to a certain extent before they are carried back under the brush. When entering, they create certain resistance conditions both on account of their temperature and of mechanical influences on the relation of the brush and carbon surface. As soon as they take part in carrying currents, they heat up and possibly are burned away, thus again causing changes in the contact condition. At the same time, new particles may tear loose from the carbon surface, bringing about further changed conditions. It is believed that phenomena of this kind may be an especially important factor under severe operating conditions. It is also believed that this phenomenon of partly or entirely loose particles varies appreci-

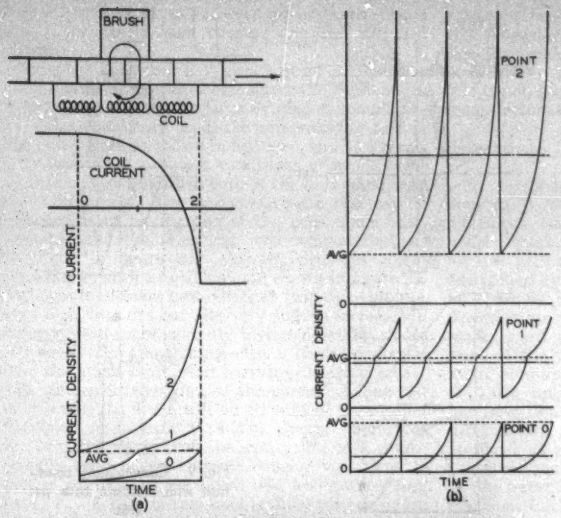


Fig. 5. A typical commutating condition for a generator (a, left), and current densities at 3 points under the brush (b, middle)

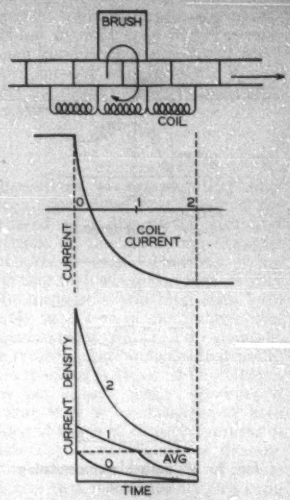


Fig. 6. A typical commutating condition for a motor

ably with the mechanical structure of the carbon used and that it may be an explanation for much of the difference in the practical performance of different grades of carbons.

So far it has been assumed that the particles are conducting; in addition it should, however, be appreciated that on account of frequently existing impurities in carbons some of the loose particles may be insulators, which may have further and quite appreciable influence upon the contact and arcing phenomena and may further explain certain differences observed in practice. Although a complete theory with regard to all these factors cannot be outlined at this time and is not essential in connection with this study, these various possibilities have been briefly mentioned in order to show that aside from the effective current densities in the contact surface, many other factors, such as the mechanical structure of the brushes, their chemical composition, the time during which the various ring or commutator portions are under the brush and between brushes, the temperature and current conditions at the instant of the test as well as the temperature and current condition preceding, are likely to have a marked influence upon the resistance and sparking conditions under the contact surface.

These suggestions are quite consistent with the theories advanced by several authors that a film of copper oxide between the brush and the ring may play a dominating part in the conduction phenomenon. In fact, the combination of such a film and "loose particles" seems to make possible a satisfactory explanation of most of the observed phenomena.

However, regardless of the practical importance of the various factors mentioned, the investigations made definitely indicate that a rapidly increased current through a brush contact will generate, at least momentarily, a contact voltage considerably in excess of that obtained if the same current passes though the brush continuously. It is also evident from the curves that repeating peaked current wave will cause abnormal contact voltages. Therefore, the transient voltage across the contact must be considered as depending upon the rate of rise of the current and the ratio of the peak to the root mean square value if the phenomenon is a repeating one. It has also been found that if this contact voltage exceeds a value of about 3.2 volts, sparking under the brush will occur. With these data obtained from the tests described, a review of some of the design features of commutator machinery will be made for the purpose of determining the desirable path in time of the current reversal in a short-circuited coil. The criterion for determining the most suitable path is that the current density in any portion of the brush must not reach excessive values and that it must not increase too rapidly.

Typical Conditions of Commutation

It is well known that in straight-line commutation the current is always equally distributed under the brush both in space and in time. It is therefore evident that with this type of commutation, ideal conditions under the brush are obtained because any densities in excess of the average are avoided and sudden changes in density are entirely elimi-

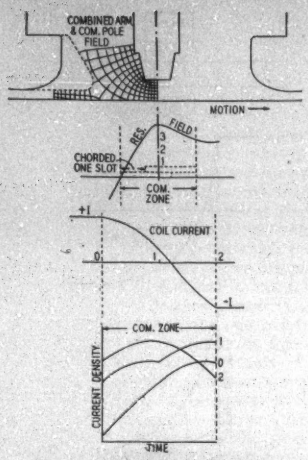


Fig. 7. A desirable commutating condition

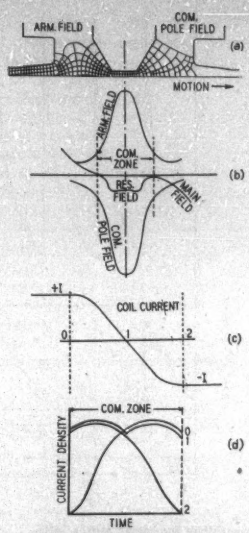


Fig. 8. An "ideal" condition of commutation practically realized

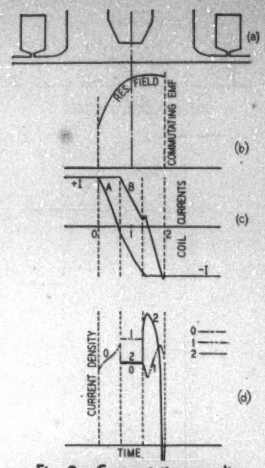


Fig. 9. Commutating condition with multiple coils per slot

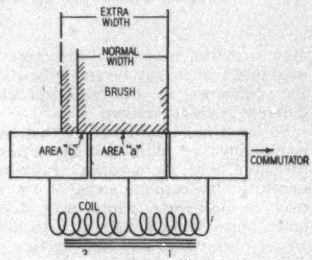


Fig. 10. Effect of multiple coils per slot at the entering brush edge

nated. However, as is also well known, straight-line commutation is difficult to obtain in actual practice.

Figure 5 shows a rather common condition of commutation in which the current is completely reversed in the available time but with most of the reversal occurring during the latter part of the commutating period. This is a condition commonly found in generator operation. One coil per slot and one bar per brush were assumed in drawing the figure.

Figure 5 also shows the variation of current density and time for 3 different points (0, 1, and 2) under the brush, and figure 5*b* shows these curves repeated for the same points, namely, the leading edge, center, and trailing edge of the brush. It will be noted that near the trailing edge the current densities are 5 to 6 times as high as the average density. Even at a point removed about $\frac{1}{8}$ from the trailing edge, densities as high as 3 times the average are obtained. It is therefore evident that in the case of overload and high average current density, a density greatly in excess of the average at the trailing edge together with a rapid change in density may lead to sparking under the brush. Assuming an average density of 100 amperes per square inch and conditions obtained from tests as indicated in curve *b* of figure 1, voltages near the trailing edge just high enough for sparking might occur.

Figure 6 shows a related condition which may occur in the case of motor operation with similar field conditions, and it is at once evident that in this case sparking may occur near the leading edge of the brush.

In figure 7, field conditions have been developed with the idea of obtaining as favorable proportions as are practicable in larger machines with relatively large interpole gaps. It will be noted that sudden rises in density as well as densities much in excess of the average have been avoided, and therefore good commutating conditions are to be expected. This latter condition has been obtained with the aid of some chording in the armature.

The ideal form for the curve of coil current and time with reference to the operation at the edges of the brush suggested by the authors in a previous paper, is shown in figure 8. These conditions frequently can be approached in practice in smaller machines with relatively small commutating pole air gaps and pointed commutating poles. From figures 8*c* and 8*d* it will be noted, however, that although no densities much in excess of the average are obtained, there are fairly sudden changes in current density, but from the test data obtained,

this is not likely to lead to sparking under the brush unless excessively high average densities are also present.

Figure 9 illustrates a typical case of a large machine with 2 commutator bars under the brush and 2 coils per slot. With the large air gaps of commutating poles commonly used, the commutating field is unsymmetrical, as shown in figure 9*b*, and as a result it is impossible to obtain conditions in which commutation is completed in both of the coils when they leave the brush. The best compromise that can be obtained is in having one of the coils under-compensated and the other one over-compensated, as indicated in figure 9*c*. Current densities corresponding to such a condition are shown in figure 9*d*, and here it becomes quite evident that there are not only high densities but also very sudden increases in density, which undoubtedly invites sparking under the brush near the trailing edge. These conditions may also appreciably affect sparking under the brush. The sudden interruption of the current in one coil as it leaves the brush will on account of the mutual induction necessitate a sudden change of current in the adjacent coil of the same slot, and consequently sudden and extreme density variations in certain portions of the brush will lead to sparking under it. A case of this kind is illustrated in figure 10. It may be assumed that a short-circuit current is suddenly interrupted in coil 1 in the position shown. An almost equal current must suddenly appear in coil 2, which will cause a sudden change of current in both portions *a* and *b* of the brush. In portion *a* the density may not be very high and therefore the sudden change may not be of practical importance, but in *b* a combined high density and sudden change in current will probably cause sparking. It is thus evident that the various factors discussed in the previous paper which are favorable toward the avoidance of sparking at the edge of the brush will for the same reasons assist in minimizing sparking under the brush. It is interesting to note that if in an a-c motor, for instance, the brush were made wider, thus reducing the current density in portion *a*, it might have a favorable effect, although a narrow brush-span in a-c motors is usually considered favorable. It has actually been found in practice that under such conditions a somewhat wider brush in a-c motors showed improvement, though this is not generally nor always the case because so many factors enter into it.

Summary

In previous discussions of commutating phenomena, it has been appreciated that many of the difficulties encountered were due to the fact that under certain portions of the brush the densities became higher than the average. However, it has been found by tests that with a constant high density no sparking is obtained on a slip ring even with densities appreciably in excess of the values commonly used in commutator work. For example, some of the tests recorded here indicate that under static conditions no sparking is obtained for densities of 1,000 amperes per square inch; however it has been found that with a combination of high densities and sudden changes in density sparking is obtained at considerably lower values of density. Consideration of the various commutating conditions in this paper indicates that it is probably this combination which results in sparking under the brush. The natural conclusion therefore is that in a detailed consideration of these phenomena both factors must be taken into account.

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A view of Cornell University, Ithaca, N. Y., scene of the A.I.E.E. 1935 summer convention to be held June 24–28

Discussions

Of A.I.E.E. Papers—as Recommended for Publication by Technical Committees

ON this and the following 13 pages appear the first discussions submitted for publication and approved by the technical committees on papers presented at the sessions on cables and overhead line problems at the 1935 A.I.E.E. winter convention, New York, N. Y., January 22–25. Other discussions of these and other winter convention papers, and authors' closures, will be published in later issues.

Members anywhere are encouraged to submit written discussion of any paper published in ELECTRICAL ENGINEERING, which discussion will be reviewed by the proper technical committee and considered for possible publication in a subsequent issue. Discussions on papers scheduled for presentation at an A.I.E.E. meeting or convention will be closed 2 weeks after presentation. Discussions should be: (1) concise; (2) restricted to the subject of the paper or papers under consideration; and (3) typewritten and submitted in triplicate to C. S. Rich, secretary, technical program committee, A.I.E.E. headquarters, 33 West 39th Street, New York, N. Y.

Dielectric Properties of Cellulose Paper

Discussion of a paper by J. B. Whitehead and E. W. Greenfield published in the October 1934 issue, pages 1389–96, and in the November 1934 issue, pages 1498–1503, and presented for oral discussion at the cables session of the winter convention, New York, N. Y., January 24, 1935.

F. W. Godsey, Jr. (Sprague Specialties Co., North Adams, Mass.): This paper invites speculation as to the nature of the absorption losses reported for the cellulose paper investigated.

Kraft (or any other paper) is not pure cellulose. In addition to approximately 90 per cent alpha cellulose, there are present other celluloses such as oxycellulose with a much greater affinity for water than alpha cellulose. Resins, lignin, and similar substances are present as impurities in the paper facilitating the beating action and the formation of cellulose gel, which is essential to the felting properties of wood pulp fiber on the paper machines. These impurities exist in the finished paper as finite particles, along with a residue of chemical impurities resulting principally from pulp cooking processes.

With or without the presence of water, such an aggregate would exhibit dielectric absorption on the basis of the Maxwell-Wagner theory. Water in the paper will accentuate dielectric absorption due to the varying liquid absorption constants of the different materials present, and it is possible that relatively small amounts of water may cause relatively large changes in absorption.

It would have been interesting to note dielectric and power factor changes had the temperature experiments been carried well below the freezing point of water. Similarly, the sudden increases in absorption capacity and absorption loss reported in table IV at 99.3 degrees centigrade, just under the boiling point of water at atmospheric pressure, would have been interesting to follow through higher temperatures.

Dried glycerol-free cellophane has been investigated by W. N. Stoops (*Am. Chem. Soc. Journal*, volume 56, page 1480). This is practically pure cellulose, yet it shows absorption losses and capacity changes at frequencies between 60 cycles per second and one megacycle per second with frequency and temperature dependence of the sort found for ice and polar liquids of both low and high viscosity.

This cellophane is similar to paper capacity-frequency characteristics of the type shown in figure 4 of the paper at low frequencies. It decreases in capacity by very small amounts until 10 kilocycles are reached, but instead of flattening out as do the curves of figure 4, capacity continues to decrease until at one megacycle the capacity has fallen approximately 10 per cent with the trend still downward. It is quite likely that if the curves of figure 4 for dry paper are carried to still higher frequencies a similar decrease will be found and the true geometrical capacity will be less than the assumed value in computing moisture content.

Likewise, power factor of cellophane may increase with decreases in temperature; but if the frequency is carried high enough, power factor increases to maximum values between 100 kilocycles and one megacycle. At 60 cycles, the shape of the power factor-temperature curve of cellophane is quite similar to the curve for paper in figure 19. Not much information is given by Stoops as to the drying process used, and small quantities of free water may have been present.

Curves of d-c discharge in figure 5 are of a shape that indicates intricate Maxwell-Wagner dielectric or electromotive equilibrium processes. Probably both exist to appreciable extents.

Electromotive equilibrium or electrolytic polarization may exist in 3 different ways in liquid films or in the solid paper structure with solid ionization. Helmholtz double layers may exist at boundaries between dissimilar materials, and are independent of frequency with a very small phase displacement. Diffusion or concentration capacity is inversely proportional to the square root of the frequency, has a phase angle of 45 degrees leading, is inversely proportional to the absolute temperature, and is usually large enough to obscure double-layer effects. In the case of an ionogent so little dissociated and of such a concentration that a polarization on account of the change in concentration of the ionogent under weak currents is imperceptible, a polarization can occur, nevertheless, if the speed of dissociation of the nondissociated part of the ionogent does not ensue quickly enough compared to the current change to prevent a change in ionic concentration. In this case the capacity is inversely proportional to the frequency and the phase displacement is close to 90 degrees. This condition might arise in cases of solid ionization.

The variations of reversible absorption capacity and absorption loss with moisture content, temperature, and frequency as shown in tables I and IV, and figures 4 and 17 permit a few comparisons.

Absorption capacities scaled from the curves of figures 4 and 17 appear to be inversely proportional to frequency except at frequencies below 200 cycles per second as closely as the curves may be scaled. Below 200 cycles per second, absorption capacity increases much too rapidly with decreasing frequency to be fully accounted for by polarization capacity. Maxwell-Wagner phenomena can account for such changes, or possibly large micelles with very high dipole moments such as are suggested for pure cellulose.

Absorption losses referred to absorption capacities calculated from short time d-c discharge curves in table I vary from power factors of 0.60 at 0.25 millimeters drying pressure to 0.73 at 765 millimeters. Table IV, which does not agree with values in table I for the same paper, shows absorption power factors from 0.375 at 23.5 degrees centigrade to 0.495 at 99.3 degrees centigrade. Diffusion capacities, which have been shown to be insufficient to account for all of the absorption capacity at 60 cycles, have a power factor of 0.707.

Likewise, the rate of decrease of absorption capacity with increasing temperature is much too high to be explained upon the basis of diffusion capacity alone where capacity is inversely proportional to absolute temperature.

The free water content of paper as estimated by the authors is normally extremely

small. Assuming 10 microns as the average fiber diameter, if all of the water is evenly distributed in surface film, for 0.05 per cent water (0.25 millimeter drying pressure) the layers are approximately one molecule thick. For 0.26 per cent water (765 millimeters drying pressure) the estimated thickness is 8 molecule layers. The approach to a monomolecular film explains the great difficulty in reducing the water content below 0.05 per cent.

It is probable that considerable portions of the ordinary losses in cellulose papers must be assigned to 3 types of reversible absorption, Maxwell-Wagner layer dielectrics, polar rotation, and electrolytic polarization; and only under extreme conditions of frequency, temperature, etc., would it be possible to separate them.

Exception must be taken, however, to the statement, "Were it possible completely to remove all moisture, the paper would show no absorption, zero power factor, and 60 cycle capacitance equal to the geometrical capacitance." Aside from the questions of polar rotation in the cellulose, solid ionization, etc., zero power factor implies a completely reversible reaction which, of course, is unknown. The power factor may be much lower than any hitherto measured losses in dielectrics, although that does not necessarily follow from test results and figure 12.

H. H. Race (General Electric Co., Schenectady, N. Y.): In line with the data presented on the electrical properties of kraft paper during drying, I should like to present correlating data from actual cable manufacturing practice.

The data shown in figure 1 of this discussion were obtained on a full length of standard single conductor paper cable of the oil filled type. Moisture and air were removed through a central channel in the core by connecting the ends of the cable to vacuum pumps. The cable was held at a temperature of 100 degrees centigrade during drying. The length of the cable was of the order of 1,000 times the length of Whitehead's sample and the thickness of paper was about 10 times greater. Variations in points on the resistivity and power factor curves are probably caused by changes in temperature as a result of washing with carbon dioxide gas, rather than by errors in measurement. No time scale is indicated on the graph since the total drying time depends largely upon the length of the cable and the thickness of the insulation.

These curves demonstrate the very interesting and rather remarkable facts that in actual practice final vacuum pressure and final power factor values are obtained quite comparable to the values reported in figure 1 of the paper for a laboratory test.

No measurements were made during the first quarter of the drying period but during the last 3 quarters the effective dielectric constant decreased only about 1 per cent, while the power factor decreased 43 per cent and the effective one minute resistivity increased 40 per cent. All 3 of these electrical yardsticks are taken as routine measurements during the drying of all lengths of oil filled paper cable during manufacture, and oil is not admitted until these electrical control measurements reach predetermined values.

In figure 2 of this discussion is plotted a long time d-c current-time curve for this same length of cable taken at the end of the drying period and corresponding to the last point in figure 2. At the end of 10 minutes

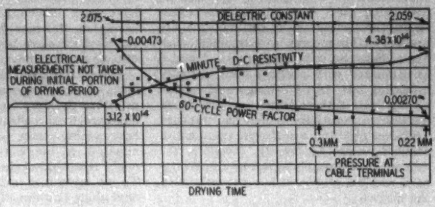

Fig. 1. Electrical measurements taken on full length of high voltage paper cable during drying period at 100 degrees centigrade

the apparent conductivity had decreased to 5.6×10^{-18} mho per centimeter cube. If the test had been continued for 40 or 60 minutes as was done by Whitehead the apparent conductivity would probably

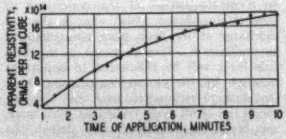

Fig. 2. Change of apparent resistivity of a length of paper cable with time of application of potential at end of drying period

Direct potential 220 volts
Apparent conductivities at ends of curve 2.3×10^{-18} and 5.6×10^{-18} mhos per centimeter cube

have been comparable to the value of 2×10^{-17} mho per centimeter cube reported by him.

Therefore it seems that electrical data obtained at the end of the drying period on Whitehead's samples agree very closely with corresponding data on a full sized length of commercial cable in regular manufacturing practice.

D. W. Roper (Commonwealth Edison Co., Chicago, Ill.): It is particularly interesting to note that the dielectric loss of the paper is improved by very low pressures during the evacuating process, that is, during the removal of the air and moisture, and, further, that the power factor-temperature curve slopes downward from room temperature to a minimum at about 70 degrees centigrade. A previous paper ("The Dielectric Losses in Impregnated Paper," J. B. Whitehead, A.I.E.E. TRANSACTIONS, volume 52, June 1933, page 673) reported that when the paper was impregnated with high grade, low loss oil, the power factor-temperature curve of the impregnated paper was determined largely by the curve of the paper. The conclusion is, therefore, readily reached that if a manufacturer utilizes a very low vacuum in removing the air and moisture from the paper and in addition uses a high grade, low loss oil, the power factor-temperature curve of the impregnated paper will slope gently downward from room temperature to about 60 degrees centigrade. This is exactly what is found in the highest grade impregnated paper insulated cables now being furnished by American manufacturers.

Apparently it is not feasible to make any further reductions of consequence in the dielectric loss of the ordinary type of impregnated paper insulation, as cable having a power factor at the maximum operating temperature of $^1/_3$ of 1 per cent or lower is now being furnished on commercial orders. In fact, the minimum values of power factor at the maximum operating temperature are below the corresponding values for oil-filled cable obtained a few years ago. It appears that if necessary we might even make some slight sacrifice in dielectric loss in order to secure increased stability of impregnated paper insulation.

A careful examination of several scores of samples of cable that has been aged in service or in an accelerated aging test shows that the deterioration invariably starts in the film of oil between successive layers of paper or in the small mass of oil between adjacent turns of the paper tape in one layer. As the deterioration of the oil proceeds, signs of deterioration may be noted on the surface of the paper tapes. One cause of this phenomenon may be explained as follows: The dielectric constant of impregnated paper is about 4 (4.83 at 60 degrees centigrade as determined by equations 1 and 2 of the paper by J. B. Whitehead previously referred to) while that of the oil is about 2.3. The successive layers of impregnated paper and the intervening films of oil can be considered as condensers in series between the copper conductor and the lead sheath, and successive layers of oil and impregnated paper will divide the stress in the inverse ratio of their dielectric constants. The dielectric strength of the oil is only about half that of impregnated paper, and so this difference in the dielectric constants of the 2 materials results in the greatest stress being placed on the oil which is least able to stand it. If an oil could be obtained having an increased dielectric constant, other properties remaining about the same, then the result would be that the stress on the oil would be reduced and the stress on the paper would be increased. This, of itself, would result in a considerably improved stability of the insulation.

Quite recently several of the leading oil refiners have introduced a new process of

petroleum refining by means of selective solvents, and it appears that it will be possible to secure presently an insulating oil that will increase in resistivity when subjected to the standard oxidation test (patent number 1,969,737 issued Aug. 14, 1934). This kind of oil would probably be more stable than the impregnating oils that are now being used. In addition, one refiner advises orally that he is getting, as a by-product of his process, a compound which has a dielectric constant between 4 and 6 as compared with about 2.3 for ordinary insulating oils. An ideal oil would be one having both of these properties, that is, an increase in resistivity under the standard oxidation test and a dielectric constant of about 4 or 5. Apparently, therefore, the long series of research papers by Dr. Whitehead and his associates has not exhausted the subject.

J. A. Duncan (Brooklyn Edison Co., Brooklyn, N. Y.) and **R. N. Evans** (non-member): In the section on theoretical discussion the authors state that "It is surprising to find the simple relationships between moisture content and electrical properties indicated in this study" and that "while as yet no obvious explanations have suggested themselves, these simple relationships seem to indicate clearly that the phenomenon of adsorption of moisture by the fibrous materials commonly used in insulation is much more regular than heretofore supposed." The relation of moisture content to pressure as given in the section under that heading is $M = KP^n$. Since n and K are constants we may make the substitutions $n' = \frac{1}{n}$ and $k = K^{1/n}$. Then, on extracting the nth root of both sides of the equation, it becomes $M^{n'} = kP$ in which form it bears a striking resemblance to the Freundlich equation for adsorption isotherms. The only point of difference is that in the Freundlich equation P is the partial pressure of the adsorbed gas while in the authors' equation P is the total pressure. It seems not unlikely that the partial and total pressures might be linearly related in which case the equations are identical in significance as well as form. One need therefore not be dismayed at the simplicity of the result but should interpret the fact that a well-known relation is obtained by a new and independent method involving no direct determination of moisture as a confirmation of the reasonableness of the method.

Cable System Neutral Grounding Impedance

Discussion of a paper by J. E. Clem published in the January 1935 issue, pages 30–40, and presented for oral discussion at the cables session of the winter convention, New York, N. Y., January 24, 1935.

W. F. Davidson (Brooklyn Edison Co., Brooklyn, N. Y.): The author states in his summary that the proposal to limit the calculated arcing ground voltages to 3 times normal line to neutral voltage has been "accepted by the operators." What is his authority for such a statement? The committee on high tension cable of the Association of Edison Illuminating Companies has assigned to its subcommittee on research the responsibility of studying the cable grounding problem and as chairman of that subcommittee I do not know of any acceptance of this proposal. In fact, suggestions have been offered that would involve a somewhat different basis for determining the need for extra insulation between conductors and ground.

The author apparently assumes that arcing ground voltages are necessarily of appreciable duration for he makes no other reference to the effect of time that would have an important bearing on any determination of the voltages cable insulation might reasonably be expected to withstand. To my mind it is rather dangerous to proceed along this line of argument to the exclusion of others because it seems not inconceivable that, for certain cases at least, designs insuring rapid disconnection in faulty circuits may be more economical than providing the extra insulation that might be deemed necessary if arcing ground conditions were allowed to continue for appreciable periods of time.

Furthermore, the analysis used is directed to a determination of the conditions of neutral impedance which change the arc discharge at the fault from nonoscillatory to oscillatory. Now it seems to me that this limit will be influenced in important measure by the circuit constants at high (oscillatory) frequencies and that the author's use of 60 cycle constants with main simplifying assumptions may defeat the very purpose of the study. As an example, I would refer to some measurements of impedance to residuals recently made on 27 kv transmission cable circuits which show 2 resonance points in the frequency range from 60 to 3,500 cycles. Therefore, I am doubtful of the soundness of the conclusions as a basis for engineering design.

C. L. Gilkeson (Edison Electric Institute, New York, N. Y.): This paper is based upon the assumption of a particular type of mechanism by which an overvoltage is built up through a step by step process caused by the periodic extinction and restriking of an arc. The conclusions as given in this paper are entirely dependent on the overvoltages being produced by this mechanism, and the author admits that it is rather difficult to understand how an arc will be extinguished at the point of maximum voltage and not restrike until the voltage has built up on the next cycle to a value higher than that at which the original breakdown occurred. Furthermore, automatic records obtained during operation on open wire lines, as presented in a recent paper by P. A. Jeanne and myself ("Overvoltages on Transmission Lines," ELECTRICAL ENGINEERING, Sept. 1934, pages 1301–9) and staged tests and laboratory measurements by other investigators, show no evidence of such a mechanism.

As a reason for considering arcing ground overvoltages the author points to the fact that higher values of insulation are ordinarily recommended for use on an isolated rather than on a solidly grounded system, and states that flashovers from time to time on partially grounded systems, not otherwise explainable, indicate that the possibility of arcing ground overvoltages cannot be disregarded. However, he neglects to call attention to the most common cause of overvoltage on a power system, aside from lightning and switching surges, namely, the shift of the neutral point. For known fault locations, calculations of voltage by the method of symmetrical components on an extensive high voltage aerial system operating with ungrounded neutral has given values up to 2.7 times normal phase to ground voltage. These are in good agreement with the measured values. The maximum dynamic voltage measured on this system was 3.9 times normal and was essentially of sine wave shape. The location of this fault was not known, therefore, no calculations were made to compare it with. Based upon observations of arcs in air and the extensive data on overvoltages on operating transmission systems I believe that periodic extinction and restriking of an arc at intervals of approximately a cycle is very unlikely, unless the arc is confined.

This is, of course, the condition that may exist for faults to ground on cable systems. Unfortunately we do not have any test or automatic measurements on a system consisting entirely, or even largely of cable; however, it would not be surprising to find voltages of much higher value than those observed on open wire lines, or to find that these voltages were of higher frequency than that of the fundamental of the supply system. Such a condition might result from series circuit, resonant at a frequency set up by the unstable condition of a confined arc in a good deionizing medium (an arc in an impregnated paper cable). Since such a series circuit may have low losses, high voltages might be encountered across certain parts of the system. However, voltages produced in this manner would not be calculable by the methods given in this paper.

Resistance and Reactance of 3-Conductor Cables

Discussion of a paper by E. H. Salter, G. B. Shanklin, and R. J. Wiseman published in the December 1934 issue, pages 1581–9, and presented for oral discussion at the cables session of the winter convention, New York, N. Y., January 24, 1935.

R. W. Atkinson (General Cable Corp., Perth Amboy, N. J.): The authors refer to what appeared at first to be a very adequate explanation of the variation of a-c current losses with the direction of phase rotation, this apparently being related to the direction of energy flow. Theoretical analysis then showed that this could not be. The losses are purely a function of current relation and are in no way related to voltage. As power flow brings in the relation of voltage phase the losses cannot be related to it or to its direction of flow. A fairly simple analysis along this line showed that the explanation of this curious phenomenon must be found elsewhere.

An explanation given in the paper for

differences in the proximity losses of certain types of strands appears to us to be susceptible of a similar definite disproof. This matter is presented in a separate discussion by Meyerhoff.

The mechanical disruptive tendency caused by heavy currents in the conductors of a 3 conductor cable was given much consideration by our company when the first type *H* cable was produced. At that time we made a number of tests leading to conclusions largely in agreement with those expressed in this paper. For instance, the conclusion that for currents up to about 20,000 amperes the lead sheath is itself adequate to resist the disruptive forces is identical with our own conclusion, our records being expressed in very similar language. Since, very commonly, short circuit currents are limited to values less than this, difficulties from this cause will ordinarily not be encountered. A very considerable number of the users of such cable, however, have raised the question as to the effect of currents greater than this.

In view of these things and of the nature of the results found, some of the data of our tests will add an important element to the information given by those authors. We also were limited to test currents of about 10,000 amperes and also found no distortion of the sheath with that current. In order to simulate the effect of currents considerably greater, we removed various amounts of the sheath, leaving circumferential rings at spaced intervals. Thus with rings 1 inch in length and spaced 8 inches between centers, we found a large distortion of the sheath with a current of 10,000 amperes, the resultant effect being comparable to what would have been obtained with 29,000 amperes with the full sheath. When 1 inch bands were spaced 5 inches apart, there was no distortion, this being equivalent to about 22,000 amperes on a complete sheath.

These tests were made on 3 conductor 4/0 cable, each conductor being insulated with $^{4}/_{32}$ inch paper insulation without belt and with a sheath $^{4}/_{32}$ inch thick, the outside diameter being 1.72 inches. It is to be noted that the disruptive forces for a given current would be greater with this conductor than with a larger one with thicker insulation, but that the restraining force of a $^{4}/_{32}$ inch thick lead sheath on this diameter would be considerably greater than with a sheath thickness usual for this diameter, and that it would be more effective for restraining distortion than a sheath of the same thickness and of a greater diameter. Thus, in general, the data applying to this cable are approximately directly transferable to usual commercial cable.

In view of these tests we believed that where a current over 20,000 amperes might occur it would be necessary to use a metal binder tape having a strength per unit length of cable considerably in excess of that of the lead sheath. We selected for the purpose a 3 mil steel or bronze tape. It seemed that only in exceptional cases might it be necessary to go to a 4 or 5 mil metal tape. However, the cloth tape sometimes suggested adds too little to the strength of the sheath to be considered as a reinforcement. It has the further disadvantage of sacrificing much of the gain of current carrying capacity which the type *H* construction normally gives.

There was found during these tests an effect not discussed by the authors which is very significant. The single phase tests which we made were with the current flowing in one conductor and returning in another, the third being idle. When sufficient current was applied, the effect produced was to throw the conductor out of the symmetrical equilateral arrangement. While at the time we were primarily concerned with type *H* cable, the results of this test are perhaps even more significant with regard to the belted type of cable. Even a slight distortion of this sort in belted cable would greatly weaken electrically the internal structure of the cable for tangential stresses and greatly magnify those effects for the elimination of which the type *H* cable was produced. It seems very probable that an effect of this sort may have had very much to do with the much poorer performance found for high voltage belted type cables than was anticipated from laboratory tests. This may also have had an important bearing upon the fact that although the initial operation of such high stress belted cable was initially very satisfactory, the failures of these installations were very severe and complete after trouble once started. Perhaps the distortions occasioned by the short circuit currents of the earliest failures resulted in rapid deterioration and consequent extensive failures of the rest of the system.

Louis Meyerhoff (General Cable Corp., Perth Amboy, N. J.): On page 1587 of the paper it is stated: "Rolling or crushing the conductor will increase the area of strand contact and reduce the concentration of current. The more compactly the strands are crushed, particularly the outer layers, the greater will be the reduction in proximity loss." I cannot agree with this statement. While it is true that crushing will reduce the concentration of current, it is also true that the amount of current will increase due to reduction of contact resistance. The induced voltage causing proximity effect is, of course, independent of contact resistance. Due to the fact that the contact resistance is fairly high, reactance plays a negligible part in determining the proximity effect current. This current will be determined practically altogether by the resistance and will thus be substantially in phase with the voltage. The current will therefore increase as contact between strands is improved and the loss, which will be substantially equal to the product of voltage and current, must also increase with improved contact.

This matter may be analyzed from another viewpoint. We have a 3 conductor cable carrying 3 phase current. The current in any one conductor may be regarded as composed of 3 separate currents, one of which is the main current from the applied voltage. The other 2 may be termed parasitic currents. One of these is caused by the electromagnetic action of the current in the conductor itself, its effect being known as skin effect. The other is caused by the electromagnetic action of the current in the other 2 conductors, its effect being known as proximity effect.

The current producing proximity effect or proximity loss is a circulating current which flows in the same direction as the main current in the part of the conductor near the center of the cable and in the opposite direction in the part of the conductor remote from the center of the cable. The proximity loss can be calculated accurately for solid round conductors. If instead of a solid conductor, we use a stranded conductor in which the strands are all parallel to the axis of the conductor, the proximity effect will be the same as for a solid conductor, and this would be true even though the individual wires were completely insulated from each other, as by enameling. The circulating current would simply flow in one direction in one part of the conductor cross section over the entire length of the cable and return in another part of the cross section, thus completing the circuit.

If, however, spiral stranding is used, again assuming perfect insulation between strands, there will be a tendency for current to flow in one direction in the part of an individual wire which lies on one side of the conductor and in the opposite direction in the part which lies on the other side of the conductor, with the result that no circulating current at all will flow, and the proximity effect will be zero.

In ordinary cable conductors the stranding is spiral, but the individual wires are not insulated from each other. The circulating current will tend to flow longitudinally from wire to wire, but there is considerable resistance to such longitudinal current flow, with the result that proximity effect in ordinary stranded conductors is always greater than zero but is never as great as in solid conductors.

The usual method of stranding is to spiral successive layers of wire in opposite directions. With this arrangement the proximity effect current has 2 paths which it may follow. One of these is longitudinally from wire to wire. The other is a zigzag path, following first along a wire in one layer, then along one in the next layer, then again along a wire in the first layer, etc. As the second path includes far fewer contacts between wires per unit length of cable than does the first path, the second path will carry by far the larger part of this circulating current. It may be expected that crushing or rolling the stranded conductor should reduce the contact resistance between adjacent wires and layers. Reduced contact resistance should increase the proximity loss. This conclusion is directly opposed to the quoted statement by the authors. It is not clear whether the authors' statement is based on experimental data or on theoretical considerations. If based on experimental data, it is clear that other conditions must have influenced the result, as, for example, shorter stranding length lay in the more crushed conductor.

Where the stranding is such that all of the wires are spiraled in one direction, only one path is available for this circulating current, that path being from wire to wire longitudinally. In conductors stranded in this manner the proximity effect has been found to be practically zero even when the conductor has been thoroughly crushed and rolled. While the crushing and rolling has undoubtedly decreased the contact resistance very materially there still appears to be high enough contact resistance so that there is no measurable proximity effect.

One of the coöperating laboratories mentioned in the paper is conducted by the

cable company which I represent. Most of our work was with conductors stranded in one direction, this being our normal construction. Our data on proximity effect of this type of strand are in complete agreement with the data reported. With this type of strand we also found, contrary to what was found elsewhere with the other type of strand, that proximity losses were no greater for nonimpregnated than for impregnated cable. This corroborates further the evidence that with this type of strand, contact resistance is much more than adequate substantially to eliminate proximity effect.

H. B. Dwight (Massachusetts Institute of Technology, Cambridge): The accurate measurement of the a-c resistance of 76 samples of power cable is a very large piece of work but it has been well worth doing since it has evidently disclosed practical forms of 3 conductor cable which, for large sizes, have approximately 10 per cent less resistance for 60 cycle current than other more common forms. To make a cable in such a way is equivalent to enlarging the cable 10 per cent at little or no increase in cost.

It might be of theoretical interest to measure the a-c resistance of cables with enameled strands, some with alternate layers laid in opposite directions and some with all layers in the same direction, to see if the crossing of the strands produces a type of local eddy currents when the strands are not in contact.

Dielectric Strength of Mineral Oils

Discussion of a paper by F. M. Clark published in the January 1935 issue, pages 50–5, and presented for oral discussion at the cables session of the winter convention, New York, N. Y., January 24, 1935.

C. S. Sprague (Purdue University, Lafayette, Ind.): This article represents a considerable contribution to our present knowledge of the mechanism of breakdown of liquid dielectrics and of the factors upon which their dielectric strength depends. Although the author has confined the work to the "uncontaminated" but "impure" oils, the correlation between the dielectric strength and the per cent air solubility or relative oil-dissolved air density is quite convincingly demonstrated.

With reference to figures 2 and 4 of the paper, the dielectric strength curve and the relative oil-dissolved air density curve for transformer oil show the same general shape with maximums at the same temperature. It may be assumed that the relative oil-dissolved air density curve for viscous cylinder oil would be similar in shape to curve *B* of figure 2. If this is true the writer would like to inquire as to the physical factors of the oils, outside of the different viscosities, which cause such a difference in the relative oil-dissolved air density curves. Why does the per cent air solubility decrease above 100 degrees centigrade, and would the relative oil-dissolved air density curve for viscous cylinder oil show a maximum at some other, say a higher, temperature?

The effect of temperature upon the dielectric strength of oil brings to mind an experience of the late Dr. H. B. Smith. With a large quantity of oil stored in an open tank, and with the oil temperature maintained a few degrees above room temperature by means of a small heating unit, it was observed that the dielectric strength of the oil showed a slow but definite increase over a period of time. Probably this same effect has been noted by others. At the time it was considered that slight traces of moisture might be evaporating from the surface of the oil due to its higher temperature but as shown by the author the increase in the dielectric strength might have been caused, in part at least, by a greater air solubility.

The continuation of work such as this is much to be desired and should provide a basis for the classification of the several types of impurities and contaminants, and for determining the effect of each type upon the dielectric strength of the oil. Some tests are being made at Purdue University using both 60 cycle and impulse voltages to determine the effects of different temperatures and varying degrees of contamination. While no conclusions are available at the present time, it is evident that in such work as this the nature of the contaminants must be known. It would seem quite probable that with certain types of contaminants, the increase in dielectric strength from greater air solubility at the higher temperature would be more than offset by a decrease in strength from the contaminant.

J. B. Whitehead (The Johns Hopkins University, Baltimore, Md.): This concise and interesting paper shows a correlation between the laws of breakdown of oils containing substantial amounts of air and the corresponding laws for the breakdown of gases. It is my understanding that the author feels that the breakdown of such liquids may actually be determined by the laws for gases as applied to the gas absorbed in the oil. The outstanding correlative feature is the increase in dielectric strength of the oil with increasing relative density of the absorbed air.

It is doubtful whether such a proposal can be successfully defended in the face of much other evidence. For example, experimental determinations of the relationship between dielectric strength of an oil and pressure vary widely, are difficult to repeat, and are known to depend particularly on traces of impurities and on the conditions at the electrode. The impulse breakdown of an oil is independent of the pressure and, within wide limits, of the dissolved impurities. More particularly, however, oil breakdown is essentially an ionization phenomenon, and the current-voltage characteristic involving the saturation and ionization regions is entirely independent of the applied pressure. Over a variation of pressure, breakdown will occur at different values of applied voltage, but the current-voltage curve up to breakdown remains the same. If the amount of contained gas is an element in the ionization process, we should expect a corresponding variation in the current-voltage curve. Furthermore, remembering the differences in density in the oil and in the absorbed air, and the relatively small proportion of the latter, it is difficult to picture an ionization process involving only the widely scattered molecules of the gas, and which is independent of the far greater number of intervening heavier liquid molecules.

It is regrettable that the author has not presented more experimental data. Those given are too few to warrant the statement of a definite law. In particular, the experiments of Kock utilized by him were made under conditions which make them unsuitable for the author's purposes. In Kock's experiments, the pressure was varied hydrostatically and the amounts of absorbed air were presumably constant. Moreover, his oils were free of gas.

Nevertheless the experiments quoted do indicate the type of correlation proposed by Clark. No certain explanation suggests itself, but I offer the following: Assuming that the stability of the atom of oil is the determining element in the process of secondary ionization, and remembering that this process involves the splitting off of an electron, it may be safely assumed that the outermost or most loosely bound electrons in the atom are those that are involved. Now these are also the electrons which are probably most actively involved in chemical combination. Oxidation is one of the most active and powerful of such chemical processes. If, therefore, we assume that the effect of increasing quantities of air is simply to afford increased amounts of oxygen available for tying down or restraining an increasing number of otherwise loosely bound electrons, fewer and fewer of such electrons would be left for the ionization process and consequently the probability of secondary ionization and breakdown would be lessened as the amount of dissolved air increased. A test of this proposal could be made by experiments using a number of different gases, among them inert gases or others known to offer little possibility of chemical reaction with the oil atom.

F. W. Godsey, Jr. (Sprague Specialties Co., North Adams, Mass.) and **Preston Robinson** (nonmember): The data presented in this paper show remarkably close agreement between gas laws and dielectric strengths of liquids. The dependence of dielectric strength upon the number of molecules of gas per unit volume of the liquid, or the relative liquid-dissolved gas density D as used in equations 2 and 3, should prove a useful relation in attacking insulation problems.

Unless the agreement between theory and experiment in the middle range of pressure investigated is of a most unusual accidental nature, differences at high pressures between theory and experiment may be so because air is not a perfect gas, especially at the higher pressures.

The only results reported upon are for equilibrium conditions between a gaseous atmosphere above the oil and dissolved gas in the oil. What will be the effects of unsaturated and supersaturated solutions of gas in oil upon equations 2 and 3?

These relations indicate that dissolved gas ions are not closely attached to molecular groups in the solvent, but have a freer distribution in which gas ions may move about

with comparative freedom. They also indicate that ionization leading to breakdown in oil is initiated by relatively light weight gas ions acquiring high velocities from electric fields imposed on the oil. Even though collisions between ions and molecules occur frequently, these collisions are elastic and ions lose a very small percentage of their previously acquired energy in such collisions because of the large difference in mass between ions and oil molecules. Ions may then gain in kinetic energy through potential drops until sufficient velocity is reached to result in inelastic collisions and ultimately, cumulative ionization leading to breakdown. As an aid to this process, ionization potentials of molecules are lowered in a medium of higher dielectric constant than air.

Assuming average values of molecular weight of oil M at 250, the mean free path λ of an electron 5×10^{-7} centimeters, and an electric field gradient X of 50,000 volts per centimeter, Compton's equation

$$U_i = \frac{\Omega}{2} + \sqrt{\frac{\Omega^2}{4} + \frac{\lambda^2 M X^2}{4.536\, m}}$$

will yield the terminal velocity of the electron U_i in volts. In the equation Ω is the molecular energy in volts and can be neglected here; m is the molecular weight of an electron. With the above values substituted in the approximation equation

$$\Omega_i = \sqrt{\frac{\lambda^2 M X^2}{4.536\, m}}$$

a terminal electron voltage of 8 volts is obtained. It is significant that this is approximately the ionization voltage of many substances.

With extension of tests to conditions of unsaturated and supersaturated solutions and further evidence in connection with an hypothesis that suggests itself, namely that hydrostatic pressure of the liquid does not influence the effective gas pressure, these relations discovered by Clark should be useful in a revision of our previous ideas concerning the nature of dielectric losses in insulating liquids.

Overvoltages on Transmission Lines

Discussion of a paper by C. L. Gilkeson and P. A. Jeanne published in the September 1934 issue, pages 130–19, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935.

Edward Beck (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): An important aspect of this paper is the bearing on the application of lightning protective devices such as lightning arresters, which are designed to clear, subsequent to a lightning discharge, system voltage between line and ground up to a magnitude defined in the arrester rating. The paper gives corroboration by actual measurement of conclusions reached from theoretical studies, such as those made by Wagner and Evans, namely that conditions exist under which the normal, dynamic voltages from line to ground may become very much distorted; in fact, to such a degree that the maximum voltage ratings of arresters normally applied may be exceeded. For instance, in the case pictured in figure 10 of the paper, a 26 kv system, it would be quite usual unless the system had been studied to apply arresters rated 30 kv maximum. The figure indicates that the voltages to ground up to $26 \times 0.58 \times 2.5 = 37.7$ kv may occur, exceeding the arrester rating by 7.7 kv or 20 per cent. This would expose such an arrester to the hazard of failure, if a surge sufficient to discharge the arrester should occur during the existence of this distorted condition.

Fortunately, the probability of occurrence of a high degree of voltage distortion is small, as indicated by the data in the paper; thus the hazard of arrester failure from excess dynamic voltage is also one of probability. However, arrester failures have occurred as a result of the conditions discussed. It is interesting to see in the paper convincing evidence of these voltage distortions.

The writer does not intend to promote the use of high rated arresters on systems except under special conditions. However, he does wish to point out that certain voltage conditions must be taken into account in the application of arresters. From this aspect the paper contributes to a thorough recognition of this factor in choosing lightning arrester ratings. The rating chosen will in the end be a compromise between protective ratio, cost, rating, and estimated risk of arrester failure.

The writer is of the opinion that these conditions exist with greater prevalence on the lower voltage distribution systems than on high voltage transmission lines and that close applications of arresters even on grounded neutral systems are not generally advisable. Measurements of voltage distortion existing in the vicinity of faults, caused by the voltage drops in the earth resistance of the fault would be of interest since they may theoretically cause in the vicinity of a fault full phase to phase voltage to appear from the sound lines to earth. We would like to ask if the authors have any information on this phase of the problem.

J. O'R. Coleman (Edison Electric Institute, New York, N. Y.): I would like to emphasize the qualification which these authors make at the beginning of the paper, that their work has been confined to systems consisting almost entirely of open wire transmission lines. In a cable system it should be noted that the relative magnitudes of the fundamental constants are entirely different. The ratio of inductance to capacitance, as well as the relative losses in any self-resonating circuit consisting of these quantities, would be much less for a cable circuit than for an open wire line. It should also be recognized that the behavior of an arc in air and the behavior of an arc confined in a deionizing medium, such as cable paper, has an entirely different behavior. Some time ago I learned of overvoltages on cable circuits under certain specified conditions which apparently well exceeded the voltages which Gilkeson and Jeanne have observed in their work. It is my understanding that this phenomenon is now being investigated and I hope the engineers will have an opportunity to study it fully so that they can give us the benefit of their work.

Constant-Current D-C Transmission

Discussion of a paper by C. H. Willis, B. D. Bedford, and F. R. Elder published in the January 1935 issue, pages 102–8, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935.

E. F. W. Alexanderson (General Electric Co., Schenectady, N. Y.): Stone has pointed out one of the objectives of this development, which is to reduce the cost and increase the range of electric power transmission by the use of d-c underground cables. I wish to point out another objective. Electronic converters of various forms have been described in several papers presented to this convention. It is a common feature of all these that they can serve to transfer power from one system to another without regard to synchronism. We have thus 2 objectives: the improvement of the transmission line and the freedom from the limitation of synchronous operation. Each of these is a separate problem which can be analyzed on its own merits. It is, however, significant that the electronic converter offers the solution for each of these problems, either separately or in combination.

W. M. Goodhue (Harvard University, Cambridge, Mass.): The properties of monocyclic networks discussed by the authors are particularly interesting in their application to rectifiers and inverters for the purpose of obtaining constant direct current for the transmission of power.

There are, however, some factors which the authors have not discussed. The system is a constant current one. When a d-c line wire breaks, or the d-c circuit is in any way interrupted, the system still attempts to maintain constant current. With the very high resistance introduced by the break, the voltage will also increase to very high values. Furthermore, the ordinary monocyclic network has practically an infinite open circuit voltage, which would puncture the condensers or cause the tubes to arc back, or damage the power transformers. It would seem that some protection against this occurrence would be necessary.

It would also be interesting to know whether or not the circuit will operate in an interconnected d-c transmission system. If the currents of the monocyclic networks regulate to a nearly constant value, the resulting interconnected d-c systems will show instability due to the independent current regulation of the several systems.

The inverter will also produce harmonics of considerable proportions and of a wide range of frequencies. These harmonics must be eliminated in order to supply a reasonably good wave form to the ordinary a-c distribution networks at the receiving end of the d-c transmission line. Also,

the harmonics cannot be tolerated because of telephone and radio interference. It will probably be impracticable to eliminate these harmonics by the use of ordinary filters, since such filters for an a-c system would be too costly.

It also seems that the use of capacitors of full kva rating in a power system is objectionable because of the danger of puncture (not surge proof, like electrolytic condensers which are generally suitable for d-c only), and also because of the cost. A condenser for use in resonant circuits such as monocyclic networks must have a very stable dielectric, such as low dielectric constant impregnated mica or paper.

It also appears questionable whether or not tubes are suitable for large power systems. The oxide coated cathode, and sealed vacuum chamber would seem to be too delicate. Something in the nature of a steel tank rectifier with mercury pool cathode would seem to be more appropriate.

A. W. Hull (nonmember): Many may wish to ask whether grid-controlled vapor-discharge tubes have attained sufficient reliability for this service, for the fact that they have been successful in railway work does not guarantee their applicability to the higher voltage and more exacting requirements of power transmission.

The answer to this question depends not only upon the tubes but upon the circuit. The constant current circuit described by the authors is unique in its fair treatment of tubes. They are never out of work; never overloaded, even during a circuit fault; and they are not punished if they fail. The tubes respond by correspondingly good behavior. The 3 causes of tube trouble in constant potential operation are idleness, overload, and severe punishment (20 to 30 times normal current) in cases of failure. Idleness is the most serious of these, as experience shows that the majority of failures occur after a period of no current.

The reliable tube operation which we have experienced is therefore due in large measure to the "good working conditions" furnished by the constant current system; and the authors are to be congratulated on this feature of their circuit.

C. W. Stone (General Electric Co., Schenectady, N. Y.): The authors, in their description of this new system, are most modest in their statements and I would like, therefore, to point out some of the essential features of this circuit which should be of great importance to the electrical industry.

One outstanding feature is that for the first time in the transmission of electric power (except with the Thury system), full control of the amount of power and the direction of the power flow is obtained. The value of this characteristic of the circuit is so great that a paper could be written on this phase of the subject alone.

As the system described is a nonsynchronous tie, the inverter is always in phase with the system to which it is connected and the frequency of the system can be like or unlike that of the system feeding the rectifier.

Major disturbances which take place on existing systems, such as short circuits which tend to pull the system apart, cannot take place if this system of transmission is used.

Heretofore, it has been difficult to maintain operation of an inverter circuit feeding into a system of lagging power factor, but apparently by the use of the monocyclic network, this particular feature is completely overcome as the circuit automatically adjusts itself to feed a load of any lagging power factor.

Both the rectifier and the inverter receive constant current. Thus, on any failure in either the rectifier or the inverter circuit, the current is limited to full load current and the power flow is always reduced.

Since this paper was prepared, a much larger circuit has been built and has been in successful operation for several months. In this case, the circuit is of 3,000 kw, operating at 15,000 volts, 200 amperes, and the results obtained to date would indicate that all the facts illustrated by the authors in their paper describing the 150 kw circuit apply equally well to this circuit of larger size.

Engineers might be inclined to hesitate to use electronic devices for large power transmission, but all indications to date are that, with this circuit, such devices can be operated for large powers, both in rectifiers and inverters, with reliability of a high order.

I would like to call particular attention to the very high efficiencies obtained; that is, conversion from constant potential to constant current, or the reverse, can be obtained with losses little greater than those usually realized in efficient transformers heretofore built.

The losses in the particular tubes used in the 150 kw outfit described by the authors and in the larger tubes used in the 3,000 kw outfit are so small that they can be neglected.

It would appear that this system of transmission is particularly applicable to underground cable installations.

Philip Sporn (American Gas and Electric Co., New York, N. Y.): The fundamental idea of constant current transmission is not new, of course; the Thury constant current system has been in use for many years. That part of the system described by the authors which is new, however, is the use of grid-controlled vapor-discharge tubes and the newness consists specifically in the utilization of a soft circuit for heavy tube work.

Those of us who have been working with and trying to find applications for these tubes for the last 5 years or so have felt all along that the tubes had many possibilities; possibilities, it sometimes seemed, the surface of which has been barely scratched in the applications developed to date. Perhaps some of the difficulties in this regard have been due to the slow development of the tube itself; but whether because of that or whether because of the fact that the circuits heretofore developed have presented too difficult a problem for the tube designer, it is pertinent to note that the particular circuit described by the authors is less severe on tubes than any other circuit developed heretofore for any heavy tube application. It is possible, therefore, that this proposed scheme of d-c power transmission may offer one of the first really important and extensive applications for grid-controlled vapor-discharge tubes.

This scheme has, under proper conditions, some theoretically attractive advantages. In examining the possible gain in changing over to such a transmission system, let us consider an existing transmission line. If it is a single circuit, with 3 conductors and ground wire, and we assume that the d-c system is to be maintained in a balanced state with respect to ground, we shall be able to use 2 conductors with either the third conductor or the ground wire as a neutral conductor; and the power that can be transmitted, assuming d-c system voltage equal to a-c system crest voltage above ground, will be $2\sqrt{2}E_nI$ as compared with $3E_nI$ on an a-c system, where E_n represents the effective alternating line to neutral voltage, the current being the same in each case. Under these assumptions, the capacity of the d-c line will be only 94.3 per cent of the a-c line. However, if the d-c line can be operated at a higher voltage than this, as may be possible, then its capacity will be increased in direct proportion to the increased voltage.

A double circuit a-c line having conductors and one or more ground wires permits a more economical utilization of the conductors, as three balanced d-c circuits, each using the ground wire as a neutral, can be obtained. In this case, assuming as before that the d-c line will be operated at alternating crest voltage, the capacity will be $6\sqrt{2}E_nI$ as compared with $6E_nI$ for the a-c line. This represents a theoretical gain of 41.4 per cent in favor of the d-c transmission. Here again, if the voltage is increased, a corresponding further gain is obtained.

In the case of a single circuit installed on a line built for 2 circuits, it might be found economical to install a single fourth conductor in order to provide for 2 balanced d-c circuits, using the ground wire as a common neutral. This would double the capacity of the single circuit line described above. If d-c transmission ever finds extensive application, this might be a logical step to take in lieu of the installation of a second complete a-c circuit, since it would provide very nearly the equivalent of a double circuit a-c line by the installation of only one additional conductor. Further increase in capacity would then be obtained by the installation of the other 2 conductors.

It should be pointed out, however, that all these discussions are based upon a consideration of the transmission line itself, without considering the effect of the terminal equipment on the problem and on the economics of any particular situation. Thus, although it appears that a great gain in capacity can theoretically be obtained by the use of a d-c system, at the same time, when the job as a whole is set up and the costs of the additional terminal equipment are considered, the chances, so far as one can judge at the present time, are quite excellent that the balance would swing in favor of a-c transmission; for it must be remembered that with a system like the one described by the authors, a-c generation and utilization both would

still continue. This necessitates the extra cost of conversion and inversion equipment in the form of tubes, transformers, reactors, and capacitors. The cost of this equipment and the extent to which it can be reduced will be one of the major factors in determining the economic feasibility of the whole scheme. No actual data bearing on that having been presented by the authors, nor by anybody else, it is hard to pass judgment at the present time as to what the economics of the scheme are.

Even assuming that the economics are sufficiently in favor of this particular scheme of transmission, there are a great many other problems, some of them highly important, dealing with the performance of such a transmission system, which will have to be solved before it will be possible to consider the system seriously or sound from a technological viewpoint. Among these are the following:

1. It has been suggested that with d-c transmission the voltage on existing types of insulators can be raised to 50 per cent of the actual flashover voltage, since switching surges will not enter into the picture, and under the proposed constant current system, dynamic follow-up in flashovers cannot occur. This disregards, of course, the lightning angle. In this connection it should be pointed out that it has taken almost a decade of very intensive research and investigation to give us the knowledge of the performance of an a-c line under lightning conditions that we have today, with the result that although lightning in the past was one of the most difficult problems in a-c transmission, it has recently been brought fairly well under control, and the late developments in the construction of transmission lines, including the use of expulsion tubes of various types, have very nearly solved the lightning question on a-c lines. If d-c transmission is to be seriously considered, a complete investigation of lightning performance should be undertaken.

2. Even if it is granted that the circuit may permit the discharge of lightning potentials on a transmission conductor without materially affecting the power voltage proper over any length of time, it must still be remembered that very little is known about the performance of insulators under d-c voltage of high levels, and a great deal of research and investigation will be required on that. Thus, it is a well recognized fact that a high voltage unidirectional field will cause the precipitation of dust and other particles. The effect of this phenomenon upon insulators carrying a d-c transmission line, particularly in industrial region atmospheres, will have to be thoroughly investigated.

3. The corona situation will also have to be studied. The suggestion has been made that the effect of the unidirectional field around the high voltage d-c conductors in building up an ionized space around the conductor will provide automatically an equivalent increased diameter, thus making the corona effect more or less independent of the actual diameter. But here again much more work will have to be done.

4. Still another problem which will have to be solved in connection with large scale use of rectification and inversion equipments, such as are called for in this and every other scheme of d-c transmission, is the problem of harmonic distortion in both the a-c and d-c systems connected to this equipment and the resulting possibility of interference with communication systems. While it may be true that the filtering of the d-c circuits involved will be technically comparatively simple, the distortion of the wave shape on the a-c systems connected to the conversion and inversion equipments may present a rather serious situation, as evidenced by the interference difficulties which have been encountered in connection with some recent mercury arc rectifier installations. No doubt ways will be found of solving this problem, but its solution will constitute no negligible factor in the cost of equipment, and again may militate against the economic feasibility of the scheme.

In pointing out the economic considerations that will have to be taken into account and some of the technical difficulties that still stand in the way, I do not in any way want to detract from the credit that the authors of the paper are entitled to for carrying through a brilliant piece of research. But it behooves us to explore it from all angles in order to definitely determine what its possibilities for practical application are. Personally, while I believe that the system described has possibilities, I cannot see that any of the work that has been disclosed so far indicates that we are as yet on the threshold of a new era in transmission; and while the business of being a prophet always has been a dangerous business, and has been particularly so in the last 5 years, I venture to predict that in view of the many both economic and technical problems that remain to be solved, 10 years hence most of our power will still be transmitted as alternating current.

D. M. Simmons (General Cable Corp., New York, N. Y.): A vital element in considering the economics of transmission by direct current is a knowledge of the level of insulation required for this purpose. An inherent characteristic of impregnated paper insulation suggests the thought that underground paper insulated cables should offer great advantage for d-c transmission. In general the flashover in air for direct-current is about the same as the a-c crest value, namely, 1.4 times the effective a-c value. It was established some years ago that the breakdown strength of paper insulation under direct-current is 2.4 times the effective a-c value and this ratio is recognized in present cable specifications. The purpose of this discussion is to point out that the advantage for transmission is probably very much greater than would be indicated above.

The ratio of d-c to a-c breakdown strength of impregnated paper which is generally accepted was determined during the period when the voltage-time characteristics of a-c breakdown strength were not fully appreciated. In other words, paper insulation will stand a certain voltage for a certain period of time and a very different voltage for a different time, the differences being very great. Very little work has been done on the d-c voltage-time characteristics of impregnated paper. It is the general belief, and my own experience supports this fully, that the voltage-time curve of breakdown for d-c potential is almost a horizontal straight line, probably with a small drop for a very short time after application. A definite ratio of breakdown strength between direct and alternating voltages would be possible only if the 2 curves were parallel. Figure 1 of this discussion shows roughly the characteristics of the 2 potentials. It is quite obvious that a "ratio" is an untenable idea. There will be a different ratio for each period of time.

The ratio 2.4, as figured, was determined before such curves were available and was determined on short time tests. Insulation thicknesses, however, are determined as a percentage of the final low time value or breakdown strength for alternating-current. It will be clear from the figure that if 2.4 is the correct ratio for short time, as seems probable, the correct ratio for long time must be much greater than 2.4. The data is not full enough to make any definite suggestions, but the correct ratio of voltage to use for d-c transmission certainly must be greater than 2.4 times the a-c value and might be 4 or 5 times as great.

The above remarks apply to direct potential as such. With constant current direct potential, there is a new feature which still further improves the characteristics of impregnated paper cable. The chief enemy of a paper impregnated cable is the

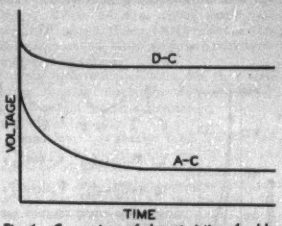

Fig. 1. Comparison of characteristics of cable insulation under alternating and direct current

voids which are created by temperature cycles. In fact, when the creation of voids is prevented, as in an oil filled cable, stresses with alternating current may be used double the value which could be used where voids are produced by temperature cycles. With constant current transmission there will be no temperature cycles, except slight ones from seasonal variation. There is little reason to expect as great a gain in direct current by elimination of voids, but there will be some gain to be superimposed upon the gain obtained by reason of other causes. The idea is very alluring. Is it possible that the use of constant direct current may make it possible to rate a new solid type cable at 5 or 6 times its present voltage rating?

Expulsion Protective Gaps on 132 Kv Lines

Discussion of a paper by Philip Spom and I. W. Gross published in the January 1935 issue, pages 66–73, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935.

K. B. McEachron (General Electric Company, Pittsfield, Mass.): It is indeed gratifying to note the record of performance of the expulsion protective gaps. Since the close of the lightning season, development has been in progress having for its object the improvement of tube characteristics such that flashover under the extreme rain conditions mentioned in the paper would be confined to the inside of the tube.

As a result of this development, it is felt that a method has been found which will materially increase the ratio of the external to the internal flashover of the tube, and at the same time offer some improvement in protection characteristics.

The improved expulsion gap was used on some new installations made this winter, and their performance will no doubt be

reported to the Institute after sufficient lightning experience has been had with them.

Expulsion protective gaps will, in general, be called upon to discharge a smaller proportion of the current of the direct stroke on a system with steel towers and overhead ground wire, as described in the paper, than would be the case with steel towers but without overhead ground wires. This is because if lightning contacts the line wire a very large part of the current of the direct stroke must pass through the expulsion gap to reach ground, while if the lightning contacts a ground wire the expulsion gap passes only the impulse current flowing into the surge impedance of the line conductor, which will be of the order of 250 ohms. Of course, with high tower footing resistances, and without ground wires, the tube current will approach that of the case where the lightning strikes an overhead ground wire. In the limiting case of infinite ground resistance, the lightning tube current from the stricken phase will be equal to that allowed by the combined surge impedances of any other tubes which operate as a result of the elevation of the potential of the tower top.

The performance of the tubes on multiple strokes shows the necessity of including the effect of multiple strokes when considering the performance of protective devices. The expulsion gap appears to have given a good account of itself in this respect. Out of 11 multiple stroke records, noted in the paper, only one was unsuccessful. This is somewhat greater than the 7 per cent faulty operation given in the paper, although it is not definitely known that all of the successive discharges shown per phase passed through the same tube. It seems likely, however, that the great majority did.

For a given tower footing resistance, the use of expulsion protective gaps on one circuit of a double circuit steel tower line offers some protection to the unprotected circuit up to a certain limit of current. As the margin between the impulse flashover of the insulator string and the protective level of the expulsion gaps is increased, the current which can be discharged to ground without causing the unprotected circuit to flashover is also increased. This applies only where the lightning contacts the ground wire or tower, or similarly one of the phase conductors of the protected circuit, but does not apply if the unprotected circuit is struck.

To obtain some idea of the protection offered by the expulsion protective gaps to the unprotected circuit, calculations have been made for the Glenlyn-Roanoke circuit as it is, and for the same circuit with the line insulation increased from 10 disks spaced $4^3/_4$ inches to 10 disks spaced $5^3/_4$ inches.

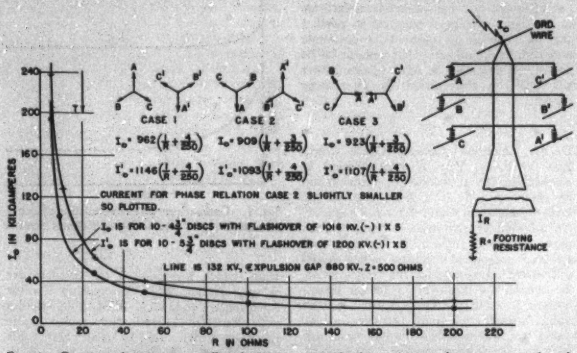

Fig. 1. Degree of protection offered 3 unprotected phases by 3 phases equipped with expulsion gaps on a double 3 phase transmission system

The assumption is made that lightning strikes the tower, raising its potential to an amount equal to the assumed current times the resistance of the tower footing and the surge impedance of the ground wire operating in parallel. Reflections over the ground wire from adjacent towers are not considered, since approximately 1.5 microseconds would elapse before any effect could be felt, and to include this effect would complicate the calculation considerably without materially changing the result since the calculations are based on the 1 × 5 microsecond wave. In making this calculation the negative flashover values used are based on those recently published by G. D. Heye ("Impulse Flashover of Suspension Insulators and Rod Gaps," *General Electric Review*, Dec. 1934, page 548) and are adjusted for change in string length.

Since it has been shown ("Multiple Lightning Strokes," K. B. McEachron, ELECTRICAL ENGINEERING, Dec. 1934, page 1633) that with negative impulse on the tower, flashover will occur first on those phases on which the power voltage is most positive, it is desirable to examine at least 3 values of instantaneous system potential for each conductor. The phase positions chosen are shown in cases 1, 2, and 3 in figure 1 of this discussion, where phase A is successively 107 kv positive, 107 kv negative, and 0. On the Glenlyn-Roanoke line the phase positions A, B, and C are reversed on opposite sides of the tower as indicated in figure 1.

Table I of this discussion shows the impulse potential which must be added to the instantaneous phase potential to cause flashover for each of the phases. For case 1, the instantaneous system potential is 107 kv positive so that a negative value of 773 kv impulse will cause the operation of the expulsion gap on phase A. Additional increase in potential causes the tubes on phases B and C to operate. If the current flowing into the ground resistance (assume 25 ohms) and into the surge impedance of 3 conductors and the ground wire exceeds approximately 54,000 amperes, then according to table I unprotected phases B' and C' will next flash, followed by A' if the current further increases.

For cases 2 and 3, however, 2 protected phases would flash first, followed by one unprotected phase when the total current equalled approximately 47,000 amperes. In this case the 2 phase conductors are carrying approximately 7,000 amperes. This indicates that a tower current of approximately 40,000 amperes would be required with a ground resistance of 25 ohms and one ground wire to cause flashover. It is interesting to note that the expulsion gap must be applied to all 3 phases to gain this increase in current to flashover, since there would be no certainty a single protected phase would be at a sufficiently positive potential to cause it to operate, before some other phase. It is necessary to have all 3 phases protected to be sure that 2 of them function before the unprotected phases flashover.

When the insulation is increased to 1,200 kv, an appreciable increase in protection results to the unprotected phases. The table shows that all 3 gaps will operate before any unprotected phases flash, which places a combined surge impedance of $\frac{250}{4} = 62.5$ ohms in parallel with the ground resistance. Due to the additional parallel path and also to the increased potential, a current of approximately 61,000 amperes would flow before the unprotected phases flashover. In this case, the ground wire and

Table I—Additional Impulse Voltage (1 × 5 Microsecond Wave) Required for Flashover of Various Phases

Phase	$4^3/_4$ Inch Spacing[1]		$5^3/_4$ Inch Spacing[2]		Instantaneous System Potential, Kv
	Kv		Kv		
Case 1					
A	(1)[3]	773	(1)	773	+107
B	(2)	934	(2)	934	− 54
C	(2)	934	(2)	934	− 54
A′	(4)	1,123	(3)	1,307	−107
B′	(3)	962	(4)	1,146	+ 54
C′	(3)	962	(4)	1,146	+ 54
Case 2					
A	(3)	987	(2)	987	−107
B	(1)	826	(1)	826	+ 54
C	(1)	826	(1)	826	+ 54
A′	(2)	909	(3)	1,093	+107
B′	(4)	1,070	(4)	1,254	− 54
C′	(4)	1,070	(4)	1,254	− 54
Case 3					
A	(2)	880	(2)	880	0
B	(1)	787	(1)	787	+ 93
C	(4)	973	(3)	973	− 93
A′	(5)	1,016	(5)	1,200	0
B′	(6)	1,109	(6)	1,293	+ 93
C′	(3)	923	(4)	1,107	− 93

1. Insulator flashover 1,016 kv.
2. Insulator flashover 1,200 kv.
3. Numbers in parenthesis indicate order of flashover.

the 3 protected phases carry away an impulse current of about 17,500 amperes.

The values given are somewhat pessimistic in that the reflections over the ground wire from nearby towers have been neglected. If flashover occurs on the front of the wave, which it may well do, the flashover values of the insulators will be increased more than the protective level of the expulsion gap. With steep waves, this gain will be offset to some degree by the time taken for reflections to travel over the length of the tower, which effect has been neglected for the conditions taken. In this discussion the effect of coupling has not been considered.

It would be interesting if the authors of the paper could check their data in those cases where 2 and 3 expulsion gaps operate, to see if one phase of the unprotected circuit flashed. The value of the tower current might also be checked against the lower curve given in figure 1 of this discussion.

E. M. Hunter (General Electric Co., Schenectady, N. Y.): The conclusion reached by the authors that the absence of external flashovers on the expulsion protective gaps would probably have resulted in 100 per cent lightning proof operation on these 2 trial lines during their first complete year of gap operation is interesting in that it suggests the possibility that a lightning proof line is at last obtainable at a reasonable cost.

In order to insure continuous service, it has often been necessary in the past to provide duplicate circuits with proper relays and oil circuit breakers so that short circuits caused by lightning may be removed with a minimum of system disturbance. This method of permitting a lightning surge to cause a short circuit before doing something about it requires that the faulty section of the system must be at least temporarily out of service.

A much better procedure would be either to prevent the lightning from striking the lines or to relieve the stress resulting from direct or induced strokes to the line without a line interruption. There has been a trend in the development in protection technique to do just these things.

Overhead ground wires in combination with low tower footing resistance, obtained with the buried counterpoise or other suitable means, tend to act as a shield to prevent the lightning surge from reaching the line conductors and building up sufficient voltage from tower to conductor to cause flashover.

The Petersen coil which has been used extensively in Europe and has had a limited acceptance in America does not prevent the lightning surge from getting on the transmission line, but it does remove all ground faults resulting from the surge without a breaker operation, provided no permanent damage is done to the line insulation.

The expulsion protective gaps also have no part in preventing lightning from getting on the lines, but do supply paths whereby the surges may be harmlessly passed to earth. Whereas the Petersen coil requires an isolated neutral system and is only suitable for removing ground faults of a temporary nature, the expulsion protective gaps will dissipate the energy of surges whether one or more phases are involved and they are applicable to the grounded neutral system which is in common use in America today. Thus, in many cases, these gaps should prove to be a worth while investment because their ability to interrupt a short circuit and restore service in a minimum time of one cycle or less should reduce the necessity for complicated relays, oil circuit breakers, and duplication of circuits to obtain continuity of service.

The general acceptance and use of the expulsion protective gap instead of other methods for mitigating transmission line troubles resulting from lightning will probably be one of economics. It is really too soon to draw any conclusions as to the total cost of using these devices, but the original cost for equipping any existing line probably will lie between the cost of installing the combination of overhead ground wires and counterpoises and the Petersen coils, the former probably having the higher cost. Thus, if the maintenance cost of the gaps is not too great, they should have a wide field of application.

Otto Ackermann (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): In the list of principal requirements for practical flashover protectors given in the beginning of the paper, the demand is made that "the tube installation . . . would have to be not only accessible, but easily removable to take care of . . . maintenance . . ." In this respect the 3 types of mountings shown in the paper are radically different. Tubes mounted below at an angle of 30 degrees as in figure 1 of the paper can be removed without taking the line out of service. With the mountings as in figures 2 and 3 this appears to be at least very difficult, whereas it seems to be almost impossible with the V mounting of figures 4 and 6.

Regarding the maintenance it should be remembered that, except possibly for the finish, the fiber tube bore is the only thing which is affected by the service and which finally limits the life of the protector due to the erosion which accompanies every operation. Although the number of operations per tube per year is small, the question will come up eventually of how much life is left in any particular protector and whether it should not be removed before failing. The deciding factor in this maintenance question is the actual diameter of the tube bore. Where the tubes are mounted conveniently, for instance in a horizontal position extending out from the tower, this bore may be easily checked by inserting a gauge plug at the grooved end.

We would appreciate the opinion of the authors regarding the removability and accessibility of the tubes in the various mountings they have had experience with and also regarding the desirability and feasibility of periodic bore checks.

A. M. Opsahl (Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.): I note that along the 133 miles of line, there were in 1934 246 tube operations where in previous years the average line outages were about 27. From this it would appear that about 9 tubes gave indications of operation for each stroke that occurred. The multiple strokes may have struck the line at different structures and in that way have involved more than one set of tubes. Such a multiple stroke in previous years would have resulted in one outage.

The authors calculate that each tube discharging carried 10,000 to 40,000 amperes when the crest ammeters in the tower legs recorded 25,000 to 80,000 amperes. Assuming that the stroke hit the tower, such a high surge current discharging into the live conductor must necessarily result in discharges through the tubes on adjacent structures. These adjacent tubes would not necessarily pass power follow current but the surge current alone might well cause an indicator operation.

Such indicator operations due to a high surge current discharge without power follow would not be a measure of the wear and life of the tube.

Some clue as to the total number of strokes to the line possibly was found from oscillograph records, and perhaps the number of tube operations per stroke or multiple stroke was indicated by the grouping of tubes that had operated.

The 8 outages on the Glenlyn-Roanoke line were caused by 12 tubes that were found to have arced over externally. Possibly the more frequent arcovers on this line were because the insulation is some 10 to 15 per cent lower than that on the Roanoke-Danville line, requiring a much closer design of the tube.

The authors seem to imply that little other work on this type of device has been done. At the time the authors were carrying on their first series of tests, a 66 kv line 50 miles long was being equipped with "deion" flashover protectors. This protector installation, as described in detail in *Electrical World*, Jan. 19, 1935, page 48, has given a very good account of itself.

During 1931, before the line was equipped with the protectors, there were 34 outages from lightning; in 1932, before the majority of the protectors were installed, there were 26 lightning outages; in 1933 there were 3 outages with all of the protectors installed; and in 1934 there were no lightning outages on this line. There are no ground wires.

Two protectors on this line failed apparently due to excessive surge current. There have been no external flashovers of any protectors which we have in service.

V. M. Marquis (American Gas and Electric Co., New York, N. Y.): As is well known, the expulsion protective gap has a maximum and minimum 60 cycle current interrupting characteristic. It is therefore necessary in applying this tube on the transmission line to make sure that the system short circuit current does not exceed the tube rating and, unlike the situation in applying an oil circuit breaker, it is also necessary to make sure that there is at least a certain minimum short circuit current which can be fed into a line fault. Therefore, before selecting the tube ratings for both the Glenlyn-Roanoke and Roanoke-Danville lines, it was necessary to make rather careful calculations of fault currents which might exist on the system under any normal system setup.

The maximum values of short circuit current were calculated on the basis of maximum generating capacity, all grounding transformer banks, and all lines in service. The minimum values were calculated on the basis of expected minimum generat-

Table II—Interrupting Capacity Rating of Expulsion Protective Gaps

Tube Rating Amperes[1]	Number of Tubes: Glenlyn-Roanoke	Number of Tubes: Roanoke-Danville
400/2,000	54	903
600/2,500	450	
900/5,000	306	
Total	810	903

1. 60 cycle symmetrical effective current.

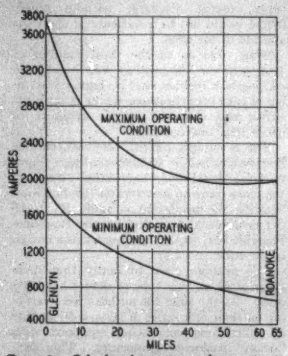

Fig. 2. Calculated system short circuit current per tube, Glenlyn-Roanoke 132 kv line

ing capacity, grounding transformer banks, and lines in service. For the maximum condition the type of fault giving the highest short circuit current and for the minimum condition the type of fault giving the minimum short circuit current were calculated. The calculated maximum and minimum currents to which the tubes might be subjected on the Glenlyn-Roanoke line are shown in figure 2 of this discussion. In this figure the upper curve represents the total current which one tube must interrupt, depending on where the tube is located on the line. The current varies from approximately 1,960 to 3,750 amperes.

The lower curve gives similar current values for one tube under conditions of minimum generating capacity on the system. These minimum currents range from about 650 to 1,900 amperes.

Since the over-all current range constitutes too great a spread for one tube, it was necessary on the Glenlyn-Roanoke line to use tubes of 2 sizes, one near the Glenlyn generating plant for a distance of approximately 25 miles out, and the other lower rated tube on the remaining 40 miles of line. On the 65 mile Roanoke-Danville line, more remote from the sources of power, it was found possible to use a tube of the same rating for the entire length.

The actual tube ratings and the number o tubes installed on each line are shown in table II of this discussion. It should be noted that the 54 low rated tubes on the Glenlyn-Roanoke line were located at the Roanoke end, and were of the 30 degree mounting type. The low rating, however, was not dictated by the short circuit characteristics of the line, but rather by a desire to obtain operating information on this lower rated tube; that is, the installation of these 54 tubes was distinctly experimental.

It is felt that the above explanation of how tube ratings were selected for these 2 lines will be of interest to those who may be considering the application of expulsion protective tubes for line protection. While it is not at present known what margin of safety there is in the tube rating, the thought immediately suggests itself that where system kilovolt ampere capacity is materially altered, it may at times be necessary to change tube ratings on lines that have tubes applied, and this of course would mean physically removing the tubes from the line and reinstalling others of a different rating. On these 2 particular lines, however, we see no immediate prospect of having to face this situation.

Multiple Lightning Strokes

Discussion of a paper by K. B. McEachron published in the December 1934 issue, pages 1633–7, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935.

G. D. Harding (nonmember): An analysis of the data included in table I of the paper indicates that in all probability the expulsion gap operations were the result of direct strokes to tower or ground wire and not to the lines themselves. This conclusion is based upon the results of the tests described in the paper and subsequent tests made in Pittsfield, Mass., coupled with the fact that a positive conductor was involved in the majority of discharges without regard to position on the line. The tests described show that when the tower has been raised to a high negative potential due to a direct stroke, insulator arcover should occur on the line or lines which are positive. Later tests were made at Pittsfield to determine if this were the same with a direct stroke to the line. To simulate this condition, two similar 300 kv transformers were connected with opposite polarities to 2 horizontal parallel rods spaced 36 inches apart. A metal point was suspended equidistant above the center of the rods, forming an equilateral triangle of 36 inches on a side. The point was connected to a 1,500 kv impulse generator. Provision was made to initiate the impulse generator on either the positive or negative crest of the 60 cycle wave. With a 60 cycle 60 kv effective voltage held on the rods, negative impulses (1.5 × 40 microsecond waves) of 680 kv crest were applied, or just sufficient voltage to arc over the gap from point to either rod. Out of 8 arcovers at this voltage 6 struck a positive rod and 2 a negative. However, when the impulse voltage was raised to 1,200 kv or 14 times the crest value of the 60 cycle wave, out of 27 arcovers only 7 struck a positive rod and 17 struck a negative rod. In the remaining 3, the discharge split and struck both conductors simultaneously. These tests show that local ionization has apparently little effect in determining which conductor is to be struck unless a definite path is established by an insulator string.

The data in the paper does not include the last record obtained with the crater lamp oscillograph, taken during a storm on September 12. This film was not available for analysis at the time the paper was prepared. The record shows a multiple stroke with 3 successive discharges having time intervals of 17 cycles and 3 cycles, respectively. The 17 cycles will change the limit of 9.5 cycles shown in figure 4 of the paper.

The accompanying table is an analysis of the record from the standpoint of polarity of phase when follow current began. The foregoing deductions are well illustrated by this oscillogram.

Discharge No.	Phase Voltage in Per Cent of Crest Value: 1	2	3
Phase 1	− 50	−98	−100
Phase 2	− 50	+34*	+ 50*
Phase 3	+100*	+64*	+ 50*

* Discharge struck these phases.

W. B. Buchanan (Hydro Electric Power Commission of Ontario, Toronto, Can.): Brief reference is made to the mechanism of lightning and the necessity of understanding it thoroughly in order to predict where a stroke might make its first contact with earthed structures. Apparently the phenomenon of the stepped leader plays an important part in this mechanism and some speculation as to its cause is intriguing even if it cannot be made profitable.

The usual theoretical discussion on lightning has followed along the lines of traveling wave theory, method of images, etc., which to the average engineer seems to be a method of treatment quite dissociated from his conception of the electrodynamics of commercial circuits. What different pictures of the mechanism of lightning might be obtained by applying the idea involved in the counter electromotive force of self-induction to the path of the lightning discharge?

If $L\,di/dt$ holds true for lightning, and L while difficult to evaluate cannot be considered infinitesimal, there should be an upper limit to di/dt beyond which the counter electromotive force of self-induction opposes further advance along the former line of travel and side slip occurs. Such counter electromotive force should be very much reduced along parallel paths at say from 30 to 50 feet distant and the discharge should resume its original direction.

Such a theory might be expanded to explain how a streamer could start from the clouds directly toward a mast, then be forced to detour and take a path greater than the shortest distance. This theory also presupposes that this phenomenon occurs only on occasions when the storage of energy in the cloud is of major magnitude, and hence is observed on a comparatively small number of the total strokes. It also provides for a wide distribution of charge in an electrically charged storm cloud which in addition to providing a very heavy initial

discharge as indicated by the stepped leader recuperates rapidly and delivers a series of discharges of gradually reducing magnitude like an electric eel.

The practical value of this discussion would be to suggest that some such phenomena might be associated with contour of the country rather than with the normal electric field. An erratic contour should tend to break up clouds and limit the number of occasions when multiple strokes take place.

It would be interesting and it might be useful if the author could list such information with his records with the view to determining if under certain topographical conditions masts might be considered as giving 100 per cent protection even though in a more general way this could not be realized.

A Carrier Current Relay Installation

Discussion of a paper by O. A. Browne and W. L. Vest, Jr., published in the January 1935 issue, pages 109–15, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935.

E. E. George (Tennessee Electric Power Co., Chattanooga): From the maps and description of the system it is easy to understand why several of the sections could not be relayed satisfactorily by any of the conventional schemes. The worst conditions are those in which the breakers associated with the tapped station are located some distance from the point where the tap is taken from the main line. We agree that the use of some form of pilot wire protection was probably the best solution.

Some earlier schemes of carrier current pilot wire protection used considerable extra equipment in order to avoid directional relays dependent on voltage as well as current. It is our opinion that directional fault detector relays using potential, current and phase angle have been developed to the point where they are sufficiently reliable for all practical purposes. We note that no mention is made of any difficulty with the directional relays during the first 2 years of operation.

The equipment itself has an excellent operating record, since most of the difficulties with any new installation or scheme will show up during the first 2 years. Probably this good record is in part because equipment is checked daily as described. Of course, this particular arrangement is feasible only if the various substations are attended.

It is interesting to note that there have been no false operations due to system swings or out of step conditions. This indicates good coördination between operating speeds of the transmitting and tripping equipments. Probably the relay time of 8 cycles is necessary in order to secure a reasonable margin of safety. We wonder if this time could be reduced since it probably represents more than half of the overall short circuit clearing time.

From the operating experience to date, we judge that the equipment has already paid for itself in the reduced number of transmission line "burn-downs," in addition to the generally recognized advantages of improved system stability and service secured through high speed relaying.

Philip Sporn (American Gas and Electric Co., New York, N. Y.): The carrier current relaying described in the paper differs in various respects from that used on our system. The use of carrier relaying as adopted by us avoids cascading of the breakers and experiences like those involving the total interruption of the supply at the "tap-off" stations, such as Amherst, East Springfield, Cobble Mountain, Westfield, or Hampden stations.

Except for one case, in our system all stations are connected in series, and in all stations the tripping is controlled either directly or indirectly by overcurrent relays as in the sectionalizing stations of the system described in the paper. Incidentally, in the latter system the elimination of all tap-off stations would result in much faster clearing of faulty line sections in that only 2 breakers would have to operate to clear the faulty section, hence insuring simultaneous tripping of the breakers at both ends of the faulty section. With the present arrangement for faults occurring near any sectionalizing station, cascading of breakers must, of necessity, occur.

The authors state that the carrier current tripping relays are all set throughout the system to close their contacts in 8 cycles. I do not understand why such a long time is necessary. On our system all tripping relays are set for 4 cycles. Furthermore, we have just developed a new relay arrangement in which the carrier tripping relays will be set to close their contacts after 1 cycle.

An analysis of the 320 operations for the past 2 lightning seasons reported in the paper discloses that 14 per cent, namely 43, were incorrect operations. In our experience with some 30 carrier current installations on our system over the same period of time, we have not experienced one single incorrect operation that was attributable to the carrier current equipment. It would be interesting if the authors could give us some additional information on the cause or causes of these incorrect operations.

E. H. Bancker (General Electric Co., Schenectady, N. Y.): Naturally there were some unforeseen difficulties that showed up in service but the authors point out that these were all readily corrected. Because of this experience any future installations will avoid them and make performance even more perfect. However, the troubles were surprisingly few when the potential difficulties of the installation were so great. The large variation in signal vs. frequency shown in figures 8 and 9 of the paper arises from the radiating taps from which reflections may arrive in such phase relation as to greatly diminish the signal at some station. In such instances it is advisable to take frequency characteristics for each of the possible operating conditions to insure adequate signal strength at all times. In an ordinary 2 ended line, carrier equipment is located at the only 2 reflecting points and if there are any standing waves they are necessarily of such a type as to raise the signal since the line traps are a high impedance point of reflection. Under these circumstances any frequency may be selected at will without the necessity of taking line characteristic curves.

One of the important points brought out by this paper is the high order of reliability of the carrier equipment and particularly the tubes. Lack of acquaintance with such apparatus seems frequently to deter protection engineers from adopting carrier pilot and its wider acceptance should be stimulated by reports such as this which show that the carrier equipment is reliable and easily maintained. If the authors will give in their closing discussion the causes of the incorrect operations it will be seen that few, if any, of them are attributable to the carrier equipment or the scheme as a whole. The fact that exceptionally severe lightning produces many outages within an hour or 2 makes it possible for a single cause to account for a number of false operations before it is found and remedied. Thus, 18 of the total of 43 incorrect operations arose from only 2 sources (both external to the equipment) and ordinarily would have occasioned only 4 or 5 wrong operations if several more faults had not followed in rapid succession each time. Taking these facts into consideration, the performance record will be seen to conform with accepted good practice while giving faster relaying than could otherwise be obtainable.

Carrier pilot relaying does give fast, selective, and reliable protection to simple or complicated systems, thereby permitting the greatest latitude in system design and operation. Its use saves relay short circuit studies, minimizes damage at the fault, reduces customer complaints, and increases revenue.

H. D. Braley (New York Edison Co., New York, N. Y.): The paper is of particular interest in that the reasons for the choice of the equipment are stated and the operating difficulties are frankly discussed. A further discussion of these phases would be of material value to others having similar problems.

It is stated that one of the chief drawbacks incident to the use of other types of relay equipment was the long time delay in clearing line sections because high current and long time settings were required for normal operation. Is it to be inferred from this that these settings were required to prevent tripping the lines from surging, or were these requirements essential for maintaining selectivity?

Among the advantages mentioned for the carrier current type of control it is stated that no extensive calculations are required. While this argument has been advanced before with respect to the advent of other new relay developments, we have not as yet found any of them, including carrier current control, to justify omitting extensive fault analysis studies. There is probably no system in which the fault current does not vary between wide limits with changes in system capacity and switching arrangements. Both of these factors affect materially the magnitude of fault currents

and their distribution in the high tension network. This variation of course establishes limits for both time and current settings even when the relays are controlled by carrier current.

Referring to the type of relay equipment used, it is noted that the type *IDP* directional relay is used for tripping at the tap stations instead of the type *IAC* overcurrent relay. Explanation of the reason for this would be helpful.

It would appear from figure 5 that no provisions were made for clearing bus faults. If protection was provided for this purpose, the scheme employed, its operating speed, and the type of back-up protection used to protect against breaker and relay failure would be of interest.

The data given in tables I and II are very interesting indeed since they are a direct measure of the effectiveness of the equipment. A detailed analysis of the 8 causes of incorrect operation found would be a valuable addition to the paper. Referring to table II it is rather surprising to find that such a large percentage of the lightning faults still involved both circuits after installation of the faster relaying. Possibly details of the line construction, such as use of ground wires, conductor spacing, insulation level employed, etc., would throw further light on this point.

The beneficial results of faster relay protection in maintaining stability during system trouble cannot be questioned. This is well brought out in the paper by the statement that thus far no trip-outs have resulted from surging. It would be of interest to compare the present operating experience with that which was had previously. I should also like to ask the authors if any special provisions were made for controlling the point of separation, under out-of-step operation.

W. A. Lewis (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The development of carrier current relaying equipment is a logical step in improving system protection. Balanced line and distance relay types of protection are capable of extremely fast fault clearing in many cases, but must employ a time delay in the final clearing of faults near one bus. With simple uniform circuit arrangements, without taps, the time delay required may be kept to the order of one breaker operating time (plus margin), and this usually may be tolerated, unless the system is operating close to its power limits. However, complex circuit arrangements, such as tapped lines, wide differences in length of associated circuits, and other causes often render much greater time delay necessary before the fault can be finally cleared. Carrier current relaying, although expensive, reduces the time delay required for selectivity from the time of breaker operation down to the time required for a relay to transmit a carrier signal, and, as a result, the average time of fault clearing may be appreciably reduced. Thus this form of protection may be expected to find a definite place on important lines throughout the country.

Although many of the lines discussed in the paper are tapped, and satisfactory protection is evidently being obtained, it does not follow that carrier current protection of the form described may be applied indiscriminately to give protection for tapped lines under all operating conditions. The principle of operation is that power flow toward a bus during a fault will transmit a carrier signal which prevents tripping of all of the breakers feeding the line section. If this can occur at one of the terminals of a faulted line section, proper tripping will be prevented. It is possible for this condition to be realized on some of the lines shown in figure 2 of the paper, for example, one of the lines between Cabot station and Chicopee, with a tap to East Springfield. Let us assume that a fault occurs on the right hand line near Cabot station and that before the fault the breaker on the left hand line at Chicopee is open. Then the fault current from Chicopee will flow over the faulted line to the point of tap, and will then divide, part going along the faulted line to the fault and the remainder passing over the tap, into the bus at Springfield, then out from Springfield into the sound line, over the sound line to the Cabot bus and then back to the fault through the faulted line from Cabot. The flow of power on the faulted line into the bus at Springfield is in the direction to cause transmission of carrier and block tripping. It is, of course, recognized that the operating condition is abnormal, but it should not be overlooked in the application of the relay system. In some cases, if the stations fed by the taps are interconnected with other stations, conditions such as described may arise with normal operating connections. The relaying of tapped lines, difficult at best, may be made easier by carrier current equipment, but each case must be investigated to make sure improper blocking will not occur, or, if it does, that the conditions and consequences are recognized.

In the paper, page 114, the long life of the type 10 tubes is attributed to the fact that the flow of plate current is intermittent. Our experience with a similar type of tube having an oxide coated filament indicates that the flow of plate current does not decrease the life of that type of tube appreciably, if the tube is conservatively applied, so that continuous plate current may be employed if desired. A system of carrier current protection using continuous carrier current, except at time of fault in the faulted section, has been designed and tested and is now being placed in service. This system has the advantages that faster operation is possible, and that an automatic indication of carrier failure is immediately given, rendering frequent checking unnecessary. The small additional amount of energy drawn by the plate circuit is negligible in most cases.

O. C. Traver (General Electric Co., Philadelphia, Pa.): The authors have given us some very interesting and valuable facts, cold facts. Table I is particularly chilly. A correct performance of 86.6 per cent would seem to leave much room for improvement but fortunately that's not the picture when the remaining facts are assembled. There must be other grounds for the authors' last sentence, which states "This installation of relay equipment has operated in an entirely satisfactory manner and has justified its cost in the results so far obtained."

Reading elsewhere we find that all causes for incorrect action have been corrected excepting for only 2 operations, which out of a total of 98 line sections in trouble during the 2 year period would indicate that one might predict a possible 98 per cent performance for the future. You may suggest that other forms of trouble may develop and that 98 per cent is therefore too optimistic. We can just as well hope that the 2 original unknown causes will have been solved and the percentage therefore raised.

I think we can say that tapped lines have been protection engineers' enemy number 1. Then keeping in mind that all these line sections were tapped you will understand why I suggest that carrier current pilot protection stands alone for this class of circuit.

No special provisions were made in these equipments for operating under oscillating conditions. It is therefore gratifying to see that the performance has been satisfactory in this regard. I am glad to tell you that equipment is now available to actually go through a definitely out-of-step condition and not trip when its own line is sound but still clear if an internal fault develops.

May I also announce that in keeping with the development of 3 cycle oil circuit breakers, carrier protection has more recently been supplied which functions in 2 cycles. And the limit in speed is not yet in sight.

Looking at the data from another angle we are struck by the statement that of 79 line sections tripping out due to lightning only one could not be immediately returned to service. What an argument this appears to be for automatic reclosing.

Vibration Analysis—Transmission Line Conductors

Discussion of a paper by W. B. Buchanan published in the November 1934 issue, pages 1479–85, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935.

E. Bate (nonmember): The paper opens with an argument for the validity of the method of analysis of dampers and other features of antivibration design of transmission lines using traveling waves instead of standing waves. This approach to accurate evaluation and comparison of certain features is reasonable when it is remembered that, in the process of establishing a response of resonant nature to wind eddies on a conductor, a period of transmission and reflection of traveling impulses must occur, and, if during this period sufficient absorption and attenuation of the eddy induced impulses can be caused, there will be little chance of resonance being achieved.

The methods described are all the more valuable since there is great difficulty in producing and controlling wind induced eddies on a transmission span, and it is essential to accurate study that the conditions of the experiments shall be under complete control.

Of the details of the methods and apparatus, I would particularly wish to know whether the curvature recorder is able to measure curvature of the conductor so close to the fixed clamp as to give an accurate indication of flexure stresses at the nose of the clamp. Judging from figure 3, the recorder, as there indicated, would be measuring the average curvature between the clamp nose and the point of attachment of the instrument some distance thereform. My impression is that there is a very rapid change of curvature close to the clamp, and that to obtain satisfactory measurements of the curvature very close to the clamp, a special arrangement of apparatus will be necessary. These remarks are based, of course, solely on the examination of figure 3, and the author might quite satisfactorily dispose of the suggestion that the curvature actually measured is not the critical quantity.

In a paper to the Institution of Engineers, Australia, in August 1930, the writer described a crude attempt to measure curvature near the clamp, in comparison with curvature in the span, and obtained a ratio of the former to the latter somewhat in excess of that quoted by Buchanan. A further examination of this point would be of great interest to those studying the fatigue of transmission conductors.

The apparatus for measurement of curvature might yield satisfactory results, as far as determination of critical curvatures close to the clamp is concerned, if the experiments were more on a single span of cable of any desired loop length, mechanically oscillated, with the curvature recorder so mounted as to give the closest possible approach to the mouth of the clamp. By recording curvature and displacement at a number of positions, curves could be obtained, extrapolation from which would enable a close approximation to be made to the critical curvature.

Having measured the curvature, the determination of stress is dependent on some assumptions as to stiffness at the point of fracture, clamping stresses, and other quantities, of which in the case of a stranded conductor our knowledge is very vague.

When dealing with the measurement of reflection and attenuation as functions of the clamp, cable, and damper arrangements, the author has translated into measurements with a convincing degree of precision, measurements of a cruder nature which have no doubt been made elsewhere. For instance, in 1929 the writer, in studying the effect of a particular damper, used a test which was then called the "bump" test, in which dampered and undampered arrangements were compared by timing and counting reflections at various points in the span, the "bump" being produced in a carefully practiced manner. These tests, which were then looked upon as generally corroborative of other visual tests and graphic records of the absorptive effect of the damper, gave, in fact, for an underhung or "festoon" damper similar results to those quoted by Buchanan.

This part of the recording work being carried out by the author is of great interest and value, because of the precision of the records, and the author's evident intention to pursue these investigations over the many conductors of the Hydro Electric Power Commission. When correlated with experience in the field, the investigations should be fruitful in an advance of both knowledge and practice.

The writer would like to suggest that the virtue of any damper arrangement may rest not only in its absorptive effect, but also in its ability to provide reflections which by their phase interference mechanically prevent progress to a resonant condition, that is, are dissonance producing. This effect was observed in the above mentioned "bump" applied to transmission spans. In the undampered span, 900 feet long, conductor 37-strand A.C.S.R. ($^1/_6$ inch strands), the original impulse would persist, traveling to and fro almost unchanged in shape for about 85 seconds, but in the span provided with an underhung damper the impulse was so broken up within a few seconds that slight wave motion appeared to exist throughout the span, and within 50 seconds the cable was quite still.

G. W. Stickley (Aluminum Company of America, Massena, N. Y.) and **R. G. Sturm** (nonmember): Before discussing the testing procedure and the results obtained therefrom as presented by the author, let us first look carefully at the nature of resonant vibrations in conductors at frequencies set up by the wind, and then look at the normal natural frequencies of vibration of a cable.

A great deal of work has been done which shows conclusively that when a uniform fluid stream passes over a cylinder, eddy currents are set up on the leeward side. These eddies have been found to oscillate regularly, whirling first one way and then the other. It has also been shown that the frequencies of these oscillations are dependent upon the diameter of the cylinder and the velocity of the fluid stream. The frequency of the eddy currents set up at a transmission line conductor when a uniform wind is blowing will all tend to be in the neighborhood of some average value depending upon the mean velocity of the wind and the diameter of the cable. It is known that the wind always varies slightly from time to time, and even at the same time, throughout a normal span. Also, due to stranding, the effective diameter of the cross section of any cable varies from point to point over such a distance, although such variations may only be of the order of a few thousandths of an inch. In view of these variations one might expect the frequency of the eddy currents to vary slightly from the average at various points along the cable, such that the phase of oscillation of the eddy currents may be slightly different for some instant at 2 points along the cable only a relatively short distance apart.

Now let us consider the natural vibration of a cable. From the principles of mechanics it can be shown that a cable may vibrate in any one of a number of forms, *e. g.*, it might vibrate in one single loop, 10 loops, or 100 loops, depending upon the frequencies at which it is agitated. The source of these agitations might be of any nature whatever, but the cable will settle down to a mode of vibration such that its natural frequency in that particular mode of vibration will most nearly agree with the frequency of the agitating forces.

The cable will always vibrate with a frequency such that there will be a whole number of loops in the span, except for very minor effects of the flexural rigidity of the cable at the ends of the span.

As described above, eddy currents are set up when a wind is blowing over the cable. These eddy currents exert minute forces on the cable, and when an average frequency of these eddy currents corresponds to a natural frequency of vibration of the cable at which a whole number of loops may be formed, harmonic vibration is possible. Because of the above mentioned variations these forces will tend to displace the cable slightly, tending to cause it to oscillate at the same frequency as the eddy currents, which will cause loops to form independent of the location of these variations along the span. If the wind varies slightly, the frequency of applied forces will vary slightly, with the result that perfect resonance is probably maintained only momentarily and the cable will assume the best average frequency of vibration. The amplitude of vibration will gradually build up and will reach a magnitude which is limited either by the variations in wind velocity and the cable diameter or by the dissipation of energy by the cable and any attachments. Thus we have vibration of transmission line conductors reaching a state of harmonic vibration without the necessity of imagining the cable struck at 2 points causing traveling waves, which in turn excite the cable to vibration.

Because of the partial flexibility of the clamps supporting the cable, and because of harmonics with vibration set up in adjacent spans or in the towers, there are sudden impulses received by the cable from the clamps *after* it has started to vibrate. Since cable spans in which nothing is in contact with the cable, except the clamps, do vibrate and do appear to have traveling waves in addition to standing waves, it would seem that the nature of the development of vibration just explained is the only one that is tenable. Therefore, the behavior of the cable in service can only be approximated by artificially plucking the cable and sending a series of traveling waves through the span. If these waves are set up at frequencies which will cause the cable to vibrate in a normal number of loops, the approximation may be close, provided excessive energy is not put into the cable, but if the waves are intermittent or relatively infrequent, such that the cable does not vibrate normally in a number of loops, the results obtained may be subject to considerable doubt.

From experience we have found that very misleading conclusions can be drawn from tests in which vibration is more or less closely approximated by artificial means. It is for this reason that in addition to our laboratory testing we have found it essential to make tests on full size spans of conductors in which all vibration is caused naturally by the wind.

The author refers to direct measure of the stresses in the cable and obviously by these stresses he refers to the increase in tension resulting from the increased length of the cable around the loops. The magnitudes of tension set up in this manner are very small for all amplitudes encountered in transmission lines, especially in comparison with the bending stresses.

News

Of Institute and Related Activities

Plans for the South West District Meeting and Student Branch Convention

THE meeting of the South West District of the A.I.E.E. will be held at Oklahoma City, Okla., from Wednesday to Friday, April 24–26, 1935. The convention of the student Branches of the South West District will be conducted jointly with this meeting on April 25 and 26. Headquarters will be at the Skirvin Hotel, where all the technical sessions will be held. The 14th floor, known as the Skirvin Roof, will be retained exclusively for the use of the meetings during the 3 days; the technical sessions will be held in the Venetian Room and the student sessions will be held in the Rose Room. An attractive program consisting of 5 technical sessions, inspection trips, dinner and dance, and a golf tournament has been arranged by the committee. A special entertainment feature has been planned for the visiting women.

Oklahoma City, located at the heart of the area comprising the South West District of the Institute, is a city of over 200,000 population. Its development has been rapid. On the morning of April 22, 1889, the site of Oklahoma City was prairie land with low curving hills, covered with high grass and with bunches of thick timber along its river banks. At noon of this historic day the territory was officially opened and thousands of eager men and women made "The Run" from the border into a country never before opened to white settlement. At evening, 6,000 pioneers from the 4 points of the compass gathered around their campfires; a city had come into being between the rising and setting of the sun. From that time on, Oklahoma City's growth has been phenomenal until now, 45 years later, it has become a thriving center of trade, industry, and education.

Oklahoma City possesses splendid transportational facilities radiating in all directions. Six trunk line railroads, interurban lines in 3 directions, 60 trucking lines, 102 daily passenger bus schedules, and 5 air line routes operate in and out of the city. Six Federal designated highways converge in the city from 10 directions.

The city is in the center of the mid-continent oil fields. From hotel or office window is available a panoramic view of one of the richest and most phenomenal oil pools in the last decade, located on the city's very doorstep. Also, 19 of the 22 major agricultural crops of the nation are produced on a commercial scale within the city's immediate trade territory. These conditions have given rise to the city's important industries, including oil and gas production and refineries; oil field supplies; steel and iron works; packing plants and livestock market; flour and grist mills; cotton gins and compresses.

Including its own Oklahoma City university, there are within a radius of 75 miles of Oklahoma City institutions of higher learning having enrolled 73 per cent of the college students of the state. Among the many points of interest to Oklahoma City visitors are the Oklahoma State Capitol, the State Historical and Indian Museum, Oklahoma City University, Lincoln Park and zoo, Packingtown and stockyards, and Oklahoma City oil fields.

Oklahoma City and the surrounding territory is served by the stations and transmission lines of the Oklahoma Gas and Electric Company, whose facilities supply most of the entire central and northwest parts of the state. The Public Service Company of Oklahoma serves the northeast section and the Southwestern Light and Power Company the southwest portion of the state. The southeastern section is served mainly by the Central States Power Company.

Entertainment Features

No special arrangements are being made for dinner on the first day of the meeting so that members may be free to look up acquaintances and dine with them. The afternoon of Thursday will be given over to general sports and inspection trips. A luncheon-bridge has been arranged for the women, and a men's golf tournament will be held in the afternoon. The usual dinner, followed by dancing and bridge, will be the feature of Thursday evening. No special entertainment has been planned for Friday and Saturday, but the committee will be glad to arrange for golf matches, further inspection trips, informal meetings, or any other activities desired by the visitors.

Women's Entertainment

The women visiting during the convention are assured of a pleasant time. On Thursday afternoon a luncheon-bridge has been arranged for their entertainment at the Oklahoma City Golf and Country Club, in addition to the main social events on the program. Trips to points of interest in and around Oklahoma City will be arranged by the committee.

Golf

On Thursday afternoon, April 25, at 1:30, there will be a golf tournament at the Oklahoma City Golf and Country Club. Two suitable prizes will be awarded, the basis to be determined by the golf committee. No entrance or green fees will be charged registered members of the Institute for this tournament.

Arrangements have been made with both the Oklahoma City Golf and Country Club and the Twin Hills Golf Club for visiting delegates to play either course on any day of the convention, upon payment of $1 green fee. Both of these courses are of championship caliber and are interesting tests of golf. The Oklahoma City Golf and Country Club was the scene of the Trans-Mississippi Tournament in 1933. The Twin Hills Golf Club was the scene of the Western Amateur Tournament in 1934, and the National P. G. A. Tournament will be held at Twin Hills during 1935. Also, there are a number of public courses available to delegates. Lincoln Park (municipal) has 2 complete 18 hole grass green courses.

Also, tennis facilities are available to those who prefer this form of recreation.

Inspection Trips

Four inspection trips are scheduled, starting at 1:30 Thursday afternoon. One of these trips will cover many interesting features of the Oklahoma City oil field, including drilling, pumping, and refining operations. A photograph showing one view of this oil field was reproduced in Electrical Engineering for February 1935, page 205. A second inspection party will visit points of interest on the Oklahoma City system of the Oklahoma Gas and Electric Company, including the Arthur S. Huey memorial generating station, the office of the chief dispatcher, and the short-circuit calculating board of the Company's transmission system. The Reno Street substation of this system was illustrated in Electrical Engineering for February 1935, page 250.

A third group will visit the 34 story First National Bank Building, the plants of the Southwestern Bell Telephone Company and the Oklahoma Publishing Company, a broadcasting studio, an air conditioning installation, and other interesting places. A fourth party will visit the University of Oklahoma at Norman, 18 miles south of Oklahoma City. One of the most outstanding departments of its engineering school is that of petroleum engineering, whose laboratory contains a complete oil refinery.

Convention Dinner

The dinner will be held Thursday evening at 7:00 o'clock in the beautiful Venetian Room of the Skirvin Hotel. Tickets are $1.50 per plate. Music and novelty entertainment features will be provided during the dinner.

Following the dinner there will be dancing in the Venetian Room, with music provided by Spencer's Orchestra, until 12:00 midnight. Provisions will be made for both auction and contract bridge at tables convenient to the dance floor for those who prefer this form of recreation, or wish to alternate bridge and dancing. Attractive bridge prizes will be offered. The evening will be informal.

Registration

All who plan to attend this meeting are urged to register in advance by mail, if possible, by writing to E. B. Jennings, Southwestern Bell Telephone Company, Oklahoma City, Okla. Members should complete their registration after arrival so as not to miss the opening session. There will be no registration fee.

Hotel reservations should be made directly with the hotel preferred. The rates of the headquarters hotel and other leading hotels are given in table I.

An information desk will be open each day on the 14th floor of the Skirvin Hotel and a bulletin board for notices will be provided for the convenience of the members.

Table I—Hotel Rates

Hotel	Single	Double
Skirvin* (headquarters)	$2.50, 3.00	$3.00, 3.50 4.00
Biltmore	$2.50, 3.00 3.50, 4.00	$4.00, 5.00 6.00
Black	$2.00, 2.50 3.00	$3.00, 3.50 4.00
Wells-Roberts	$2.00, 2.50 3.00	$3.00, 3.50 4.00
Huckins	$2.00, 2.50	$3.00, 3.50
Kinkaid	$1.25, 2.50	$2.00, 3.50

All of the foregoing rates are with bath or shower.
* Special rates at headquarters hotel for students only: 4 to 6 in room with bath, $1 per person.

Ample parking facilities have been arranged at the Auto Hotel, 112 West First Street, located conveniently to the Skirvin Hotel, for $0.50 per day with in-and-out privileges and with delivery and pick-up service at the hotel.

Technical Program

The papers committee has arranged in so far as possible a broad program which should be of interest to many members. Some of the papers scheduled were selected expressly to bring out in the discussion the latest trends in new developments and operating practice. For example, the paper on the "Use of Instantaneous Overcurrent Relay for Distance Relays" should bring out in the discussion other comparable methods of relaying which may be applicable to the type of power systems that exist in the South West District.

The papers in the insulation and protection session will afford opportunity for discussions of this topic from the standpoint of both telephone and power system equipment. Another paper on "Recommended Transformer Standards," presented at the Institute's 1935 winter convention, has been rescheduled to give engineers from this District an opportunity to discuss the proposed standards. This paper and the one on "Protective Devices for Substations and Their Relation to Insulation Strength" will provide a basis for discussing the questions of insulation coördination, insulation strength, and protective devices.

In the same way rescheduling of the paper entitled "Portable Schering Bridge for Field Tests" will present an opportunity for a broader and more recent discussion of field testing of insulation by other methods.

In another session 2 papers on metering will present the present trends in metering practices with particular reference to outdoor meters. The discussion should bring out a suggested method for evaluating the factors to be considered in determining the extent to which it is economical to go in modernizing present metering installations. Another paper on "Prevention of Cable Sheath Corrosion" is of interest to both power and communication engineers. It describes a method of mitigating soil corrosion of cable sheath by means of applying counterpotentials. Still another on "Step Type Feeder Voltage Regulators" offers an opportunity for an expression of opinion in discussion as to the size and number of steps most desirable in this type of regulator.

The distribution and transmission session will be devoted principally to design and operation of distribution systems. One of the papers will show the economies that can be effected by the use of supplementary regulating devices, not only for compensating of the normal drop in voltage in distribution systems but also for reducing abnormal fluctuations in voltage which result from the use of large appliance motors in residential districts. The discussion of this paper with that of another on circuit interrupting and reclosing devices should also advance other principles or practices which have a bearing on the economical design and operation of distribution systems.

The symposium on engineering education will consist of discussions based upon the various papers which have been published on this subject in Electrical Engineering during the past 2 years.

The oral discussion of these papers at the meeting in the foregoing manner is desirable but only discussion which is pertinent to the papers which have been published in advance will be acceptable for consideration for publication. Rules governing discussions of both unpublished papers and published papers are given in the paragraphs immediately after the following list of papers tentatively scheduled for presentation. For all papers in this list which have been published in Electrical Engineering, reference is given to the issue and page.

Tentative Program

Wednesday, April 24

9:00 a.m.—Registration—Venetian Room, 14th floor

9:30 a.m.—Opening of Meeting—Venetian Room, 14th floor

Presiding: F. J. Meyer, vice president, South West District, A.I.E.E.

General Technical Session

Presiding: R. F. Danner and H. R. Fritz

Use of Instantaneous Overcurrent Relay for Distance Relays, C. H. Frier, Oklahoma Gas and Electric Co.

* Electrical Engineering in Geophysical Exploration, L. J. Neuman, Houston, Texas.

A Power Company Communication System, H. E. George, Tennessee Electric Power Co., and O. J. Huie, Southern Bell Telephone and Telegraph Co. March issue, p. 262–5

12:15 p.m.—Luncheon Meeting of the District Executive Committee

2:00 p.m.—Insulation and Protection Session—Venetian Room, 14th floor

Presiding: Ralph Pittman and L. C. Starbird

* Telephone Protection, A. T. Campbell, Southwestern Bell Telephone Co.

Skirvin Hotel in Oklahoma City, Okla., which will be the headquarters for the Institute's South West District meeting, April 24–26, 1935

* Protective Devices for Substations and Their Relation to Insulation Strength, A. M. Opsahl, Westinghouse Electric and Mfg. Co.

Recommended Transformer Standards, H. V. Putman, Westinghouse Electric and Mfg. Co., and J. E. Clem, General Electric Co.
Dec. 1934 issue, p. 1594–7

Portable Schering Bridge for Field Tests, C. F. Hill, T. R. Watts, and G. A. Burr, Westinghouse Electric and Mfg. Co.
Jan. 1934 issue, p. 176–82

Thursday, April 25

9:00 a.m.—Student Technical Session—Rose Room, 14th floor

9:00 a.m.—General Technical Session—Venetian Room, 14th floor

Presiding: C. I. Hendricks and R. W. Linney

* Present Trends in Metering Practices, H. P. Sparkes, Westinghouse Electric and Mfg. Co.

* Economics and Engineering of New Metering Methods and Equipment, R. G. Meyer and, Union Electric Light and Power Co.

Causes and Mitigation of Cable Sheath Corrosion, J. B. Blomberg and Norvel Douglas, Southwestern Bell Telephone Co.

12:15 p.m.—Luncheon Meeting of Committee on Student Activities

Chairman, Professor J. A. Correll

1:30 p.m.—Assemble for Inspection Trip

7:00 p.m.—Dinner—Venetian Room, Hotel Skirvin

9:00 p.m.—Dancing and Bridge—Venetian Room, Hotel Skirvin

Friday, April 26

9:00 a.m.—Student Technical Session—Rose Room, 14th floor

9:00 a.m.—Distribution and Transmission Session—Venetian Room, 14th floor

Presiding: Stanley Stokes

* Economics and Application of Supplementary Regulating Devices for Distribution Circuits, P. E. Benner, General Electric Co.

* Circuit Interrupting and Circuit Reclosing Devices for Distribution Systems, D. C. Prince, General Electric Co.

Step Type Feeder Voltage Regulators, L. H. Hill, Allis-Chalmers Mfg. Co.
Feb. 1935 issue, p. 154–8

2:00 p.m.—General Session—Venetian Room, 14th floor

Presiding: M. C. Hughes

Demonstration lecture: Vacuum and Gas Filled Tubes and Their Application in the Power Industry—D-C Transmission, C. W. Stone, General Electric Co.

Symposium on Engineering Education—Discussers: J. B. Thomas, Texas Electric Service Co.; T. F. McMains, Western Union Telegraph Co.; F. C. Bolton, Texas A. and M. College; B. D. Hull, Southwestern Bell Telephone Co., and I. H. Lovett, Missouri School of Mines and Metallurgy

* These papers will be presented and discussed at the meeting but they have not been accepted for publication and neither the papers nor the discussion based upon them will be published.

Rules for Presenting and Discussing Papers

In general, the time allowed for the presentation of each paper should not exceed 15 minutes unless otherwise arranged with the chairman of the program committee, R. F. Danner, care of Oklahoma Gas and Electric Company, Oklahoma City, Okla., or unless the presiding officer meets with the authors preceding the session to arrange the order of presentation and allotment of time for papers and discussion. Each speaker unannounced by the presiding officer is to step to the front of the room and announce, so that all may hear, his name and professional affiliation.

Discussion of Unpublished Papers. Those wishing to discuss any of the unpublished papers should write to R. F. Danner (at the above address) for mimeographed copies. It is suggested that discussers be limited to 10 minutes each and preference will be given to those who have sent copies in advance to R. F. Danner, chairman of the program committee. After these discussions have been given, the meeting will be opened for general discussion. The discussions of the unpublished papers will not be considered for publication.

Discussion of Published Papers. The same procedure governing the presentation of discussions of published papers should be followed as for the unpublished papers except that the *written* discussion to be submitted for consideration of publication should not be longer than the equivalent of 5 minutes' reading time. Discussion to be considered for publication should be based only upon the published papers and it must be submitted in triplicate (one of these copies to be the original, typed double spaced) to C. S. Rich, secretary of the technical program committee, A.I.E.E. headquarters, 33 West 39th St., New York, N. Y., on or before May 10, 1935. Discussion received after this date will not be accepted.

Future AIEE Meetings

South West District Meeting,
Oklahoma City, Okla., Apr. 24–26, 1935

Summer Convention,
Ithaca, N. Y., June 24–28, 1935

Pacific Coast Convention,
Seattle, Wash., Aug. 27–30, 1935

Great Lakes District Meeting,
Indianapolis—Lafayette Section territory, Oct. 24–25, 1935

Winter Convention,
New York, N. Y., Jan. 28–31, 1936

North Eastern District Meeting,
New Haven, Conn., May 1936

Summer Convention,
Los Angeles, Calif., June 22–26, 1936

Middle Eastern District Meeting,
Akron, Ohio (date to be determined)

Committees

The committees handling the work in connection with the Oklahoma City meeting are:

General Convention Committee—F. J. Meyer, vice president, District 7; C. W. Mier, secretary, District 7; A. Naeter, *chairman*, Oklahoma City Section; C. E. Bathe, secretary, Oklahoma City Section; and the chairmen of the 6 committees which follow.

Papers Committee—R. F. Danner, *chairman*, D. D. Clarke, C. I. Hendricks, H. R. Fritz, R. J. Foley, J. A. Correll, M. C. Hughes, G. N. Pingree, M. B. Wyman, and R. R. Pittman.

Attendance and Publicity Committee—W. A. Kitchen, *chairman*, Roscoe Schaffer, J. S. Wantland, G. A. Dyer, A. L. Maillard, C. H. Kraft, E. G. Conroy, and J. B. Burr.

Transportation and Trips Committee—E. D. Freeman, *chairman*, O. E. Larsson, R. W. Coursey, C. H. Frier, S. H. Lyons, T. E. Cutler, J. W. Shawver, W. H. Stueve, and E. T. Harrison.

Reception and Registration Committee—E. B. Jennings, *chairman*, Roy Jones, C. E. Musson, J. D. Browder, Leo Valentine, R. G. Brown, J. S. Wantland, Leonard King, E. E. Miller, Chris Heffner, W. A. Murray, Carl Almquist, and E. C. Fisher.

Finance Committee—F. B. Hathaway, *chairman*, C. E. Bathe, and W. M. Groves, Jr.

Entertainment and Arrangements Committee—A. C. Bookout, *chairman;* Hotel and Convention Hall Arrangements, E. H. Dinwiddie, *chairman*, John Wallis, J. S. Porter, and B. McDermott; Banquet, Ralph Randall, *chairman*, Roscoe Schaffer, and J. S. Joseph; Dance, C. M. Mackey, *chairman*, D. J. Mahaney, and J. W. Shawver; Bridge, W. A. Murray, *chairman*, L. B. Bass, and E. G. Green; Women's Luncheon-Bridge, C. L. Jobe, *chairman*, J. P. White, and S. H. Lyons; Women's Entertainment, Mrs. F. J. Meyer, *chairman;* Golf, O. K. Morell, *chairman*, Leo Valentine, and J. B. Kibler; Student Entertainment, R. W. Coursey, *chairman*, R. L. Jones, and E. T. Harrison.

Counselors and Branch Chairmen of District 2 Meet

A meeting of the committee on Student activities of the Institute's Middle Eastern District, number 2, and of the student Branch chairmen of that District was held at Pittsburgh, Pa., January 8, 1935. The morning was devoted to an inspection trip with a luncheon at noon, and the Pittsburgh Section meeting was attended in the evening. During the afternoon separate meetings were held by the committee on Student activities and by the Branch chairmen.

Conference of Committee on Student Activities

The committee on Student activities consists of the District vice president and secretary, and all student Branch counselors in the District. The following student Branch counselors were present at the conference:

J. T. Walther, University of Akron, Ohio
G. A. Irland, Bucknell University, Lewisburg, Pa.
G. McC. Porter, Carnegie Institute of Technology, Pittsburgh, Pa.
H. B. Dates, Case School of Applied Science, Cleveland, Ohio
T. J. MacKavanagh, Catholic University of America, Washington, D. C.
A. G. Ennis, George Washington University, Washington, D. C.
H. E. Dyche, University of Pittsburgh, Pa.
H. S. Bueche, Villanova College, Villanova, Pa.
A. H. Forman, West Virginia University, Morgantown

In addition to the above, Prof. A. M. Wilson of the University of Cincinnati, Ohio, and vice president from Institute's Middle Eastern District, and Dr. C. F. Scott, professor emeritus, of electrical engineering Yale University, New Haven, Conn., were present.

At this conference, the following action was taken "Resolved that it is the sense of this meeting that there shall be an annual combined meeting of the counselors and Branch chairmen, preferably in the early fall. Resolved that the next meeting be held in the early fall of 1935." It

was also stated that many counselors preferred that when the annual meetings of the Middle Eastern District are resumed, the Branch conference be held at the same time and place.

The advantages of electing student officers early in the fall was discussed. The importance of choosing good student officers was pointed out, and the advantages of daytime meetings of the student Branches also were discussed.

The history of the committee on Student activities in this District was reviewed, and opinions were expressed on possible modifications of the present form of organization. It was resolved that a chairman be elected annually at the time of the annual counselors conference, and that there be no other elected officers. It was also resolved that the incoming chairman be instructed to appoint an advisory committee, consisting of the retiring chairman and 3 other counselors, although the chairman "shall be held responsible to the counselors of the District for the efficient promotion and organization of conferences and meetings of counselors and student chairmen." The power was given to the chairman of designating to other counselors such duties as he might deem necessary.

Prof. A. H. Forman, head of the department of electrical engineering of West Virginia University, Morgantown, was elected chairman of the Branch counselors of the District. He assumed office immediately.

Conference of Branch Chairmen

At the conference of the student Branch chairmen, methods for improving the effectiveness of A.I.E.E. Branches in the District were discussed in considerable detail, and many valuable suggestions were introduced. This conference afforded an opportunity for an effective exchange of ideas among the different Branches.

Sixteen of the 20 student chairmen in the District attended. Those present were:

W. Anvil, University of Akron, Ohio
C. A. Beers, Case School of Applied Science, Cleveland, Ohio
W. B. Schuyler, Jr., Catholic University of America, Washington, D. C.
W. C. Keiber, Jr., Lafayette College, Easton, Pa.
T. M. Gluyas, Jr., Pennsylvania State College, State College
F. L. Musselman, University of Pennsylvania, Philadelphia
C. A. Motz, George Washington University, Washington, D. C.
C. B. Jacoba, Ohio Northern University, Ada
C. R. Hope, Ohio State University, Columbus
R. C. Woltz, Ohio University, Athens
J. A. Klekotka, Villanova College, Villanova, Pa.
J. W. Kyle, West Virginia University, Morgantown
A. J. Hornfeck, University of Pittsburgh, Pa.
F. W. Francis, Bucknell University, Lewisburg, Pa.
H. B. Coleman, Drexel Institute, Philadelphia, Pa.
H. J. Corning, Carnegie Institute of Technology, Pittsburgh, Pa.

Innovations Being Planned for the Summer Convention

The development of the program for the 51st annual summer convention of the Institute, to be held on the campus of Cornell University, Ithaca, N. Y., June 24–28, 1935, is progressing rapidly. Advantage will be taken of the splendid facilities which the university offers in the way of meeting halls and modern dormitory accommodations to present an enlarged program at moderate cost to those who will be in attendance.

Already 10 technical sessions have been tentatively scheduled in 9 distinctly different fields of activity. Each of these sessions embraces several papers which will present the latest theories and practices in the following fields: protective devices, instruments and measurements, electrical machinery (2 sessions), education, communication, applications to iron and steel production, electrochemistry and electrometallurgy, power generation, and power transmission. Some of the papers for the protective devices session have been published already in the February issue of Electrical Engineering. They deal with circuit breaker performances, voltage recovery rates and oscillography in connection with such tests, as well as the selection and operating performance of relay protective equipment for fault and out-of-step protection of lines, and surge current investigation in relation to the economics of lightning arrester installations.

Other papers for the program appear in this issue and still others will appear in succeeding issues up to the time of the convention so that ample opportunity will be afforded for advance study and the preparation of good discussion. Thus those in attendance will be assured of hearing excellent and pertinent discussions. They should also feel free to take part when the meeting is opened for general discussion.

In addition, and as a trial, plans also are being made to schedule a number of informal round table meetings for the benefit of specialists and the younger members. The success of several of these meetings at the winter conventions and the growing numbers of specialist groups which desire to meet periodically for discussion of their own problems have caused the technical program committee in coöperation with the summer convention committee to plan an enlarged program. The informal meetings will be sponsored by the technical committees through their subcommittee chairmen. Leaders in their respective fields will be invited to speak informally, and all of those interested will be invited to attend and participate in the discussion. No provision will be made for printing of papers, discussions, or conclusions reached at these informal round table meetings.

The purposes to be served by these round table meetings as planned are 4. First, it is hoped that various leaders in the art will be willing to speak informally at these meetings, pointing out the lines of future progress as they see them and commenting on recent developments. It is hoped that these talks will direct the work of the Institute committees into new and pertinent channels. Second, the programs will afford opportunities for meetings of groups of Institute members who are interested in specialized activities, but those subjects are of too little interest to the great majority of the membership to warrant publication in Electrical Engineering. Third, these round table discussions afford an opportunity for technical committees or their subcommittees to obtain assistance from individuals, not members of the committees, but interested in the particular subject under discussion. Fourth, if desirable, arrangements will be made for round table discussions confined specifically to those phases of the art which are of particular interest to students.

The chairmen of the technical committees are invited to sponsor round table meetings of their subcommittee groups. Suggestions from the members for subjects to be discussed should be sent to C. S. Rich, secretary, technical program committee, at Institute headquarters, and they will be forwarded to the technical committees for consideration and approval.

Membership—

Mr. Institute Member:

Our membership messages to you month by month are representative of the constancy with which the Section membership committees are continually carrying on their work.

You are doing your part of this work when you send in the names of persons who you feel should be invited to join the Institute.

Since May 1, 1934, the beginning of this Institute year, 685 applications for membership had been received as of February 1, 1935.

Everett S. Lee

Chairman National Membership Committee

Reports on Committee Meetings Held During Winter Convention

During the recent winter convention of the A.I.E.E. held in New York, N. Y., Jan. 22–25, 1935, many of the general and technical committees of the Institute held meetings. A summary of each of these meetings is given in the following paragraphs, with the exception of the meetings of those few committees for which no adequate reports were available for publication. Activities of one of these, the standards committee, are reported month by month in the "standards" department of Electrical Engineering.

Automatic Stations

At the meeting of the committee on automatic stations, a resolution was passed (unanimously) directing the chairman to appoint 5 members of this committee to membership in a telemetering subcommittee to be composed also of 5 members of the committee on instruments and measurements. Papers and activities pertaining to telemetering would be handled by the subcommittee. The portion pertaining to the general subject of power dispatching and supervisory control would be sent to the committee on automatic stations while the portion on design and applications other than power dispatching and load control would be given to the committee on instruments and measurements. The chairmanship of the subcommittee would be alternated each year between the 2 committees.

The revision of the subcommittee report on "Telemetering and Supervisory Control" is ready for publication. The policy on the method of publishing has not been settled and D. W. Taylor was appointed to settle the details with H. P. Charlesworth. It was recommended that the revised report be published in Electrical Engineering.

Papers for a session at the next midwinter convention were discussed and it is believed that a sufficient number of good subjects will be available.

The subcommittee on the revision of standards number 26 will have their work completed on March 1, 1935. The old issue of May 1930 is badly in need of revision and it was recommended that this work be carried through promptly.

A partial summary is available on each of these subjects:

A. Storage battery charging in unattended station.
B. Effectiveness of protective devices.
C. The use of fuses in unattended stations.

Electrical Machinery

The committee on electrical machinery discussed the following subjects constituting the principal items that the committee is interested in at the present time.

Test Codes for Electrical Machinery. For the past 2 or 3 years the committee has been very active in preparing test codes for various types of electrical machinery. Preliminary reports on the test code for transformers, test code for polyphase induction machines, and test code for synchronous machinery, have been printed and can be obtained, free of charge, by applying to A.I.E.E. headquarters. The test code for d-c machinery is under preparation and it is expected that it will be completed during the coming year. These codes supplement the present A.I.E.E. Standards and are a valuable contribution to the Institute's publications, as they represent the most up-to-date methods in the testing of electrical apparatus, a phase of work which it is not possible to cover in the regular standards.

Round Table Discussions During National Conventions. The committee sponsored 2 round table discussions during the winter convention, one of these being on transformers and the other on the induction motor test code. These discussions were well attended and considerable interest was shown. At the induction motor test code discussion there were 7 prepared and written discussions and 4 oral discussions presented. The attendance at each discussion was around 25 or 30.

Insulation Resistance. No satisfactory rule has ever been worked out to determine the condition of electrical machinery by measurement of its insulation resistance. This question has become quite active and the committee has appointed a subcommittee with K. A. Reed, of the Hartford Steam Boiler Inspection and Insurance Company, as chairman to study the possibilities of formulating a rule that may be used by operators to determine, by means of its insulation resistance, when electrical machinery is not in a safe operating condition.

Electrochemistry and Electrometallurgy

The committee on electrochemistry and electrometallurgy continues to show the increased interest which is developing within the Institute membership in the importance of electrochemistry and electrometallurgy to manufacturers and users of equipment and to producers of power to serve such industries.

Considerable progress has already been made in the coördination of the committee's activities with those of other societies interested in similar work and further work will be done along this line. The committee has already established contact with representatives in England and Japan and will establish further contacts in foreign countries so that it will be kept informed as to activities throughout the world in the field of electrochemistry and electrometallurgy.

The plans for a session at the summer convention at Ithaca were presented and it can be said at this time that a most successful meeting is definitely assured.

The committee discussed the importance of directing its activities along the lines which are of most interest to the membership of the Institute and it is most encouraging to report a definite increase in the general interest displayed in the subjects which come under the scope of its activities and toward which its future programs are being directed.

A definite start has been made in formulating plans for next year's mid-winter convention.

Electrophysics

The committee on electrophysics at its meeting devoted much of the time to discussing plans for a series of round table discussions of subjects in the fields of physics, chemistry, and mathematics, which may be of interest and value to the electrical engineer. It is proposed to hold the first 2 of these at the time of the summer convention. One round table session will be devoted to a discussion of tensile analysis which is proving to be a very helpful tool in dealing with a number of complicated electrical circuit problems, such as the multicircuit transformer, rotating machinery, and vacuum tubes. Some interesting analogies have been developed between the phenomena in rotating electrical machinery and Einstein's space theories.

Another meeting will discuss X rays and their engineering application. It is planned to coördinate this meeting with some of the research in X rays being done at Cornell by Professor Richtmeyer and his associates.

Instruments and Measurements

At the meeting of the instruments and measurements committee the papers that had been submitted for possible presentation at the A.I.E.E. summer convention were discussed. It was decided to recommend that the paper "Definitions of Power, Power Factor and Related Quantities," by Doctors Curtis and Silsbee should be presented in its present form and be published in full. Among other papers discussed were "A Method of Precise Speed Control for Use in Measurement Work," by R. H. Frazier, J. Eisler, and W. P. Frantz; "The Design of Pivot Bearings for Indicating Instruments," by J. H. Goss; "Effect of Lubrication on the Life of Watthour Meter Bearings," by Abbott and Goss; and "The Surge Crest Ammeter—A New Instrument for Surge Current Measurements," by C. M. Foust.

Power Generation

At the meeting of the committee on power generation, there was formulated the tentative program for the session sponsored by this committee at the 1935 summer convention.

It is expected that there will be presented at this session a paper by H. M. Cushing, chief engineer of the Buffalo General Electric Company, covering some new features of the Huntley Station; a paper by R. E. Greene of the Detroit Edison Company, covering rehabilitation of generating stations, and a paper by L. N. McClellan, chief electrical engineer of the United States Bureau of Reclamation, on the general subject of power production at Boulder Dam. It is planned also to include a third report of the subcommittee on hydroelectric survey.

There was considerable discussion of subjects which should be covered in the near future by papers sponsored by this committee and the committee members will endeavor to arrange that some of these subjects will be covered by papers to be presented at the next Mid-Winter Convention.

Power Transmission and Distribution

At the annual meeting of the power transmission and distribution committee the chairman outlined the committee's main activities in Institute work for the past year, namely, 2 sessions at 1934 mid-winter convention, 1 on transmission line problems and the other on distribution; 1 session at the annual convention at Hot Springs on insulators; 2 sessions at the Pacific Coast convention in Salt Lake City, 1 on lightning and 1 on transmission line subjects; and 2 sessions at the present mid-winter convention, 1 on transmission lines and the other on cable. Plans for the coming conventions were discussed.

Reports were then submitted by each subcommittee chairman on their activities, plans, what research they have sponsored, etc., during the past year and their plans for the future. These reports came from the following subcommittees: conductors, towers and poles; lightning and insulators; distribution; interconnection factors and stability; cable developments; and standards.

A report submitted by the subcommittee on conductors, towers, and poles on the prestretching of conductors was read and approved for publication.

Research

At the meeting of the committee on research it was reported that up to January 19th, 156 copies of the list of research suggestions prepared by the committee and announced in the November 1934 number of Electrical Engineering (also in a journal of the S.P.E.E.) had been issued to 100 individuals, 71 of whom applied to headquarters for copies of the list in response to the published announcements. Certain suggestions were made for giving the availability of this list further publicity. It was also agreed that a second list should be prepared for issuance in the fall. It is proposed to follow up each recipient of a copy of these lists with a view to determining how many of the suggestions have been actually taken up and what progress is being made.

An extended discussion was had of other means which are feasible at this time of calling attention to and encouraging research, particularly in educational institutions. A number of suggestions were made which will be acted upon.

The need for certain library researches in the electrical field was stressed in this discussion but it was agreed that such an effort to be worth while should be on an organized basis with some financial support rather than on a purely individual, voluntary basis.

Several fundamental experimental researches in various branches of the electrical engineering field were discussed—researches which ought to be under way on an organized and financed coöperative basis. One of these, dealing with liquid insulations, will, it is hoped, be initiated in the near future under the auspices of a group of utility companies. Two other researches involving pathological matters would be appropriate for support by one of the foundations operating in the medical field.

In lieu of a comprehensive annual review of published research work which the committee feels cannot be properly done through individual, voluntary effort, it was proposed that brief reviews of research accomplishments in each of those fields in which one of the committee members specializes be published "piecemeal" in Electrical Engineering during the year.

The arrangement of the details for carrying out some of the suggested plans was left to a small steering committee which can meet readily and as often as may be necessary.

Discussion on Noise

A discussion on noise was sponsored by the A.I.E.E. committee on sound, which is a subcommittee of the A.I.E.E. standards committee. At this afternoon discussion meeting, which in effect was an extension of the symposium on noise measurements held in the morning at which several Institute papers were presented, the discussion concerned principally with the papers which had been presented.

As a result of the interest shown at this meeting, it is tentatively planned to have an informal round table discussion on noise, without any printed papers, at the Institute's 1935 summer convention at Ithaca, N. Y. Emphasis at the proposed meeting would be placed upon the question of what are acceptable and generally existing noise levels under different living conditions.

An Oil Gusher in the Oklahoma City Oil Field

An oil gusher in the oil field adjacent to Oklahoma City, Okla., before it was placed under control. This oil field will be visited by most of those attending the South West District meeting of the A.I.E.E., to be held in Oklahoma City, April 24–26, 1935. This oil field, another view of which was shown in Electrical Engineering for February 1935, page 105, has 1,032 wells producing, with an average of one well for every 6 acres. The connected capacity for pumping and other purposes in this field is 25,000 horsepower; with the amount continually increasing. The Reda pump is used extensively in this field, the pump and motor being located in the bottom of a well, some installations being made as low as 6,000 feet below the surface. The motor varies in size from 75 to 110 horsepower and is placed inside the 6 inch casing.

Dates Selected for Pacific Coast Convention

The committee in charge of arrangements for the Institute's forthcoming Pacific Coast convention has definitely selected the dates of August 27–30, 1935, for the convention. It will be held at Seattle, Wash. Committees are being appointed and plans are being made for an interesting technical program and attractive entertainment features.

Translations Available From Engineering Library

Engineers and technical men in all parts of the country call on the service bureau of the Engineering Societies Library for exact, technically accurate translations because they know that they will find there a well equipped staff that can handle translations from any language and on any aspect of engineering.

The service bureau has translated more than 2,750,000 words from many languages in a 5 year period. Translations from German were required most frequently and made up about one-half of the total, but French, Italian, Spanish, Russian, and other languages are frequently called for. The service bureau keeps in its files a collection of more than 1,500 translations that may be obtained by paying a moderate revision and copying charge. Charges are moderate because they cover only the actual cost of doing the work.

For further information or rates write the Engineering Societies Library, 29 West 39th Street, New York, N. Y.

(Information on other services available from the Engineering Societies Library was given in Electrical Engineering for December 1934, pages 1668–9, and January 1935, pages 130–1.)

New Rules Governing Award of A.I.E.E. Prizes for Technical Papers

AUTHORS who plan to present papers before the Institute during the calendar year 1935, and others who may wish to submit papers for prizes, would do well to bear in mind that such papers are eligible for consideration for Institute prizes. These awards are made each spring for papers presented during the preceding calendar year and fall into 2 main classes, national and District prizes.

Important changes in the rules governing the award of A.I.E.E. prizes for technical papers have been made since the publication of the "Announcement of A.I.E.E. Prizes for Technical Papers" in ELECTRICAL ENGINEERING for December 1934, page 1665. The new rules, which entirely supersede the previous ones, and which are retroactive to include papers already presented during 1935, are as follows:

NATIONAL PRIZES

The following national prizes may be awarded each year at the discretion of the committee on award of Institute prizes:

1. Prize for best paper in: (1) engineering practice; (2) theory and research; and (3) public relations and education.
2. Prize for initial paper.
3. Prize for Branch paper.

The national prize for best paper in each of the 3 classes, namely, engineering practice, theory and research, and public relations and Education, may be awarded for the best original paper presented at any national, District, or Section meeting of the Institute, provided the author, or at least one of co-authors, is a member of the Institute.

The national prize for initial paper may be awarded for the most worthy paper presented at any national, District, Section, or Branch meeting of the Institute, provided the author or authors have never previously presented a paper which has been accepted by the technical program committee, and the author, or at least one of co-authors, is a member of the Institute or is a graduate student enrolled as a Student of the Institute.

The national prize for Branch paper may be awarded for the best paper based upon undergraduate work presented at a Branch or other Student meeting of the Institute, provided the author or authors are Enrolled Students of the Institute.

Only papers presented during the calendar year shall be considered for any of the prizes, except those for the best paper prize in the class of public relations and education. In this class, all papers presented subsequent to those considered at the time of the last previous award in this field will receive consideration. All papers approved by the technical program committee which were presented at the national conventions or District meetings will be considered for the best paper prizes and initial paper prize without being formally offered for competition. All other papers which were presented at Section, Branch, or Student meetings must be submitted in triplicate with written communications to the national secretary on or before February 15 of the following year, stating when and where the papers were presented. This may be done by authors, by officers of the Institute, or by the executive committees of Sections or geographical Districts.

Each national prize shall consist of a certificate of award issued by the Institute and $100 in cash. When papers are written jointly, the cash awards shall be divided and a certificate shall be issued to each author. The board of directors may, at its discretion, omit the cash awards for any of the prizes.

Committee on Award of Institute Prizes. This committee shall consist of the chairman of the technical program committee, acting as chairman; the chairmen of the publication committee, the committee on research, the technical program committee of the previous year, and the chairmen of such other committees as the board of directors may designate. This committee shall award at its discretion all the national prizes. It may award a single paper more than one of the prizes available and it may make honorable mention of papers which do not receive prize awards. All the national prizes for a given calendar year shall be awarded prior to May 1 of the succeeding year. They shall be presented at the next summer convention of the Institute.

For the national best paper prizes the technical program committee shall indicate to the committee on award of Institute prizes the class under which each paper is to be considered for first prize.

Basis of Grading Papers. The technical committees shall assist the committee on award of Institute prizes by grading papers at the time they are initially reviewed for acceptance. The valuations which shall govern the grading of papers for purposes of making awards shall be as follows:

Analysis of Subject ..... **10 per cent**

The paper shall present a clear outline of the situation out of which arises the need for the preparation of a paper on the particular subject, explaining the point of view assumed in the presentation.

Logical Presentation ..... **10 per cent**

The presentation should include an analysis of the difficulties encountered, the methods of attack and the solution of the problem.

Originality ..... **10 per cent**

Credit should be given to the paper which brings to its subject matter a fresh point of view, a healthy open-mindedness or a discarding of some outworn traditions.

Unity ..... **10 per cent**

While brevity and conciseness are important they should not be attained at the sacrifice of unity and completeness of presentation.

Value in Its Field ..... **30 per cent**

The value of the paper as a contribution to the literature in its own field should receive particular consideration.

Value to Electrical Engineering ..... **30 per cent**

The paper should be considered from the standpoint of the quality of its contribution to the advancement of electrical engineering and its value to civilization.

Publication. Papers awarded prizes shall be published in full or in abstract, in ELECTRICAL ENGINEERING, in the TRANSACTIONS, or in pamphlet form:

DISTRICT PRIZES

The following District prizes may be awarded each year in each geographical District of the Institute:

1. Prize for best paper.
2. Prize for initial paper.
3. Prize for Branch paper.

The District prize for best paper may be awarded for the best paper presented at a national, District, or Section meeting, provided the author, or at least one of co-authors, is a member of the Institute.

The District prize for initial paper may be awarded for the most worthy paper presented at a national, District, Section, or Branch meeting, provided the author or authors have never previously presented a paper before a national, District, Section, or Branch meeting of the Institute, and the author, or at least one of co-authors, is a member of the Institute or is a graduate student enrolled as a Student of the Institute.

The District prize for Branch paper may be awarded for the best paper based upon undergraduate work presented at a Branch or other Student meeting of the Institute, provided the author or authors are Enrolled Students of the Institute.

Each District prize may be awarded only to an author who, or to co-authors of whom at least one, is located within the District, and for a paper presented at a meeting held within, or under the auspices of the District.

Only papers presented during the calendar year shall be considered. They must be submitted in duplicate by the authors or by the officers of the Branch, Section, or District concerned to the District secretary, on or before February 15 of the following year.

Each District prize shall consist of a certificate of award issued by the officers of the geographical District and $25 in cash. When papers are written jointly, the cash awards shall be divided and a certificate shall be issued to each author. The board of directors may, at its discretion, omit the cash awards for any of the prizes.

Committees on Awards. All the District prizes for a given calendar year shall be awarded prior to May 1 of the succeeding year by the District executive committee or by a committee appointed by the District executive committee and authorized to make such awards.

Basis of Grading Papers. The valuations which shall govern the grading of papers for purposes of making awards shall be the same as those for the national prizes but the papers will not be graded by the technical committees.

Copies of a pamphlet entitled "National and District Prizes" may be secured, without charge, upon application to Institute headquarters. The information given in this pamphlet is identical with that presented above. These rules were originally adopted by the Institute's board of directors June 23, 1927; they were revised December 7, 1928, January 27, 1932, and January 21, 1935. The rules given above include the latest revisions.

E.C.P.D. Plan for Accrediting Engineering Colleges

THE work in which the Engineers' Council for Professional Development is now actively engaged is being carried on by its 4 working committees, namely, the committee on student selection and guidance, committee on professional training, committee on engineering schools, and committee on professional recognition. In an article "E.C.P.D. Reports Substantial Progress During 1934" which appeared in ELECTRICAL ENGINEERING for February 1935, pages 249–50, a brief résumé of the work accomplished by these 4 committees was given. Further details of the work of the committee on engineering schools is given in the present article.

The board of directors of the A.I.E.E. on May 25, 1934, approved the E.C.P.D. as an agency for the accrediting of engineering schools, but at that time reserved the right to approve the actual working plan for such accrediting. This working plan as developed by E.C.P.D. was transmitted to the A.I.E.E. November 19, 1934, and was considered at the meeting of the Institute's executive committee on December 7, but that committee felt that action should be deferred until the plan could be considered by the full board of directors. As announced in the above-mentioned article in the February issue of ELECTRICAL ENGINEERING, the Institute's board of directors on January 21, 1935, decided to sanction the plan as submitted. As also announced in that article, all societies concerned have now given the authorization needed to inaugurate the accrediting procedure; in addition to the A.I.E.E., the other participating bodies are The American Society of Mechanical Engineers, American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, Society for the Promotion of Engineering Education, the National Council of State Boards of Engineering Examiners, and the American Institute of Chemical Engineers.

E.C.P.D. through its committee on engineering schools announces the following principles and procedures in accordance with which accrediting will be conducted:

BASIS FOR ACCREDITING

I. Purpose of accrediting shall be to identify those institutions which offer professional curriculums in engineering worthy of recognition as such.

II. Accrediting shall apply only to those curriculums which lead to degrees.

III. Both undergraduate and graduate curriculums shall be accredited.

IV. Curriculums in each institution shall be accredited individually. For this purpose, the E.C.P.D. will recognize the 6 major curriculums: chemical, civil, electrical, mechanical, metallurgical, and mining engineering—represented in its own organization, and such other curriculums as are warranted by the educational and industrial conditions pertaining to them.

V. Curriculums shall be accredited on the basis of both qualitative and quantitative criteria.

VI. Qualitative criteria shall be evaluated through visits of inspection by a committee or committees of qualified individuals representing the E.C.P.D. The visits of inspection either as to entire institutions or as to specific curriculums may be waived at the discretion of E.C.P.D.

VII. Quantitative criteria shall be evaluated through data secured from catalogs and other publications, and from questionnaires.

VIII. Qualitative criteria shall include:

1. Qualifications, experience, intellectual interests, attainments, and professional productivity of members of the faculty.
2. Standards and quality of instructions: (a) in the engineering departments; and (b) in the scientific and other coöperating departments in which engineering students receive instructions.
3. Scholastic work of students.
4. Records of graduates both in graduate study and in practice.
5. Attitude and policy of administration toward its engineering division and toward teaching, research, and scholarly production.

IX. Quantitative criteria shall include:

1. Auspices, control, and organization of the institution and of the engineering division.
2. Curriculums offered and degrees conferred.
3. Age of the institution and of the individual curriculums.
4. Basis of and requirements for admission of students.
5. Number enrolled: (a) in the engineering college of division as a whole; and (b) in the individual curriculums.
6. Graduation requirements.
7. Teaching staff and teaching loads.
8. Physical facilities. The educational plant devoted to engineering education.
9. Finances; investments, expenditures, sources of income.

The purpose of E.C.P.D. is to substitute a single accrediting for the uncoördinated methods that have been used in the past; E.C.P.D., representing the national engineering societies, the state licensing boards, and the colleges of engineering, is the only agency that can accredit colleges under properly inclusive auspices. As a not unimportant incidental advantage, accrediting by this one agency will avoid the needless duplications of present procedures.

E.C.P.D. is merely authorized by its constituent organizations to publish a list of accredited colleges for use by those agencies which require such a list. It has no authority to impose any restrictions or standardizations upon engineering colleges, nor does it desire to do so. On the contrary, it aims to preserve the independence of action of individual institutions and to promote the general advancement of engineering education thereby.

As stated in the foregoing paragraphs headed "Basis for Accrediting" appraisal of institutions will be based upon statistical information as obtained from catalogs and questionnaires, and upon evidence of quality of instruction, adequacy of equipment, and of teaching staff, and other factors not susceptible of statistical analysis, as determined by visits of inspection by committees of qualified representatives of the committee on engineering schools. Emphasis will be given to quality of work rather than to statistical information to a greater degree than in former accrediting procedures. No hard-and-fast prescriptions are laid down for the curriculum, the physical facilities, the investment or expenditures, or other specific points relating to a given institution, though all of these, and others will be taken into account in appraising the institution as a whole.

Final decision as to accrediting of each institution rests with the E.C.P.D. which will pass upon the recommendations made to it by the committee on engineering schools.

The general expenses of developing the accrediting program will be borne in part by a grant of funds from Engineering Foundation. Expenses of the visiting committees representing the Council will be met by a charge made to the individual institutions sufficient to cover cost of travel and subsistence during the inspection. This is in accord with the practice of certain other accrediting agencies.

Committees of inspection will comprise both teachers and practicing engineers, the criteria for selection being competency to judge educational institutions, good judgment, and availability. For the purposes of organization and administration of the accrediting program the country has been divided into 7 geographical regions which include within their boundaries approximately equal numbers of engineering colleges; New England, the Middle Atlantic States and Maryland, the Southeastern States, the Upper Mississippi Valley, the Lower Mississippi Valley, the Southwest, and the Northwest. Committees in the 7 geographic areas will include representatives of each of the organizations consituting the E.C.P.D. Alternates will be provided who will serve instead of the regular members when the latter would be called upon to judge a neighboring or rival institution, or the one with which the individual himself is connected. A member of the E.C.P.D. committee on engineering schools will serve as chairman of each regional committee.

Accrediting of individual institutions and of curriculums offered by them will be, of course, upon invitation of the institutions. Formal notification of the launching of the accrediting program will be sent by the committee to officials of the institutions in the near future.

The membership of the E.C.P.D. committee on engineering schools was given in the previously mentioned article in ELECTRICAL ENGINEERING for February 1935, page 249–50, along with the membership of the other E.C.P.D. committees. Inquiries as to any phase of accrediting should be addressed to the committee on engineering schools, Engineers' Council for Professional Development, George T. Seabury, secretary, 29 West 39th Street, New York, N. Y.

INFORMATION COMMITTEE APPOINTED

Supplementing the list of the members of the various E.C.P.D. committees given in the article in the February issue, the following committee, not included therein, is in charge of publicity and information released by the E.C.P.D.:

Information Committee

DR. H. C. PARMELEE, *chairman*, vice president, McGraw-Hill Publishing Company, Inc., New York, N. Y.

GEORGE A. STETSON, editor, The American Society of Mechanical Engineers, New York, N. Y.

SIDNEY WILMOT, manager of publications, American Society of Civil Engineers, New York, N. Y.

E. H. ROBIE, assistant secretary and editor, American Institute of Mining and Metallurgical Engineers, New York, N. Y.

G. ROSS HENNINGER (A'22, M'27) editor, American Institute of Electrical Engineers, New York, N. Y.

Another High Speed Diesel-Electric Train

External streamlining and internal comfort feature the railroads' constructive bid for increased passenger travel

THE new "Flying Yankee," diesel-electric 3-unit train delivered by the Edward G. Budd Manufacturing Company (Philadelphia, Pa.) to the Maine Central-Boston and Maine Railroad, is the first such unit to be placed in regular operation on an eastern railroad. On a trial run February 5, 1935, on a short stretch of track out of Philadelphia, this train attained a speed of 100 miles per hour with a substantial passenger load. From a practical operating standpoint, the rapid and smooth acceleration and retardation were particularly noteworthy, comparative data showing that by the time this train and a comparable steam train could reach a 90 mile an hour cruising speed, the "Flying Yankee" would be some 6 miles ahead of the steam train. This is a particularly important matter in connection with local service.

Reflecting the successful pioneering operation of the now famous "Zephyr" placed in service last year between Lincoln, Neb., and Kansas City, Mo., by the Burlington Railroad, the "Flying Yankee" is a 3-section 4-truck articulated unit of light weight stainless steel construction, completely self-contained and air conditioned. Providing seats for 144 passengers in addition to an engine room, a baggage department, and an electrically equipped buffet, the over-all length of the unit is 199 feet $2^3/_4$ inches; its weight about 106 tons complete. The weight of a complete steam train replaced by a lightweight unit of this kind is in the neighborhood of 400 tons. An ordinary pullman car weighs nearly as much as the lightweight train. Another important feature of the lightweight train is its economy of operation; ordinary furnace oil is used as fuel.

In the "Flying Yankee" a 600 horsepower 2 cycle 8 cylinder Winton diesel engine supplies power to the forward trucks of the train through the medium of a direct connected differentially wound d-c generator which feeds the 2 traction motors mounted on the driving axles. Principal mechanical equipment including engine and air conditioning apparatus was supplied by the General Motors Corporation; electrical equipment including generators, traction motors, and control system by the General Electric Company.

In connection with the actual construction of the "Flying Yankee" and other similar units now in the Budd shops, is the fact that the entire train with the exception of truck mountings was fabricated from thin sheets of special high strength steel literally built up piece by piece by a special electric spot welding process. This process has been termed the "shotweld" process by the Budd company because both the amount and duration of current flow to each spot weld is subject to automatic control by means of an electronic device after having been predetermined according to the weight of the particular sheets to be welded. Thus the welding operator merely clamps the 2 sheets between the electrodes of his hand tool and pulls the trigger, welding up to 20 or more spots per minute.

The "Flying Yankee" is scheduled to be placed in regular service making a daily run from Portland, Me., to Boston, Mass., a round trip from Boston to Bangor, Me., and an evening run from Boston back to Portland, a daily schedule of nearly 700 miles.

Safety Engineers' Society Suggests Coöperation

The American Society of Safety Engineers, engineering section, of National Safety Council through its committee on coöperation with other engineering societies, has taken steps to bring about the coördination of the technical aspects of safety work now being carried on by different organizations. It is the hope of this committee that the work of all engineering societies and interested technical and industrial agencies in handling the technical aspects of accident prevention may be properly correlated.

The plan of procedure proposed by the committee consists of the appointment of a member of the A.S.S.E. executive committee to be the contact man with each of the engineering societies and other organizations concerned; the appointment by these other organizations of their contact man to work with the A.S.S.E.; the establishment of relations with the various industrial sections of National Safety Council; the interchange of information between all interested agencies; and the rendering of assistance to the committee for development of interest in safety education in technical colleges.

Inasmuch as the A.I.E.E. is cognizant of the importance of the technical aspects of accident prevention and desires to coöperate in the exchange of information, it has taken steps to supplement the individual contacts of the Institute's membership already existing with other engineering societies and industrial organizations. Therefore, the appointment has been announced of F. D. Knight, chairman of the Institute's committee on safety codes, as the A.I.E.E. contact man with the A.S.S.E. He will consult the membership of the committee on safety codes and secure the benefit of their judgment in all matters referred to him.

Montefiore Prize Award Still Open. Announcement that the Montefiore prize award constituting the interest on 150,000 Belgium francs, distributed triennially in international competition for the best original work presented on scientific advancement and progress in technical application of electricity, is open to candidates, was given in ELECTRICAL ENGINEERING for June 1934, page 1026. Conditions governing the award were given therein. The final date for the reception of manuscripts by the jury has been fixed as April 30, 1935. Communications should be addressed to Omer De Bast, president of the Montefiore Foundation, Rue Saint Gilles, 31, Liege, Belgium.

Engineering Index Plans Expansion

Engineering Index, Inc., will appeal to the nation's industry operating in technical fields for a working capital fund of approximately $160,000 with which to continue the service and spread its use throughout the engineering offices, libraries, and colleges of the country, over a 5 year period after which it is estimated it will be self-sustaining. This project has just been announced by Collins P. Bliss, dean of the school of engineering at New York University and president of the board of directors of the Index.

Thus will this 50-year-old engineering institution enter a new and wider field, according to Dean Bliss. At the annual meeting of The American Society of Mechanical Engineers in 1933 it was voted to discontinue the society's responsibility for, and financial losses accruing from, the operation of the Index. This decision became effective the beginning of 1934. In June of 1934 the Index was formally incorporated as a nonprofit organization in its own right. This followed an extensive study by an outside organization which developed the conclusions that if it were not for the Index, the engineering field would be without a complete and effective organization of its current literature. To those not already familiar with the Index, it may be described as a virtually complete catalogue, with annotations, of technical literature in all branches of engineering. The merits claimed for the service include completeness, descriptiveness, promptness, and accuracy.

The Index is published in 2 separate forms. The annual volume is roughly similar to complete indexes in other scientific fields. More unique is the card service which is a cumulative card index of technical literature sub-divided into approximately 280 divisions which may be had in any desired combination. About 2,000 publications are reviewed by Index editors. These periodicals come from 40 different countries and are in 20 languages.

The present board of directors includes, besides Dean Bliss, H. V. Coes, manager of the industrial department of Ford, Bacon, and Davis; R. E. Flanders, president of Jones and Lamson Machine Company; R. M. Gates, vice president of Combustion Engineering Company, Inc.; and C. F. Hirshfeld (A'05), chief of the research department of Detroit Edison Company. The charter of the Index, which describes the typical membership nonprofit corporation under the New York State law, provides for 50 trustee members who Dean

A Reading List for Junior Engineers

A LIST of books recommended for reading by junior engineers has been prepared by a number of eminent men, many of them distinguished in the engineering profession. Sections of this list have been published in ELECTRICAL ENGINEERING for December 1934, page 1667, and January 1935, page 133. Another section is published herewith, and others are scheduled to follow in subsequent issues. The complete list includes more than 100 titles.

Systematic reading of worth while books adds breadth and vision to the background of an engineer and should be considered a part of the intellectual development designed to fit the young engineer for full professional recognition. It is suggested that over a period of about 4 years a minimum of about 25 of these books might be selected and read, with the limiting recommendation that the selection made will include at least one book in each classification, preferably in accord with the individual engineer's most vital interests.

Economics and Sociology

Mexico: A Study of the Two Americas, Stuart Chase. Macmillan, 1931. A thought-provoking contrast between 2 civilizations—the one based on handcraft and the other on machines.

Guide Through World Chaos, G. D. H. Cole. Knopf, 1932. Survey of world crisis and its background of war conditions and in the light of capitalism of past 2 centuries. Valuable material for discussion of communism and capitalism.

Introduction to Sociology, Carl Dawson and Warner Gettys. Ronald Press, 1929. Statement of fundamental sociological principles. Many concretely described social situations relating to urban life and economic activities.

Causes of Industrial Unrest, J. A. Fitch. Harper, 1924. Judicial consideration of prevailing conditions and phenomena which cause and contribute to industrial unrest, but makes no attempt at a solution.

Taming Our Machines, R. E. Flanders. R. R. Smith, 1931. Attainment of human values in a mechanized society. Written in popular manner—clear and simple. A fresh view of the world's present troubles.

Economic Stabilization in an Unbalanced World, A. H. Hansen. Harcourt, Brace, 1931. Treats: 1, international causes of instability; 2, causes of world-wide unemployment; 3, population stabilization; 4, discussion of value of possible or desirable stabilized capitalism.

Economic History of the United States, E. F. Humphrey. Century, 1931. Narrative of economic development of United States, for purpose of discovering conditions of today from a record of country's growth.

Constructive Citizenship, L. P. Jacks. Doubleday, Doran, 1928. He has "brought into captivity many ideas which have waged a solitary fight in isolated places, and has regimented them into such shape that they deal a smashing blow against mechanical schemes of social deliverance."

Man's Rough Road, A. G. Keller. Yale University Press, 1932. A study of age-old institutions—property, religion, and marriage, especially in primitive manifestation. Condensation of a 4-volume work.

Industrial Economics, Dexter S. Kimball. McGraw-Hill, 1929. Discussion of industrial history, the high lights of which are handcraft production, the industrial revolution, and the effect of mechanical inventions. This is followed by a discussion of major topics, such as, division of labor, production economics, management principles, etc.

Middletown: A Study in Contemporary American Culture, R. S. and H. M. Lynd. Harcourt, Brace, 1929. A painstakingly statistical, yet sympathetic appraisal of a typical small city.

The Meaning of a Liberal Education, Everett Dean Martin. Norton, 1926. Discusses what education is, and is not; condemns utilitarian aim so prevalent today, and pleads for education which will reveal spiritual values of life.

Capital, Karl Marx. Kerr, 1919. A critique of political economy. Written originally to make plain the fallacy of capitalistic economy, and is still held to be the source from which anti-capitalistic movements draw their constructive power.

Principles of Political Economy, With Some of Their Applications to Social Philosophy, J. S. Mill. Appleton, 1898. Abridged edition, with critical, bibliographical and explanatory notes and a sketch of the history of political economy, by J. L. Laughlin.

Economic Tendencies in the United States, F. C. Mills. Little, Ives, 1932. Statistical study from 1900 to 1929 of economic conditions.

Readings in the History of Economic Thought, S. H. Patterson. McGraw-Hill, 1932. Selected readings omitting recent ideas. Arranged by schools of thought from times of earliest expositions of economics down to neo-classicism. Stresses minor rather than major orthodoxies.

Recovery: The Second Effort, Sir Arthur Salter. Century, 1932. Analyzes the broad causes which have brought the world into the present state of distress and indicates new requirements, economic, financial, commercial, and political, upon which to base a new world order.

America Comes of Age; a French Analysis, Andre Siegfried. Harcourt, Brace, 1927. Analysis, by a keen observer, of our ethnic, economic, and political situation. Displays extraordinary insight into the characteristics of American civilization.

Wealth of Nations, Adam Smith. Putnam, 1904. Inquiries into the nature and cause of wealth of nations. A landmark in history of thought, but parts are now out of date.

A Planned Society, George Soule. Macmillan, 1932. Critical analyses of our present unmanaged civilization, followed by an attempt to build up case for economic planning. Informed and well-balanced discussion of need for social plan.

Industrial Discipline and the Governmental Arts, R. G. Tugwell. Columbia University Press, 1933. An economist's picture of the social machine guided by government to achieve more perfect adaptation to machine society.

Bliss says, are to represent all the important engineering bodies in the country.

The plans for the campaign call for a national campaign committee, and local committees for each of 12 industrial centers. National committee headquarters have been established in the Engineering Societies' Building at 29 West 39th Street, New York, N. Y.

Japanese Government Bestows Honors. Clark H. Minor, president of the International General Electric Company, and Dr. Irving Langmuir, associate director of the research laboratory of the General Electric Company at Schenectady, N. Y., have recently been awarded the Fourth Order of the Rising Sun by the Japanese government. Doctor Langmuir has also been elected an honorary member of the Institute of Electrical Engineers of Japan, as reported in ELECTRICAL ENGINEERING for January 1934, pages 129–30.

A.I.M.E. Elects Officers. Election of officers for the American Institute of Mining and Metallurgical Engineers for the coming year was made during the recent A.I.M.E. convention held in New York, N. Y., Feb. 18–21, 1935. The individuals elected took office on February 19. H. A. Buehler, a geologist, was elected for the office of president. John M. Lovejoy, president of the Seaboard Oil Company, and Paul D. Merica, of the International Nickel Company were elected as vice presidents. As directors of the A.I.M.E., the following were elected: C. K. Leith, chairman of the department of geology at the University of Wisconsin, Madison; Edwin E. Ellis, vice president of the U.S. Steel Corporation in charge of mining, raw materials, and lake shipping; Wilber Judson, vice president of the Texas Gulf Sulphur Company; Ralph M. Roosevelt, vice president of the Eagle Picher Lead Company; and Wilfred Sykes (A'09, F'14) assistant to the president in charge of operation for the Inland Steel Company.

Electrochemical Society to Meet. The spring meeting of the Electrochemical Society will be held March 21–23, 1935, at New Orleans, La. Requests for information regarding this meeting should be addressed to Mr. Colin G. Fink, secretary of the society, in care of Columbia University, New York, N. Y.

Bulletin on Unbalance in A-C Machines. A study of the operating conditions of a-c machinery when operating under a partial or full load, entitled, "Unbalance in Alternating Current Machines," by DR. E. M. SABBAGH (A'28), of the Purdue University school of electrical engineering, has been published in bulletin form recently by the Purdue Engineering Experiment Station. The study is the result of a long and theoretical investigation confirmed by experimental test results of practical conditions of operation. The comparatively recently developed method known as symmetrical components has been applied by Doctor Sabbagh to the analysis of a-c machinery when operating under normal loads. This analysis points out the conditions of limiting loads and voltage regulation under operating conditions which, although abnormal, are often met in practice. Copies of the bulletin may be obtained by writing to the Purdue University Engineering Experiment Station, Lafayette, Ind.

Consulting Engineer and Former Professor Dies. Harry de Berkeley Parsons, consulting engineer of New York, N. Y., died January 26, 1935. He had been professor of steam engineering at Rensselaer Polytechnic Institute from 1891 to 1907. Mr. Parsons was born at New York, and received the degrees of bachelor of science from Columbia University in 1882 and mechanical engineer from Stevens Institute of Technology in 1884. After several years of railroad engineering in Texas he entered the field of mechanical engineering and for 16 years was at Rensselaer Institute, leaving with the title of professor emeritus of practical engineering. As a private consultant he served New York City on street cleaning and waste disposal problems, and was chairman of the commission on street cleaning and waste disposal and a member of the metropolitan sewerage commission 1908–1914. Mr Parsons was president of the Institute of Consulting Engineers in 1926, and a member of the American Society of Civil Engineers. In 1925 he was awarded the Rowland prize, and in 1930 the Croes medal.

Dean Ketchum Dies. Milo S. Ketchum, former director and vice president of the American Society of Civil Engineers, past president of the Society for the Promotion of Engineering Education, and dean of engineering at the college of engineering, University of Illinois since 1922 (emeritus since 1933) died in Urbana, Ill., December 19, 1934, at the age of 63. A native of Illinois, he graduated from the University of Illinois in 1895, took his civil engineering degree in 1896. His career as an engineering teacher began at the University of Illinois immediately after his graduation where he served as a faculty member from 1895 to 1897, again from 1899 to 1903, and finally from 1922 to the time of his death. With the intervening years spent in field service as a bridge and structural engineer, Dean Ketchum was professor of civil engineering at the University of Colorado from 1904 to 1905, dean of his department from 1905 to 1919; he was professor of civil engineering at the University of Pennsylvania from 1919 to 1922. Dean Ketchum was a prolific technical writer on civil engineering subjects.

Construction Camps for the Grand Coulee Project

GENERAL view of Coulee City, the government camp site which will house the men and their families who will construct the PWA irrigation dam and power plant of the Grand Coulee project in the Columbia River basin, Wash. Across the river can be seen Mason City, the contractor's town site. The construction railroad connecting the Northern Pacific Railroad with the dam site has been completed, and work on the dam and power plant is being carried forward under the contract awarded last fall. It is reported that this project will cost $63,000,000, the Public Works Administration having made an initial allotment of $15,000,000 to carry on the work.

Municipal Engineers and Public Works Officials Establish Joint Organizations. A policy of expanded service to members of the engineering and public works professions was recently announced by the American Society of Municipal Engineers and the International Association of Public Works Officials, upon the establishment in Chicago, Ill., of a joint secretariat for the 2 organizations. The secretariat will be administered by a joint board of 4 members from each association, with Donald C. Stone as executive director. It is planned to make available to member municipal engineers and public works officials a clearing house of information on their current problems and to perform various other services to aid them in their profession of municipal service. Local, state, and regional chapters to encourage coöperation of public works officials within an area will be fostered by the association. The first joint annual conference of members of the 2 societies, which have a total membership of 1,000 is scheduled for Cincinnati, Ohio, during October 1935.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part; or to reject them entirely.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

CORRECTION—Figure 1 of the "Letters to the Editor" by David J. Ball entitled "Graphical Solution of Star-Delta Transformations" in the December 1934 issue of ELECTRICAL ENGINEERING, page 1680, is in error in that y_C should have been extended to the next lower dashed line; the distance which y_C should extend is indicated correctly in figure 2 on the same page.

Regarding the practical use of this graphical solution, the author states that the greatest advantage over a purely mathematical solution results when the diagram is constructed on "polar coördinate graph paper with a triangle as the only instrument, reading the required values directly from the paper without the use of a scale. If necessary, a special graph paper can be constructed consisting of concentric circles and vertical lines with a rigid arm rotating about the center to indicate various radii as they are required in reading the graph. With a device of this sort a solution may be obtained from the graph with no actual construction work and with approximately the same ease as is obtained in reading a curve.

Mapping of Fields

To the Editor:

The following refers to the "Letters to the Editor" by J. F. Calvert and L. A. Kilgore (see ELECTRICAL ENGINEERING, February 1935, pages 253–4) discussing the paper "Mapping of Fields" by Ernst Weber, which appeared in ELECTRICAL ENGINEERING for December 1934, pages 1563–70.

Mr. Calvert has worked extensively in the development and application of the semi-graphical methods of field mapping and any contribution on his part is, therefore, to be highly appreciated. As I stated in the last paragraph of the section on "Graphical and Semigraphical Mapping" (page 1565 of the December 1934 issue), these "methods are of utmost value in all design problems. . . . ." but they have their limitations. As I had worked rather extensively at the Siemens-Schuckert Company in this particular field I had more than one opportunity to long for a general mathematical solution from which general conclusions might be drawn, especially in the case of commutation of large d-c machines, a-c machines, and the pole form and leakage flux evaluations of large a-c generators. I may recall at this point the simple formulas, used in transformer leakage, slot, tooth, and end leakage of machines, which had been derived once with high rigor and simplified by practical experience until now there is hardly need for graphical detail work. The other more complex problems are as yet in the preliminary stage of graphics. If more use were made of mathematical mapping, probably some ambitious younger engineer would sit down and develop a few fundamental formulas which, with at least the same degree of approximation, could replace months of graphical work. With this I do not want to discredit graphical mapping at all—only to indicate future developments and to justify the stress laid in my paper upon the less known methods and their possibilities. As Mr. Calvert indicated in his last paragraph, only when mathematical detail work can be omitted is there assured wide application of a method. So also for mathematical mapping of fields. Once the formulas have been developed there should be no need for mathematical or graphical detail work and consequently more economy in design would take place, which is rather important because relatively few designs are ever actually carried out in practice.

The additions to the bibliography by Mr. Kilgore are extremely helpful to the student of graphical methods. There are, in fact, numerous papers and discussions in all periodicals of the civilized countries dealing with graphical mapping in all fields of engineering. I did not feel justified to take up much space with a method as well developed as the graphical mapping but did want to call attention to the originators of this method since the textbook by S. S. Atwood on "Electric and Magnetic Fields" gives a rather extensive modern presentation of the principles. Unfortunately, this book, as so many "textbooks," does not give any references.

Very truly yours,
ERNST WEBER (A'31)
(Research Prof. of Elec. Engg., Brooklyn (N. Y.) Polytechnic Institute)

Overcompounded D-C Generators in Parallel Without an Equalizer

To the Editor:

The renewed interest in the problem of the operation of 2 overcompounded d-c generators in parallel without an equalizer, promps us to submit a résumé of our paper which was presented at the A.I.E.E. student convention, New York Section, on April 26, 1934. (Previous "Letters to the Editor" on this subject have appeared in ELECTRICAL ENGINEERING as follows: by J. G. Brainerd, volume 51, October 1932, page 745; by O. W. Walter, volume 53, November 1934, pages 1553–4; by J. G. Brainerd, volume 54, January 1935, page 135; and by J. O. Reid, this issue, pages 348–9.

Doctor Pender, in his text "Direct Current Machinery," states that if the speed of one of the generators should increase slightly, due to any cause, thereby giving that generator a higher regulation curve,

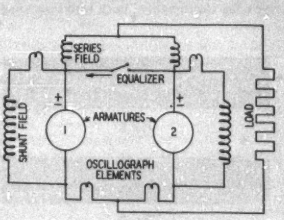

Fig. 1

the current output of that machine would decrease. Evidently those who oppose this statement have not offered sufficient evidence to either prove or disprove the argument of Doctor Pender and his associate, Professor Brainerd.

Keeping in mind the fact that Doctor Pender specifies variable speed as one of the requirements of the test, we first determined the other variables influencing the instability by coupling both generators to the shaft of a synchronous motor.

Connecting the 2 generators with their series fields to the positive side of their respective armatures (figure 1), the field currents of each machine were so adjusted that the equalizer current flowed from machine 2 to machine 1. Upon opening the equalizer bus, the equalizer component of the armature current of machine 2 is made to flow through its series field in the same

direction as the line current flows in the steady state. Thus, this increased current must strengthen the series field, resulting in an increased induced electromotive force. On the other hand, the current through the series field of machine 1 is decreased, causing a proportionate decrease in its electromotive force. The difference between the electromotive forces of the machines causes a current to circulate in a counterclockwise direction, further increasing the induced electromotive force of machine 2, and decreasing the electromotive force of machine 1. This obviously results in a larger circulating current. The action is thus cumulative, causing machine 2, the machine with the greater electromotive force, to take all of the load and perhaps drive machine 1 as a motor. The oscillogram (figure 2), clearly shows the transient condition which exists. Upon opening the equalizer, the current I_3 increases and the current I_1 decreases. The equalizer bus was closed before the line circuit breakers opened and all steady state values were resumed. When the equalizer current was made to flow in the opposite direction, from machine 1 to machine 2, the generator which formerly took the greater load now lost it; the machine which previously surrendered now assumed the load (figure 3). Therefore the results show that if the series fields are connected to the positive side of their respective armatures, the current in the equalizer will flow away from the machine which would take the load if the equalizer were opened. By similar reasoning it can be readily seen that if the series fields are connected to the negative armature terminals, the equalizer current will flow toward the machine which would take the load. The explanation of an increasing electromotive force with increasing

Fig. 2

Fig. 3

load is the analysis to which Professor Walter referred, November 1934 issue of ELECTRICAL ENGINEERING, page 1553, when he stated that our views were contrary to those of Doctor Pender.

Another important observation that was made with the generators still connected to the synchronous motor was the relationship between the line and field currents of both machines. Reconsider the case where generator 2 takes the load. With the equalizer closed, the direction of the currents in the shunt and series fields and the resultant flux ϕ_f, are as indicated in figure 4. When the equalizer bus is opened, the current through the series field rises at an increasing rate, because of the cumulative action of the system. The resulting flux in the field poles increases, inducing an electromotive force in the series and shunt field windings. This induced electromotive force in the shunt field winding opposes the normal flow of shunt field current. Since the electromotive force varies at an increasing rate, the resultant shunt field current must decrease proportionately, even though the load taken by this machine increases (figure 5). Similarly, it was found that the shunt field current of the machine which loses the load increases cumulatively.

In order to determine the effect of variable speed, as required by Doctor Pender, the generators were removed from the shaft of the synchronous motor and were driven by independent prime movers. Under these conditions, oscillograms of speed and line current of each of the machines were taken. From the oscillograms it was observed that the variations of the speed and

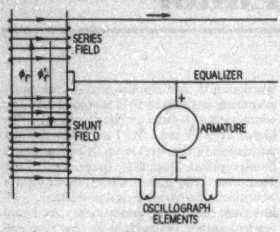

Fig. 4

line current of each generator were in direct agreement with those obtained by Professor Brainerd, October 1932 issue of ELECTRICAL ENGINEERING, page 745. Since the prime movers had a drooping speed-torque characteristic, it had to follow that the generator which took the load caused its prime mover to provide a greater torque which, naturally, decreased the speed of that machine. Conversely, the generator that surrendered the load was driven at a higher speed. Although these last tests were made using separate prime movers, the direction of flow of the equalizer current and the sides of the armatures to which the series fields were connected had the same effect upon the distribution of the load between the generators as for the condition with constant speed. It was also noted that the variations of the field and line currents were qualitatively the same for both cases.

On first thought, our 2 sets of results may seem to be contradictory, but upon further analysis they will be shown to be complementary. Under the initial condition (constant speed) we showed that the machine which took the load had an increasing electromotive force; while under the second condition (variable speed) we showed that the speed of the machine which took the load decreased. In both tests, the distribution of the load between the 2 generators was found to depend *only* upon the direction of flow of the equalizer current and the sides of the armatures to which the series fields were connected. It therefore follows that in the second case the machine which took the load had an increasing electromotive force as well as a decreasing speed. Conversely, the generator which lost the load had a decreasing electromotive force and an increasing speed. Since it has been shown that the induced electromotive force

Fig. 5

of the generator that takes the load increases cumulatively, it must be concluded that the increasing electromotive force due to the series field more than overcomes the tendency to decrease that electromotive force which results from the decreasing speed. Even if the series fields were weakened, the results would still be the same. The limiting condition occurs when the generators become undercompounded, in which case the system is stable.

A tabulation of the results, outlined in the foregoing paragraphs, indicates that,

First: Except in the case where zero equalizer current could be constantly maintained, overcompounded generators in parallel are unstable without an equalizer.

Second: Whether a generator will lose the load or take it is dependent only upon the direction of flow of the equalizer current and the polarity of the armature terminal to which its series field is connected.

Third: The effect of the series field in increasing the induced electromotive force, when one of the generators takes the load, more than overbalances the combined tendency to reduce that electromotive force because of a decreased speed and field current.

In attempting to find a theoretical reason that would agree with all of our experimental data, it was found necessary to advance explanations for some conditions which were found to exist but which were not heretofore mentioned in any of the previous discussions.

We hope that this explanation of the problem will help clear up the difficulties which have arisen in its solution.

Very truly yours,

ERIC H. NELSON (Enrolled Student) (55 West 184th St., New York, N. Y.)

SIDNEY ROCK (Enrolled Student) (317 East 178th St., New York, N. Y.)

To the Editor:

Within the last few months there have appeared in ELECTRICAL ENGINEERING letters concerned with the question of the parallel operation of overcompounded d-c generators. These letters seem to leave the matter in some confusion, which I hope the following lines may serve to clarify. (Previous "Letters to the Editor" on this subject have appeared in ELECTRICAL ENGINEERING as follows: by J. G. Brainerd, volume 51, October 1932, page 745; by O. W. Walter, volume 53, November 1934, pages 1553–4; by J. G. Brainerd, volume 54, January 1935, page 135; and by E. H. Nelson and Sidney Rock, this issue, pages 347–8.

The subject which has been under discussion is that of the behavior of overcompounded d-c generators when operated in parallel without an equalizer. It is common knowledge that a condition of unstable equilibrium will exist under such circumstances unless the speed-load characteristics

of the prime movers are more drooping than voltage-load characteristics of the generators are rising. It is axiomatic that if this condition does exist, a small increment to the load of one machine at the expense of the other will precipitate a general transfer of load to the first machine.

Such a transfer may be caused by a momentary increase or decrease of the power input to either prime mover. If an increase, the terminal voltage of the machine will rise due to its momentarily greater speed, it will take additional load, and a general transfer to it will follow, during which the speeds of both machines will be determined by the speed-load characteristics of their prime movers. If a decrease, the terminal voltage of the machine will fall and it will lose its load.

The ultimate cause of the upsetting of balance may not be speed variation, but the variation of some other factor such as field strength. In any case the resulting unbalance of terminal voltage will cause a transfer of load to the generator of higher voltage.

It is seen that a continuous decrease in speed accompanies gain of load; a continuous increase, loss of load. (A drooping speed characteristic is assumed.) However, if the transfer is the result of a momentary speed variation, this variation will be in the opposite direction from that resulting from the load transfer.

In closing I refer to Dr. Harold Pender's discussion in his book "Direct-Current Machinery." As I interpret his reasoning, he gives as the original cause of loss of load an increase of speed, which is very wrong. Such an increase in speed must be followed by an increase in load. No other result is possible.

Very truly yours,

John O. Reid (A'34)
(51 Cleveland Terrace,
East Orange, New Jersey)

Accounting and Engineering

To the Editor:

Speaking of "more and better apples"—I refer to J. Allen Johnson's "A Message From the President" printed in the August 1934 issue of Electrical Engineering, page 1142—it may seem a far cry from accounting to engineering; but I'll hazard the prognostication that the "economic advancement" of engineers, emphasized by President Johnson, is bound up inextricably with accounting considerations.

From this assumption directly flows the conclusion that engineers ought to be personally interested in accounting. Accounting represents, in point of fact, the economic aspect of their professional careers. And I find that engineers are interested when they bother to think about accounting at all.

Once engineers advance in understanding beyond the idea that accounting is arithmetic merely and think of accounting as coextensive with organization, economic organization, which hits them every day at every turn, they do become interested in accounting.

Accounting, in its present state of development, is one half of something. The other half of this something is the engineering, or scientific, outlook upon the physical apparatus upon which all of us are dependent for our economic well being. The name of this something is not yet very definite: cost engineering fits it better perhaps than rationalization, or "technocracy," or even scientific management. The name is of little moment as compared with the large responsibility which faces engineering and accounting. These fields of professional activity must coalesce along their borders where this "something" is sprouting.

Very truly yours,

Leo J. Richards (A'34)
(2818 Shasta Road,
Berkeley, Calif.)

Calculation of Induced Bus Bar Currents

To the Editor:

The paper on "A 7000-Ampere Station Bus" by H. L. Unland, W. B. Morton, and V. R. Bacon in Electrical Engineering, June, 1934, pages 994–1004, presented very interesting 3-phase test results. One phenomenon observed was that when the 3-phase bus crossed a steel beam, the hottest spot in the beam was under one of the outer conductors and when the phase rotation was changed the hottest spot was under the other outer conductor. This condition was illustrated and calculated by the writer. (See discussion, Electrical Engineering, December 1934, pages 1646–7.)

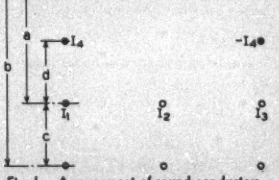

Fig. 1. Arrangement of round conductors

Although the smallest amount of watts might be produced under the central conductor, that need not necessarily be the coolest of the 3 hot spots on the steel beam, since the center one received heat by conduction along the beam from the 2 hot spots which surrounded it.

The calculation on page 1646 did not apply, as mentioned in the discussion by V. R. Bacon, to the test in which a copper plate was interposed between the 3-phase bus and the steel beam, resulting in the hottest spot being changed from one side to the other without the phase rotation being changed. It appears, however, that a similar calculation with round conductors can be made to illustrate this phenomenon also.

Assume the same arrangement of round conductors as on page 1647 and in addition 2 one-inch copper rods forming a short-circuited loop carrying I_4, all as shown in figure 1 of this letter. The lower pairs each form short-circuited loops. The resistance of the rods in these lower loops is R and that of the rods carrying I_4 is R', in abohms per centimeter. The radius of the rods in all the loops is r.

Let the power currents be

$$I_A = (-0.5 + j\,0.866)\,I$$
$$I_B = I$$
$$I_C = (-0.5 - j\,0.866)\,I$$

Taking voltages in the loop carrying I_4 and dividing by $j\omega$,

$$I_A \log_n \frac{4s^2 + (a-d)^2}{(a-d)^2} - I_C \log_n \frac{4s^2 + (a-d)^2}{(a-d)^2} + 2I_4\left(\frac{R'}{j\omega} + \log_n \frac{4s^2}{r^2}\right) + I_1 \log_n \frac{(c+d)^2}{d^2} - I_1 \log_n \frac{4s^2 + (c+d)^2}{4s^2 + d^2} + I_3 \log_n \frac{4s^2 + (c+d)^2}{4s^2 + d^2} - I_3 \log_n \frac{(c+d)^2}{d^2} = 0 \qquad (1)$$

Taking voltages in the loop carrying I_1,

$$I_A \log_n \frac{b^2}{a^2} + I_B \log_n \frac{s^2 + b^2}{s^2 + a^2} + I_c \log_n \frac{4s^2 + b^2}{4s^2 + a^2} + I_4 \log_n \frac{(c+d)^2}{d^2} - I_4 \log_n \frac{4s^2 + (c+d)^2}{4s^2 + d^2} + 2I_1\left(\frac{R}{j\omega} + \log_n \frac{c^2}{r^2}\right) + 2I_3 \log_n \frac{s^2 + c^2}{s^2} + 2I_3 \log_n \frac{4s^2 + c^2}{4s^2} = 0 \qquad (2)$$

These equations and 2 similar ones for the other loops give the loop currents in terms of I.

Let $a = 8$ inches, $b = 12$ inches, $c = 4$ inches, $d = 4$ inches, $r = 0.5$ inch, $s = 5$ inches, frequency $= 60$ cycles, and the conductivity of the conductors in the 3 lower loops $= 20$ per cent of that of copper at 20 degrees centigrade.

$$j\,3.43\,I + (11.98 - j\,1.80)\,I_4 + 1.040\,I_1 - 1.040\,I_4 = 0 \qquad (3)$$

$$(0.0372 + j\,0.358)\,I + 1.040\,I_4 + (8.32 - j\,9.02)\,I_1 + 0.989\,I_2 + 0.297\,I_3 = 0 \qquad (4)$$

$$0.1697\,I + 0.989\,I_1 + (8.32 - j\,9.02)\,I_2 + 0.989\,I_3 = 0 \qquad (5)$$

$$(0.0372 - j\,0.358)\,I - 1.040\,I_4 + 0.297\,I_1 + 0.989\,I_2 + (8.32 - j\,9.02)\,I_3 = 0 \qquad (6)$$

Then

$|I_1| = 0.0075\,I$, and $|I_3| = 0.0066\,I$.

It is seen that I_1 is larger than I_3 whereas before the interposition of the loop carrying I_4 which represents the copper plate, I_1 was 6 per cent smaller than I_3, as given on page 1646.

The size of the $^5/_8$ inch air gap between the 2 parts of the square conductor shown in figure 1 of the paper on page 994 is of considerable importance, as stated in the discussions by F. R. Dallye and O. R. Schurig. If this gap were enlarged a little, the copper loss in the metal close to the gap would be larger, but it would be very little altered in the greater part of the conductor.

However, the volume of air rising through the gaps and therefore the convection of heat would probably be changed by a considerable percentage. The relative amounts could be determined only by test. Probably curves of temperature rise plotted on air-gap width, for 5,000, 6,000, and 7,000 amperes, would give the required information in the most convenient form, so that the most advisable size of air gap could be selected.

Similar curves showing the effect of variation in the ratio of depth to breadth of the channels would also be very valuable and might result in savings of space and metal.

If the bus conductors are to be lacquered or painted when in operation, that should be done before testing, as it changes the radiation constant and assists the dissipation of heat.

Very truly yours,

H. B. Dwight (A'11, F'26)
(Professor of Elec. Machinery, Massachusetts Institute of Technology Cambridge)

Loading a Bank of Dissimilar Transformers

To the Editor:

The writers were interested to learn that a problem which they had considered as having mainly academic interest is also of sufficient practical importance to warrant the publication of the paper by J. A. Bock on "Loading a Bank of Dissimilar Transformers." (See Electrical Engineering for December 1934, pages 1597–8.) The paper gives equations for determining the performance of 3 dissimilar single-phase transformers connected to form a delta-delta bank. The transformers may have different impedances and voltage ratios.

Since the problem is essentially one of an unbalanced 3 phase circuit the method of symmetrical components (see "Symmetrical Components," by C. F. Wagner and R. D. Evans, published by the McGraw-Hill Book Company) should provide a convenient solution. This proves to be the case, as is shown in the following discussion.

Let

$\bar{I}_0, \bar{I}_1, \bar{I}_2$ = respectively, the zero sequence positive sequence, and negative sequence components of the transformer secondary currents

$\bar{E}_1, \bar{E}_2$ = symmetrical components of the secondary terminal voltages

$\bar{E}_1', \bar{E}_2'$ = symmetrical components of the primary terminal voltages

$\bar{Z}_0, \bar{Z}_1, \bar{Z}_2$ = symmetrical components of the transformer impedances, referred to the secondary sides

These are all vector quantities and are all referred to phase A.

Since the voltage ratios N_A, N_B, and N_C may be unequal, the ratio N_A can be resolved into its symmetrical components $\bar{N}_0$, $\bar{N}_1$, and $\bar{N}_2$, by means of the same well-known relations which are used to resolve impedances, currents, voltages, etc., into symmetrical components. This is a logical but novel idea.

To one familiar with the method of symmetrical components, it is at once apparent that the following 3 vector equations can be set down:

$$\bar{E}_1 = \bar{N}_0\bar{E}_1' + \bar{N}_1\bar{E}_2' - \bar{I}_0\bar{Z}_1 - \bar{I}_1\bar{Z}_0 - \bar{I}_2\bar{Z}_2 \quad (1)$$

$$\bar{E}_2 = \bar{N}_1\bar{E}_1' + \bar{N}_0\bar{E}_2' - \bar{I}_0\bar{Z}_2 - \bar{I}_1\bar{Z}_1 - \bar{I}_2\bar{Z}_0 \quad (2)$$

$$0 = \bar{N}_2\bar{E}_1' + \bar{N}_1\bar{E}_2' - \bar{I}_0\bar{Z}_0 - \bar{I}_1\bar{Z}_2 - \bar{I}_2\bar{Z}_1 \quad (3)$$

These equations result from the substitution of the symmetrical components in equations 4, 6, 8, and 10 of Bock's paper.

If we assume, as in Bock's paper, that the primary line voltages and the secondary line currents are balanced, then:

$$\bar{E}_1' = \bar{E}_A' \quad \bar{E}_2' = 0, \bar{I}_2 = 0$$

and hence, from equation 3:

$$\bar{I}_0 = \frac{\bar{N}_2\bar{E}_A' - \bar{I}_1\bar{Z}_2}{\bar{Z}_0} \quad (4)$$

Equation 4 serves the same purpose as equation 11 of Bock's paper. By means of equation 4 we can calculate $\bar{I}_0$ when $\bar{E}_A'$ and $\bar{I}_1$ are given. Knowing $\bar{I}_0$ and $\bar{I}_1$, the actual currents in the secondary windings can be calculated by the well-known rules of the method of symmetrical components. The symmetrical components of the secondary terminal voltages can be calculated from equations 1 and 2.

If required, the symmetrical components $\bar{I}_0'$, $\bar{I}_1'$ and $\bar{I}_2'$ of the primary winding currents can be calculated from the following equations:

$$\bar{I}_0' = \bar{I}_0\bar{N}_0 + \bar{I}_1\bar{N}_2 + \bar{I}_2\bar{N}_1 \quad (5)$$

$$\bar{I}_1' = \bar{I}_0\bar{N}_1 + \bar{I}_1\bar{N}_0 + \bar{I}_2\bar{N}_2 \quad (6)$$

$$\bar{I}_2' = \bar{I}_0\bar{N}_2 + \bar{I}_1\bar{N}_1 + \bar{I}_2\bar{N}_0 \quad (7)$$

For the particular case considered in Bock's paper, $\bar{I}_2 = 0$. However, this does not mean that $\bar{I}_2' = 0$. Because of the unequal voltage ratios of the 3 transformers, negative sequence current will flow in the primary windings even when no negative sequence current is present in the secondaries.

Example 1

The data are as given in Bock's paper.

$\bar{Z}_A = 0.0290 + j\,0.0983$

$\bar{Z}_B = \bar{Z}_C = 0.0328 + j\,0.2275$

$\bar{N}_A = 0.0667$

$\bar{N}_B = \bar{N}_C = 0.0697$

By the method of symmetrical components:

$$\bar{N}_0 = \frac{1}{3}(N_A + N_B + N_C) = 0.0687 + j_0$$

$$\bar{N}_1 = \frac{1}{3}(N_A + \alpha N_B + \alpha^2 N_C), \text{ and}$$

$$\bar{N}_2 = \frac{1}{3}(N_A + \alpha^2 N_B + \alpha N_C)$$

where $\alpha = -0.5 + j\,0.866$, and $\alpha^2 = -0.5 - j\,0.866$.

Since $N_B = N_C$,

$$\bar{N}_1 = \bar{N}_2 = \frac{1}{3}(N_A - N_B) = -0.0010 + j\,0$$

Also

$\bar{Z}_0 = 0.0315 + j\,0.1844$

Since $\bar{Z}_B = \bar{Z}_C$,

$\bar{Z}_1 = \bar{Z}_2 = -0.0013 - j\,0.0431$

Let $\bar{E}_A' = 33{,}000 + j\,0$, and $\bar{I}_1 = 455(0.8 - j\,0.6)$, as in Bock's paper.

Substituting in equation 4 gives $\bar{I}_0 = 62 + j\,123$. Hence, by the method of symmetrical components:

$$\bar{I}_A = \bar{I}_0 + \bar{I}_1 = 426 - j\,150$$

$$\bar{I}_B = \bar{I}_0 + \alpha^2\bar{I}_1 = -356 - j\,55$$

$$\bar{I}_C = \bar{I}_0 + \alpha\bar{I}_1 = 117 + j\,575$$

These results check Bock's to within slide rule accuracy.

The symmetrical components of the secondary terminal voltages can be calculated from equations 1 and 2, giving:

$$\bar{E}_1 = 2198 - j\,56, \bar{E}_2 = -26 + j\,18$$

The following problem is an interesting extension of the simple case discussed in Bock's paper, and one which can only be solved by the method of symmetrical components. Consider an unsymmetrical delta-delta connected transformer bank supplying power to an induction motor which we shall also consider as delta connected. At the slip at which the induction motor is operating, its impedances to positive sequence and negative sequence currents are, respectively, $\bar{Z}_{m1}$ and $\bar{Z}_{m2}$ ohms per phase, delta. Neglect the impedance of the feeder connecting the motor to the transformers. Then

$$\bar{E}_1 = \bar{I}_1\bar{Z}_{m1} \quad \bar{E}_2 = \bar{I}_2\bar{Z}_{m2}$$

Hence, from equations 1, 2, and 3:

$$\bar{N}_0\bar{E}_1' + \bar{N}_1\bar{E}_2' = \bar{I}_0\bar{Z}_1 + \bar{I}_1(\bar{Z}_0 + \bar{Z}_{m1}) + \bar{I}_2\bar{Z}_2 \quad (8)$$

$$\bar{N}_1\bar{E}_1' + \bar{N}_0\bar{E}_2' = \bar{I}_0\bar{Z}_2 + \bar{I}_1\bar{Z}_1 + \bar{I}_2(\bar{Z}_0 + \bar{Z}_{m2}) \quad (9)$$

$$\bar{N}_2\bar{E}_1' + \bar{N}_1\bar{E}_2' = \bar{I}_0\bar{Z}_0 + \bar{I}_1\bar{Z}_2 + \bar{I}_2\bar{Z}_1 \quad (10)$$

If the primary voltages are known, these 3 equations can be solved simultaneously for the symmetrical components of the transformer secondary currents. The exact solution is rather awkward to handle.

Let us assume that the primary voltages are balanced. Then $\bar{E}_2' = 0$. In any practical case, the term $\bar{I}_1(\bar{Z}_0 + \bar{Z}_{m1})$ will be by far the largest of the 3 terms on the right-hand side of equation 8. Hence, very nearly,

$$\bar{I}_1 = \frac{\bar{N}_0\bar{E}_A'}{\bar{Z}_0 + \bar{Z}_{m1}} \quad (11)$$

That is, there is little error in computing the positive sequence current as if the transformer bank were balanced and each transformer had an impedance and ratio of transformation equal to the average values of these quantities.

Knowing $\bar{I}_1$ we can now solve equations 9 and 10 simultaneously for $\bar{I}_0$ and $\bar{I}_2$. If we assume, as in Bock's example, that the B and C transformers are alike, then, as shown in example 1 of this discussion, $\bar{N}_1 = \bar{N}_2$ and $\bar{Z}_1 = \bar{Z}_2$, and the approximate values of $\bar{I}_0$ and $\bar{I}_2$ are

$$\bar{I}_0 = \frac{(\bar{N}_1\bar{E}_A' - \bar{I}_1\bar{Z}_1)(\bar{Z}_0 - Z_1 + Z_{m2})}{\bar{Z}_0(\bar{Z}_0 + \bar{Z}_{m2}) - \bar{Z}^2_1} \quad (12)$$

$$\bar{I}_2 = \frac{(\bar{N}_1\bar{E}_A' - \bar{I}_1\bar{Z}_1)(\bar{Z}_0 - \bar{Z}_1)}{\bar{Z}_0(\bar{Z}_0 + \bar{Z}_{m2}) - \bar{Z}^2_1} \quad (13)$$

In a typical case, the error in this approximate solution was found to be less than one per cent.

Very truly yours,

Waldo V. Lyon (A'07, F'33)
Charles Kingsley, Jr. (A'30)
(Both of Massachusetts Institute of Technology, Cambridge)

First Electric Street Railway

To the Editor:

In response to your inquiry in the "Letters to the Editor" columns of the February 1935 issue of ELECTRICAL ENGINEERING under "First Electric Street Railway," I desire to call the attention of our sister state of Vermont to the fact that she should be celebrating the centenary of the electric railway, born in the year 1835 in the village of Brandon, Vt.

One Thomas Davenport, village blacksmith, was sponsor. In the Davenport model, motors were driven with current supplied by primary batteries carried on the car. Following Davenport were Robert Davidson, of Aberdeen, Scotland; Prof. C. G. Page, of the Smithsonian Institute at Washington, D. C., and others. All of these experiments were given up on account of the excessive cost of batteries as a source of electrical energy used on the locomotive principle.

In 1847, Prof. Moses G. Farmer operated a small experimental model of an electric car at Dover, N. H., and during 1850–51, aided by Thomas Hall, he exhibited in Boston a model road on which a car ran back and forth, and automatically reversed its direction of motion at each end of the road.

This was one of the first known instances of the use of rails, upon which the car ran, as a means of conveying the current from stationary primary batteries to the motor on the car, and embodied the principle of running the motor at a high speed and gearing it down to a lower speed on the car axle so that a smaller and cheaper motor, for the power supplied, could be used.

At that time the steam locomotive was in its infancy, the law of the conservation of energy was known to but few, and a working knowledge of Ohm's law was confined to mathematicians. The dynamo had not yet been invented.

George F. Green, Kalamazoo, Mich., rescued and revived the abandoned and almost forgotten idea in 1875. He was too poor to buy a dynamo and did not know how to make one.

Siemens and Halske, in Europe, built the first electric railway on a practical scale, using the third rail system, about 1879.

About the same time, Stephen D. Field, in America, was the first to suggest underground conduits, so extensively used in New York.

Thomas Edison did not come into the field until 1880, but did not make any radical improvements.

In May 1881, the first commercial electric road was opened to the public in Lichterfeld, Germany; and the next in 1883, at Portrush, in Ireland. Up to 1883 progress in the direction of commercially developing electric traction was mainly confined to Europe. In 1884 in Cleveland, Ohio, a little later in Kansas City, and in 1885 in Baltimore and Toronto, roads were thrown open to the public. Sprague came into the commercial picture in 1887 with contracts for overhead trolley roads in Richmond, Va., St. Joseph, Mo., and Wilmington, Del. Most of the above mentioned information was obtained from the "Electric Railway Number" of *Cassier's Magazine*, August 1899.

Yours truly,

WALTER S. WHEELER (A' 34)
(Dover, New Hampshire)

Personal Items

HENRY E. WARREN (A'02) president of the Warren Telechron Company, Ashland, Mass., has been awarded the 1934 Lamme Medal of the A.I.E.E. This medal, which will be presented to Mr. Warren at the 1935 summer convention of the Institute which is to be held at Cornell University, Ithaca, N. Y., June 24–28, was awarded him "for outstanding contributions to the development of electric clocks and means for controlling central station frequencies." Mr. Warren was born in Boston, Mass., May 21, 1872, and graduated from Massachusetts Institute of Technology with the degree of bachelor of science in 1894. From 1897 to 1902 he served as electrical and mechanical engineer of the Saginaw Valley Traction Company at Saginaw, Mich. Returning to Boston in 1902 he became engineer and general superintendent of the Lombard Governor Company, which position he held during the next 16 years. In 1904 the factory was moved from Boston to Ashland, Mass. While associated with this company he made improvements in the design of hydraulic speed governors which were installed in many of the largest water power plants of the United States. During the World War he designed several types of hydraulically operated machines which were used in the production of heavy shells and he also developed a new type of fire control mechanism. In 1907 Mr. Warren settled on a farm in the town of Ashland. Here he spent considerable time and thought in designing and constructing various forms of electric clocks as an avocation. One of the farm buildings was converted into a workshop. After several years of experimenting the Warren Clock Company was organized in 1912 to build and sell battery operated clocks. Not satisfied with the product, he undertook in 1916 the problem of utilizing commercial alternating current for the purpose of time-keeping. This involved first, the invention of a new form of self-starting synchronous motor which would be adaptable for use in clocks under conditions quite different from those to which ordinary power motors are subjected; and second, the development of an instrument for measuring frequency with great precision, which later became known as a Warren master clock. Then it was necessary to persuade engineers of power companies to use this instrument so that the frequency of alternating current might be controlled with sufficient accuracy. These objectives were reached before the end of 1916, when the Edison Electric Illuminating Company of Boston adopted the new method of frequency regulation by means of the first Warren master clock. Other companies soon recognized the merits of the idea and within 10 years the use of regulated alternating current as a new kind of time service became general. As a result, the proportion of electric clocks to all clocks exclusive of alarm clocks produced and

H. E. WARREN

sold annually has risen from less than 2 per cent in 1916 to more than 60 per cent in 1933 and the increase still continues. Mr. Warren has been engaged since 1916 in adapting time-keeping synchronous motors to many fields of usefulness and in providing improved devices for frequency control. More than 100 patents have been granted to him. During the past 15 years he has served as president of the Warren Telechron Company and consulting engineer for the General Electric Company. He has held several town offices, is actively concerned with the Boy Scouts of America, and has been involved in numerous public enterprises. He has presented several technical papers on the subject of electric time keeping before the Institute and other organizations.

VLADIMIR KARAPETOFF (A'03, F'12, and Life Member) professor of electrical engineering, Cornell University, Ithaca, N. Y., has been awarded the honorary degree of doctor of music by the New York College of Music, New York, N. Y. Professor Karapetoff has been experimenting lately with the phonograph as an accompaniment for the playing of musical instruments, and with making records by combining individual recordings of separate instruments. He has been a member of the Institute's committee on research since 1923 and has served on several other committees, having been chairman of the electrophysics committee 1926–29.

H. C. LEONARD (A'18) since 1930 general superintendent of light and power of the El Paso Electric Company, El Paso, Texas, has been promoted to the position of vice president and general manager of the Gulf

States Utilities Company, Louisiana division, with headquarters at Lake Charles. Mr. Leonard is a graduate of Worcester Polytechnic Institute, and was for a time with the General Electric Company. In 1919 he became connected with the Stone and Webster organization, and in 1927 became head of the engineering department of the Virginia Electric and Power Company at Norfolk. For a short time in 1930 he was head of the electrical department at Richmond, Va.

F. A. Gaby (A'06, F'18) assistant to the president, Canadian Pacific Railway, with headquarters at Montreal, Que., Can., was elected president of the Engineering Institute of Canada at its recent annual meeting in Toronto, Ont. Mr. Gaby received the degree of bachelor of applied science from the University of Toronto in 1904, and subsequently was employed as an erecting engineer by the Canadian General Electric Company, Toronto. In 1906 he became chief assistant electrical engineer on the Pointe du Bois development, Winnipeg, Man., and the following year became assistant chief engineer of the

F. A. GABY

Hydro Electric Power Commission of Ontario. From 1912 until 1934 he held the position of chief engineer, changing recently to his present position as reported in the January 1935 issue of Electrical Engineering, page 140. Mr. Gaby is a member of a number of societies, and in 1930 was representative for Canada to the second world power conference, held in Berlin, Germany. Since 1930 he has been a member of the Edison medal committee of the Institute.

R. W. McNeill (A'13, M'27) formerly engineering supervisor, Westinghouse Electric and Manufacturing Company, Salt Lake City, Utah, is now in the bureau of reclamation of the U. S. Department of the Interior with headquarters at Denver, Colo., and is at present assigned to the inspection of power plant equipment for Boulder Dam and other projects at General Electric Company plants. He has written various articles on electric material handling and mining machinery.

K. E. Estler (A'31) is now associated with the Holophane Company, New York, N. Y., being in training for the position of sales engineer in the New York district. Since graduation from New York University in 1929 he had been with the Electrical Association of New York, which sponsored the Electric Institute (formerly Westinghouse Lighting Institute) and at the time of leaving was chief guide.

J. T. Mountain (A'04, F'20) formerly assistant to the chief operating engineer, Commonwealth Edison Company, Chicago, Ill., has been appointed assistant to the general service manager, a newly established position with duties including supervision of the lamp renewal division and the service bureau.

E. A. Deeds (A'00) chairman of the board, National Cash Register Company, New York, N. Y., has been elected a director of the American Rolling Mill Company, Middletown, Ohio. Colonel Deeds is also interested largely in the General Machinery Corporation, Hamilton, Ohio.

A. O. Summerville (A'23) Malden Electric Company, Malden, Mass., has been appointed superintendent of production, having previously been assistant superintendent and electrical engineer of the company, which is a subsidiary of the New England Power Association.

A. R. Leinbach (A'22) power supply engineer formerly with the Metropolitan Edison Company, Reading, Pa., is now with the New York State Electric and Gas Corporation, Binghamton, N. Y. Both companies are units of the Associated Gas and Electric system.

A. S. Gould (A'26) of Mt. Vernon, N. Y., is now employed as coöperative advisor for the emergency relief administration of the State of California, and is located at Los Angeles.

R. C. Samuels (A'30) of Willows, Calif., is now employed as an electrical engineer by the American Potash and Chemical Corp., Trona, Calif.

G. F. Castellan (A'30) Romford, Essex, England, is not connected with Clements and Son, London, as announced on page 141 of Electrical Engineering for January 1935.

J. K. Johnson (A'28) radio engineer formerly with the Hazeltine Service Corporation, New York, N. Y., is now connected with Wells-Gardner and Company, radio manufacturers in Chicago, Ill.

W. A. Morgan (A'34) is now employed in the substation maintenance department of the Metropolitan Water District of Southern California and is located at Banning.

F. S. Taylor (A'33) formerly assistant field engineer, Henry J. Kaiser Company, Oakland, Calif., is now a junior engineer with the Shell Oil Company, Martinez, Calif.

H. H. Fry (A'34) is now working as a relief operator in the power plant of the Patchogue Electric Light Company at Patchogue, N. Y.

C. A. Poppino (A'30) International General Electric Company, who has been a sales engineer at New York, N. Y., is now office engineer at Schenectady, N. Y.

R. D. Miller, Jr. (A'34) Washington, D. C., is now employed by the National Electrical Supply Company, Washington.

Obituary

Leslie Lawrence Perry (F'22) advisory electrical engineer, Sargent and Lundy, Inc., Chicago, Ill., died at Cuttingsville, Vt., on February 1, 1935. He was born July 13, 1874, at Lawrence, Mass., and was a graduate of Tufts College, receiving the degree of bachelor of science in electrical engineering in 1896. Later, in 1906, he received the degree of master of science. After experience in the engineering and testing departments of the General Electric Company at Schenectady, N. Y., during the period 1897–1900 he went to South America, and was employed by F. S. Pearson (A'92, M'93, deceased 1915), consulting engineer, on the construction of the power and railway systems in the city of Sao Paulo, Brazil. In 1903 he went to Canada, where he was engaged on the construction of the system supplying power from Niagara Falls to Toronto. From 1905 to 1909 he was again in South America, having charge of the electrical design of the power and railway system for Rio de Janeiro, Brazil. The following 2 years were spent in the power and mining department of the General Electric Company at Schenectady, after which Mr. Perry joined the staff of Sargent and Lundy, where he was engaged in the electrical design of large steam power stations, substations, and transmission and distribution systems for cities throughout the United States. He had been advisory electrical engineer since 1930. Mr. Perry had been serving on the Institute's power transmission and distribution committee since 1928, and had presented papers before the Institute. He was also a member of the Western Society of Engineers (Chicago).

William Charles Adams (M'19) consulting engineer, Northern Electric Company, Ltd., Montreal, Que., Can., died January 7, 1935. He was born in Martin County, Minn., September 10, 1880, and was graduated from the University of Minnesota with the degree of electrical engineer in 1905. Following graduation he was employed for a year by the Stromberg-Carlson Telephone Manufacturing Company,

Rochester, N. Y., and then by the Western Electric Company, where he entered inspection engineering work. He followed this through successive positions of responsibility until in 1917 he was in charge of all of the company's engineering inspection work and the clerical and accounting work connected with it. In 1919 Mr. Adams left the Western Electric Company to become chief engineer of the Northern Electric Company, with which he had been connected since, more recently as consulting engineer reporting to the president. In addition to his Institute membership he was a member of the Engineering Institute of Canada, and represented the Canadian Manufacturers Association on the main committee of the Canadian Engineering Standards Association and his company in the American Society for Testing Materials.

George Stafford Gardner (M'32) inspector, excise tax division, tax commission, State of Ohio, Columbus, died in December 1934. He was born at Titusville, Pa., March 11, 1875. In 1900 he was employed by the Home Telephone Company at Dayton, Ohio, and later by the Citizens Telephone Company at Columbus. In 1907 he returned to the former company as assistant engineer and chief inspector in charge of estimates and field work during the construction of the plant at Detroit, Mich. Later he was construction engineer for the United States Telephone Company and the Ohio State Telephone Company, Columbus. From 1920 to 1924 he conducted a private construction engineering business, including street light and traffic signal systems. Mr. Gardner then joined the Hirsch organization in Columbus as associate engineer in charge of all telephone and utility engineering. In 1929 he became superintendent of construction with the Associated Telephone and Telegraph Company, Chicago, Ill., and was engaged in line construction in Colombia, South America, running a 400 mile line through almost impassable country between Buenaventura and Bogota. Since his return to the United States recently he had been employed by the tax commission.

John Edward Donoghue (M'18) managing director, The Electric Light and Power Supply Corporation, Sydney, Australia, died December 28, 1934. He was born at Sheffield, England, December 9, 1871, and studied at Sheffield University. He was employed in England until 1902, when he went to Melbourne, Australia, as a resident engineer for the Melbourne Electric Supply Company, having charge of 2 power houses. From 1906 to 1909 he was chief assistant engineer and acting chief engineer for the Sydney municipal council, and became general manager and chief engineer of the Electric Light and Power Supply Corporation in 1909, when the plant was started, for the design and construction of which he had been responsible. In addition to his duties with this company he served as a consulting engineer for various municipal power plants and industrial companies in Australia. He was appointed to the position of managing director of the company in 1929.

Fred Dunham Emory (A'15, M'27) Portland, Ore., northwest representative, Line Material Company, South Milwaukee, Wis., died November 30, 1934, following an operation. He was born at Winnipeg, Man., Can., May 29, 1891, and after a short period of time with the railway company there attended the Bliss Electrical School at Washington, D. C. In 1911 he returned to Canada and was subsequently employed in a number of companies, including the Canadian Westinghouse Company and the Ferranti Electrical Company of Canada. From 1915 to 1918 he was city electrician at Kaslo, B. C., and until 1921 district inspector of gas and electricity at Nelson, B. C. After 2 years with the Kootenay Power Company, in 1924 he became an electrical engineer in the engineering department of The California-Oregon Power Company, Medford, Ore. Mr. Emory's work for these companies involved the design of power houses, substations, transmission lines, and distribution systems. He had been a representative for the Line Material Company since 1929.

George Dania (A'25) Westfield, N. J., died January 28, 1935. He was born at Ilford, England, July 30, 1895, and received his education at Wembley and London. He was employed in the Metropolitan Railway Company in London from 1912 until 1916, when he became a lieutenant in the British air service. Following the war he formed a partnership in the business of repairing electrical machinery and manufacturing switchgear, and in 1921 joined George Dania, Sr., as assistant engineer, testing and inspecting electrical machinery. In 1924 he became a draftsman in the electrical department of the New York Central Railroad, New York, N. Y., and shortly after took the position of electrical inspector. Mr. Dania went to Cleveland, Ohio, as assistant engineer in the Cleveland Union Terminals Company in 1929, later moving to Lakewood, Ohio, where he remained until recently.

Harry von Turffs (A'31) division superintendent, Montana Power Company, Bozeman, was killed January 15, 1935, in an automobile accident. He was born at Odessa, Russia, March 23, 1886. He studied at the Imperial Gymnasium, Weisbaden, Germany, and at the Naval Academy at Kiel, leaving the latter to go to sea. Since 1909 he had been connected with the Montana Power Company.

Membership

Recommended for Transfer

The board of examiners, at its meeting held February 19, 1935, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Gilt, Carl M., asst. E.E., Bklyn Edison Co. Inc., Bklyn., N. Y.
Hawley, Kent A., chief engr., Locke Insulator Corp., Baltimore, Md.
Hinson, Noel B., chief engr., So. Calif. Edison Co. Ltd., Los Angeles.
Kinsley, Carl, cons. engr., research lab., U.S. Steel Corp., Kearny, N. J.

4 to Grade of Fellow

To Grade of Member

Aiden, Dean W., E.E., Blackstone Valley Gas & Elec. Co., Pawtucket, R. I.
Bossemeyer, C. O., gen. mgr., The Rio Grandense Lt. & Pwr. Syndicate, Ltd., Pelotas, Rio Grande do Sul, Brazil, S. A.
Douglas, John F. H., assoc. prof., E.E., Marquette Univ., Milwaukee, Wis.
Elberty, Robert S., Jr., industrial sales dept., Westinghouse E. & M. Co., E. Pittsburgh, Pa.
Freeman, E. D., supt. of elec. dept., Okla. Gas & Elec. Co., Oklahoma City.
Jensen, Marion A., plant engr., Crowell Pub. Co., Springfield, Ohio.
Judd, Robert S., chief engr., Southern New England Tel. Co., New Haven, Conn.
Kane, Edward W., asst. prof., E.E., Marquette Univ., Milwaukee, Wis.
Lemaire, Arthur B., managing elec. engr., Water Conservation and Irrigation Commission, Leeton, N.S.W., Australia.
Lynch, Edward, meter engr., Gen. Elec. S.A., Rio de Janeiro, Brazil, S. A.
MacFarren, Mabel, asst. engr., The Metropolitan Water District of So. Calif., Los Angeles.
Miller, Clarence E., district plant supt., Ohio Bell Tel. Co., Springfield.
Perkins, Edward B., Jr., asst. E.E., U.S. Treasury Dept., Federal Warehouse, Washington, D. C.
Porter, Roland G., assoc. prof. of E.E., Northeastern Univ., Boston, Mass.
Reiber, Albert H., engr. of development and research, Teletype Corp., Chicago, Ill.
Remine, H. H., elec. engr., Montreal Lt., Heat & Pwr. Cons., Montreal, Que., Can.
Snyder, L. G., in charge of engg. and sales, Landis & Gyr, Inc., New York, N. Y.

17 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before Mar. 31, 1935, or May 31, 1935, if the applicant resides outside of the United States or Canada.

Ahlstedt, H. E., Reedsport, Ore.
Albright, D. C., 604 Mott St., Kendallville, Ind.
Andersen, C. J., Gibbs & Hill, N. Y. City.
Anderson, H. H. I., Standard Oil Co. of N. J., Elizabeth.
Anderson, V. J., Western Union Tel. Co., Omaha, Neb.
Andraca, R., Calle 10, 218 Vedado, Havana, Cuba.
Andree, W. A., 462 Pioneer Ave., Glendale, Calif.
Applegrad, A., Western Union Tel. Co., N. Y. City.
Avakian, K. A., Maurice R. Scharff, Mt. Vernon, N. Y.
Ayer, R. W., Simmons Co., San Francisco, Calif.
Baker, J. C., U. S. Elec. Mfg. Co., Los Angeles, Calif.
Barbier, E. G., Ferguson Radio Corp., N. Y. City.
Bassett, E. D., F. W. Sickles Co., Springfield, Mass.
Battit, B. E., Mass. Inst. of Tech., Cambridge.
Bauer, R. V., Montana Pwr. Co., Roundup.
Baumann, F. W., Gen. Elec. Co., Schenectady, N. Y.
Beck, G. P., York, N. Dak.
Bender, J. B., Sky Line Adv. Co., Inc., Oklahoma City, Okla.
Bennett, G. A., Jr., 101 Main St., Ashland, Mass.
Benton, W. T., Pub. Serv. Co. of No. Ill., Forest Park.
Berri, T. L., Southwestern Lt. & Pwr. Co., Lawton, Okla.
Blasberg, A. E., 10 Mechanic St., Shelburne Falls, Mass.
Bliesner, G. H., State Col. of Wash., Pullman.

Blum, R. G., 1500 N. Webster Ave., Scranton, Pa.
Bogen, S., Maurice Scharff, Inc., N. Y. City.
Borgman, T. J., Southern Bell Tel. & Tel. Co., Louisville, Ky.
Botterill, T. L., 4025 E. 19th Ave., Denver, Colo.
Bouchard, J. E. A., Shawinigan Water & Pwr. Co., Three Rivers, Que., Can.
Boyd, R. H., Southwestern Bell Tel. Co., Little Rock, Ark.
Boyd, W., Am. Treibach Chem. Wks., Niagara Falls, N. Y.
Boyle, J. M., 5255 Rodman St., Phila., Pa.
Braunlich, W. E., Braunlich-Koessel Co., Pittsburgh, Pa.
Bremmer, A. J., Gen. Elec. Co., Schenectady, N. Y.
Brian, J. M., Annapolis Metropolitan Sewerage Commission, Md.
Brown, J., 1024 Hill St., Ann Arbor, Mich.
Brubaker, D. G., Penn. R. R., Baltimore, Md.
Bruner, T. W., Standard Oil Co., Milwaukee, Wis.
Bryan, L. B., Louisville Gas & Elec. Co., Ky.
Buchanan, R. O., Univ. of Vt., Burlington.
Buck, H. L., Day & Zimmerman, Inc., Phila., Pa.
Burns, G. K., Western Elec. Co., N. Y. City.
Burr, L. W., Texas Gulf Sulphur Co., Newgulf.
Burt, W. P., Gen. Elec. Co., Phila., Pa.
Byers, R. M., Cons. Gas, Elec. Lt. & Pwr. Co. of Baltimore, Md.
Cairone, A. R., Atlantic City Elec. Co., N. J.
Calhoun, D. R., RCA Victor Co., Inc., Camden, N. J.
Callender, B. M., Am. Hammered Piston Ring Co., Baltimore, Md.
Chambers, C. C., Univ. of Pa., Phila.
Chapman, G. E., 6258 Newark Ave., Chicago, Ill.
Chapman, J. H., Bklyn. Edison Co., Inc., Bklyn., N. Y.
Chun, M. E., Houston Police Station KGZB, Texas.
Clouse, W. W., Penn. R. R. Co., Baltimore, Md.
Colbert, C. J., Potomac Elec. Pwr. Co., Washington, D. C.
Collins, J. G., Clayton Mark & Co., Chicago, Ill.
Cooper, P. O. Jr., Intl. Business Machine Co., Endicott, N. Y.
Corrington, M. S., Kadoka, S. Dak.
Cosentine, M., Eastern Ptg. Corp., N. Y. City.
Coykendall, J. C., Gen. Elec. Co., Bridgeport, Conn.
Crabtree, H. K., New Eng. Pwr. Co., Shelburne Falls, Mass.
Craig, R. L., 4418 N. Whipple St., Chicago, Ill.
Crippen, M. E., Box 133, Pernell, Okla.
Crouter, J. F., Univ. of Mich., Ann Arbor.
Culver, R. L., Clinton Heights, Rensselaer, N. Y.
Cummins, O., Dallas Pwr. & Lt. Co., Texas.
Darrah, J. E., Ohio Pwr. Co., Steubenville.
Day, A. E., Tung-Sol Radio Tubes Inc., Newark, N. J.
Dennis, N. T., Acme Elec. & Mfg. Co., Cleveland, O.
Dick, K. A., Louisville Gas & Elec. Co., Ky.
Dixon, C. R., 31 Greylock Ave., Taunton, Mass.
Dorst, S. O., Sprague Specialties Co., North Adams, Mass.
Ducat, A. C., 218 Springfield Ave., Rochester, N. Y.
Duguid, W. D., Shell Chem. Co., Pittsburgh, Calif.
Dunlap, G. W., 937 Laurel Ave., San Mateo, Calif.
Edelman, J. R., Route 2, Thiensville, Wis.
Elliott, R. B., 1104 S. State St., Belvidere, Ill.
Erickson, L. H., Pub. Serv. Co. of Colo., Denver.
Fairbanks, J., 186 Temple St., West Roxbury, Mass.
Finger, T., R. H. Bowligny, Inc., Charlotte, N. C.
Fleischman, J., 246—24th Ave., Venice, Calif.
Fletcher, J. F., Courtlaud's (Ltd.), Cornwall, Ont., Can.
Floyd, J. G., Iowa State Col., Ames.
Forman, J., Meyer's Confectionery Store, Bklyn., N. Y.
Foster, R. M., Guardian Elec. Mfg. Co., Chicago, Ill.
Fraker, C. L., Box 116, Pompeii, Mich.
Frankenfield, A. W., Metropolitan Edison Co., Easton, Pa.
Frederick, W. H., Westchester Ltg. Co., Pleasantville, N. Y.
Frenzel, E. E., Freeport Sulphur Co., Port Sulphur, La.
Frint, A. E., Wells Coal Co., Sioux City, Iowa.
Fritz, L. J., Ohio Bell Tel. Co., Toledo.
Fromm, W. H., Jr., Harnischfeger Corp., Milwaukee, Wis.
Fuchs, H. I., Am. Tel. & Tel. Co., N. Y. City.
Funk, A. L., Idaho Seed & Produce Co., Aberdeen.
Gaetjens, A. K., Gen. Elec. Co., Cleveland, Ohio.
Galloway, C. A., 1129 South Ave., Plainfield, N. J.
Gates, E. M. (Member), Superheater Co., & Combustion Engg. Co. Inc., N. Y. City.
Glimer, J. W., Mont. State Col., Bozeman.
Gonzalez, E. M., Cia. Impulsora de Empresas Electricas, S. A., Mexico, D. F., Mex.
Goodwin, H. B., Harvard Business School, Boston, Mass.
Gose, J. H., Gen. Elec. Co., Lynn, Mass.
Gouchoe, R. L., Central Vt. Pub. Serv. Corp., Rutland.
Gove, E. L. (Member), Radio Air Serv. Corp., Cleveland, Ohio.
Grant, H. A., Jr., 214 Glenwood Ave., E. Orange, N. J.
Graunke, N. C., Home Owner's Loan Corp., Chicago, Ill.
Greenawald, H. E., Stanton Operating Co., Pittston, Pa.
Greidanus, S. C., Holland Furnace Co., Newark, N. J.
Hagopian, H. D., 52 Burnside St., Medford, Mass.
Hampshire, R. A., Ford Instr. Co., L. I. City, N. Y.
Hampson, K., Cumberland High School, Valley Falls, R. I.
Hanan, C. J., Pub. Serv. Co. of Okla., Hugo.
Hancock, J. B., Gen. Elec. Co., Schenectady, N. Y.
Hartman, W. T., 4416—40th Ave., S., Minneapolis, Minn.
Harvey, N. L., Des Moines Register & Tribune, Ames, Iowa.
Hayes, R. Y. V., Tidewater Oil Co., N. Y. City.
Heckendorn, H. R., Am. Tel. Co., Hiawatha, Kans.
Heick, B. K., Louisville Gas & Elec. Co., Ky.
Henderson, E. D., Walter Baker Co., Milton, Mass.
Henderson, J. G., Gen. Elec. Co., Schenectady, N. Y.
Herron, J. H. (Member), James H. Herron Co., Cleveland, Ohio.
Hilbert, E. H., % M. R. Scharff, N. Y. City.
Hipple, F. A., Keasbey & Mattiss Co., Ambler, Pa.
Hlavaty, E. M. J., F. I. Tourtelot Co., Chicago, Ill.
Hofmann, P., Potomac Elec. Pwr. Co., Washington, D. C.
Hollister, K. C., Westinghouse E. & M. Co., East Pittsburgh, Pa.
Hunt, H., Carmel, N. Y.
Hutchins, C. N., Gen. Elec. Co., Schenectady, N. Y.
Huyett, S. S., Colo. Sch. of Mines, Golden.
Hyad, R. F., 3482 E. 5th Ave., Vancouver, B. C., Can.
Ingham, P. W., 5800 Halwyn Ave., Baltimore, Md.
Jackson, C. E., Route 2, Sheridan, Wyo.
Jackson, W. L. (Member), Route 3, Colorado, Texas.
Jaeger, J. J., Mass. Inst. of Tech., Cambridge.
Janken, S. C. & H. Sugar Refining Corp., Crockett, Calif.
Janz, W. F., Northern Ind. Pub. Serv. Co., Hammond.
Jarest, J. R., Hillsboro Mills, Wilton, N. H.
Johnson, T. C., Gen. Elec. Co., Schenectady, N. Y.
Johnson, W. C., Gen. Elec. Co., Schenectady, N. Y.
Jones, C. W., Station WJR, Detroit, Mich.
Jones, J. E., Oliver Continuous Filter Co., Oakland, Calif.
Jurasek, F. P., Ford Motor Co., Richmond, Calif.
Kap, F. W., Sanitary Dist. of Chicago, Ill.
Keene, C. L., Ocean Accident & Guarantee Corp., N. Y. City.
Kehoe, J. W., 105 Spring Mill Ave., Conshohocken, Pa.
Kelley, R. K., R.C.A. Radiotron Co., Inc., Harrison, N. J.
Kihn, H., Passaic Evening Vocational Sch., N. J.
Kirker, J. W., Jr., Carrier Engg. Corp., Allentown, Pa.
Klein, M., Ludlow Serv. Station, Yonkers, N. Y.
Klempner, Dan (Member), R.C.A. Radiotron Co., Inc., Harrison, N. J.
Klose, H. C., Am. Coal Co. of Alleghany Co., McComas, W. Va.
Koether, G. H., Jr., Round Bay, Severna Park P. O., Md.
Lackey, B. E., Intl. Business Machines, Inc., Endicott, N. Y.
Lamley, R. A., Interlake Iron Corp., Toledo, Ohio.
Lathrop, L. L., Industrial Heater Co., N. Y. City.
Lay, C. R., 36 Madison St., Huntington, Ind.
Leech, E. M., CRI & P Ry., Trenton, Mo.
Leffowitz, H., United Transformer Co., N. Y. City.
Lepple, H., WLW of the Crosley Radio Corp., Cincinnati, Ohio.
Levy, C. F., U.S. Coast & Geodetic Survey, Norman, Okla.
Lewis, J. H., R. F. D. 4, Fort Collins, Colo.
Libby, C. J., Phoenix Assurance Co., Ltd., N. Y. City.
Lieb, J. S., N. Y. Edison Co., N. Y. City.
Lindheimer, C. M., Potomac Elec. Pwr. Co., Washington, D. C.
Lindholm, F., 329 S. 19th St., Newark, N. J.
Lindquist, R. G., West Penn Pwr. Co., Kittanning, Pa.
Livermore, W. N., 60 Covington Road, Buffalo, N. Y.
Loew, E. A., Ford, Bacon & Davis, Inc., Seattle, Wash.
Lowry, G. F., Consumers Pwr. Co., Grand Rapids, Mich.
Lyons, J. S., 5938 Chester Ave., Phila., Pa.
Mackensen, H. T., Jeffrey Mfg. Co., Columbus, Ohio.
Mackey, S. D., 3 Maple St., Oneonta, N. Y.
MacQuivey, D. R., President Van Buren Dollar S.S. Co., Berkeley, Calif.
Manahan, M. J., 812 Orleans St., Chicago, Ill.
March, L. A., Gen. Elec. Co., Schenectady, N. Y.
Marchett, C., Safety Car Heating & Ltg. Co., New Haven, Conn.
Mary, A. J., La. Motor Fuel Bureau, Baton Rouge.
Mason, C. N., Jr., Green Mt. Jr. Col. & Troy Conference Academy, Poultney, Vt.
Massell, B. M., Maurice Scharff, Inc., N. Y. City.
Mayo, G. E., Jr., Racquette River Paper Co., Potsdam, N. Y.
McCandless, W. H., Lincoln Elec. Co., Cleveland, O.
McClain, F. J., Metropolitan Water Dist. of So. Calif., Indio, Calif.
McDonough, J. B., Firebaugh Canal Co., Mendota, Calif.
McLaren, F. R., Pub. Serv. Co. of N. H., Manchester.
Meckstroth, C. R., United Mills Co., Inc., Grafton, O.
Milewski, L. A., Landers, Frary & Clark, New Britain, Conn.
Miller, T. L., 1308 E. N. Grand Ave., Springfield, Ill.
Minarik, W. J., Bud Radio Inc., Cleveland, Ohio.
Minor, E. E., Jr., Johns Hopkins Univ., Baltimore, Md.
Mitchell, G. E., N. Y. State Elec. & Gas Corp., Binghamton.
Montaudon, R. A., Cia. Mexicana de petroleo, Tampico, Tamps, Mex.
Moore, J. M., United Illum. Co., New Haven, Conn.
Morr, H. S., Utah Pwr. & Lt. Co., Salt Lake City.
Morris, G. C., Sunbeam Elec. Mfg. Co., Evansville, Ind.
Mortensen, H., Kelvinator Corp., Detroit, Mich.
Moses, O. J., Atlantic Refining Co., East Hartford, Conn.
Moskalek, S., Ford Motor Co., Dearborn, Mich.
Mott, G., Jr., Maurice R. Scharff, Mt. Vernon, N. Y.
Mueller, W. S., 22735 Grand River Ave., Detroit, Mich.
Muhl, J., Jr., 584 Albany St., Little Falls, N. Y.
Murbach, J. F., Jr., 563 Senator St., Bklyn., N. Y.
Nelson, C. E. (Member), Phila. Elec. Co., Pa.
Nelson, E. H., Anaconda Wire & Cable Co., Hastings-on-Hudson, N. Y.
Neuhauser, F. L., Louisville Gas & Elec. Co., Ky.
Nisula, W. O., 93 Town Hill St., Quincy, Mass.
Nolan, V. B., Florida Pwr. & Lt. Co., Bradenton, Fla.
O'Brien, A. E., N. J. Bell Tel. Co., Newark, N. J.
O'Brien, G. W., N. Y. Tel. Co., N. Y. City.
Oettinger, C. W., Duquesne Brewing Co., Pittsburgh, Pa.
Oliver, F. J., 330—6th St., Marietta, Ohio.
Oliver, R. C., Jr., Geophysical Serv., Inc., Kansas City, Mo.
Olson, J. H., Austin Henderson Co., Coeur d'Alene, Idaho.
Orkney, W., Harvard Graduate Sch. of Business, Soldiers Field, Mass.
Owings, A. J., James R. Kearney Corp., St. Louis, Mo.
Packard, R. H., Raytheon Production Corp., Newton, Mass.
Paine, W. E., Rochester Gas & Elec. Co., N. Y.
Parker, C., Indianapolis Street Ry. Co., Ind.
Paschedag, C., Allis-Chalmers Mfg. Co., Pittsburgh, Pa.
Patton, W. L., Calif. Pacific Intl. Exposition, Balboa Park, Calif.
Penn, W. D., Harvard Law School, Cambridge, Mass.
Perez, R. R., 1611—10th Ave., Tampa, Fla.
Peth, H. R., Hoskin Paper Co., Menominee, Mich.
Pettigrew, J., Sansbury Elec. Serv., Florence, S. C.
Phillips, E. H., Bayard, N. Mex.
Piskun, B. D., 552 E. 3rd St., Bklyn., N. Y.
Potter, F. M., Gen. Elec. Co., Schenectady, N. Y.
Pournaras, G. A. (Member), N. Y. Edison Co., N. Y. City.
Pratt, L. C., Forstmann Woolen Mills, Garfield, N. J.
Race, C. R., 31-52—80th St., Jackson Heights, L. I., N. Y.
Raemsch, W. P., Hartford Steam Boiler Insp. & Ins. Co., N. Y. City.
Ranney, N. J., Ferro Enamel Corp., Cleveland, Ohio.
Ray, W. O., Texas A. & M. Col., College Station.
Reuter, P. A., Am. Platinum Works, Newark, N. J.
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Foreign

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8 Foreign

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16 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

(The) ALLOYS of IRON and COPPER. (Alloys of Iron Research Monograph Series). By J. L. Gregg and B. N. Danilloff. N. Y. and Lond., McGraw-Hill Book Co., 1934. 454 p., illus., 9x6 in., cloth, $5.00. All the essential information upon copper-iron alloys, including a bibliography of 399 articles, selected as most important.

L'ALLUMAGE des MOTEURS a EXPLOSIONS par Bobine d'Induction. (Mises au Point Electrotechniques). By A. Boury and A. M. Touvy. Paris, J. B. Baillière et Fils, 1934. 274 p., illus., 7x5 in., leu., 35 frs. This volume reviews the subject of battery ignition systems for internal-combustion engines, discussing the historic development of ignition systems, the conditions necessary for the ignition of explosive mixtures, and present day methods. Also considered are the principles governing induction-coil ignition, their mathematical representation, and the construction of distributors, ignition coils, etc.

A.S.T.M. TENTATIVE STANDARDS 1934. Phila., American Society for Testing Materials. 1257 p., illus., 9x6 in., cloth, $8.00: paper, $7.00. Contains 236 specifications, methods of testing, definitions of terms, and recommended practices covering materials of engineering, which have been tentatively approved by the society. This relates to metals, ceramic, and concrete materials, paints, petroleum, insulation, textiles, etc. Proposed revisions of standards are also included in the volume.

BESSEL FUNCTIONS for ENGINEERS, N. W. McLachlan. Oxford (England), The Clarendon Press; N. Y., Oxford Univ. Press, 1934. 192 p., illus., 10x8 in., cloth, $5.00. This book aims to provide a course on Bessel functions and their practical applications. No prior acquaintance with these functions is necessary. The theory is simply presented, and many worked examples illustrate the analytical processes and practical applications, with 15 tables of numerical values of functions useful in acoustical and electrical work.

COURS de LÉGISLATION et RÉGLEMENTATION des SERVICES RADIOÉLECTRIQUES. M. Olivier. Paris, Librairie de L'Enseignement Technique, 1934. 181 p., 9x7 in., paper, 25 frs. This textbook, intended for ship or airplane radio operators, covers the laws and regulations governing radio communication and the operation of radio stations, as they affect the operator and his duties.

DIRECT-CURRENT MACHINERY. R. G. Kloeffler, J. L. Brenneman, and R. M. Kerchner. N. Y., Macmillan Co., 1934. 403 p., illus., 9x6 in., cloth, $4.00. This text is intended for junior students in electrical engineering. The theory of direct-current machinery and the applications of direct-current machines are emphasized; but little attention is given to matters of design. The characteristics of this machinery, methods of operation, efficiency, costs, and methods of testing are discussed.

FORSCHUNGSHEFT 368. Mechanische Schwingungen im Maschinenbau. By F. Bielitz and L. Maduschka. Berlin, VDI-Verlag, 1934. 30 p., illus., 12x8 in., paper, 5 rm. In these papers are discussed the inversion of linear mechanical vibrating systems, problems of damping the vibrations of machinery, and a mathematical study of the vibrations of block foundations for machinery.

IONS, ELECTRONS, and IONIZING RADIATIONS. J. A. Crowther. 6 ed. N. Y., Longmans, Green & Co., 1934. 344 p., illus., 9x5 in., cloth, $4.25. This textbook of atomic physics is intended for undergraduate students who have been grounded in the more elementary portions of physics, and desire a systematic knowledge of its later developments.

KOHLEBÜRSTEN zugleich eine Darstellung des veränderlichen Verhaltens der Stromwendung bei Gleichstrommaschinen. J. Neukirchen. Munich and Berlin, R. Oldenbourg, 1934. 135 p., illus., 10x7 in., paper, 6.80 rm. An extensive study of the behavior of carbon brushes in direct-current generators with special reference to the effect of various conditions upon the efficiency of commutation. Commutation and sparking are considered at length, and an explanation of the observed effect of atmospheric changes upon sparking is offered.

Das NEUMEYER-BUCH. Band 1. Die Übertragung von Schwachströmen durch Kabel, deren Bau und Eigenschaften. By H. W. Droste. 2 ed. Nürnberg, Kabel- und Metallwerke Neumeyer Aktiengesellschaft, 1934. 460 p., illus., 9x6 in., cloth, 12.50 rm. This is a manual on the construction and properties of telegraph and telephone cables and their use. It aims to be a textbook for beginners in communication engineering, and also a ready reference work for the engineer. The mathematics of telephone circuits is considered in detail, and in addition a large collection of numerical data is presented in tables and charts.

Die ORTSKURVENTHEORIE der WECHSELSTROMTECHNIK. G. Oberdorfer. Munich and Berlin, R. Oldenbourg, 1934. 87 p., diagrs., 10x7 in., paper, 4.50 rm. The advantages of the polar curve in the solution of alternating current problems are explained, the underlying theory is presented, directions for determining the more important curves are given, and their use illustrated by numerical examples.

PRÉCIS de RÉGLEMENTATION et d'EXPLOITATION des SERVICES RADIOÉLECTRIQUES, Olivier. Paris, Librairie de l'Enseignement Technique, 1934. 120 p., 10x7 in., paper, 20 frs. A manual upon the operation of ship and airplane radio stations, giving the international rules governing the transmission and reception of messages and the regulations adopted at the Madrid and Lucerne conferences with a practical commentary.

Engineering Societies Library

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MAINTAINED as a public reference library of engineering and the allied sciences, this library is a cooperative activity of the national societies of civil, electrical, mechanical, and mining engineers.

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Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

Industrial Notes

Westinghouse Awarded Steel Mill Order.—The first important steel mill electrification announced in 1935 includes an award to the Westinghouse Electric & Mfg. Co. for part of the electrical equipment to be installed in the McDonald Works of the Carnegie Steel Co., near Youngstown, O. Large d-c motors, totaling 16,000 hp, motor generator sets, and control equipment comprise the bulk of the order. The new mill is expected to be in operation this summer.

New Heavy Duty Brushes.—The National Carbon Co., Cleveland, announces a new series of electrographitic brushes designed especially for service on heavy duty, direct-current equipment. It is stated that this new series is the product of a four year program of research applied to the problem of determining the fundamental physical properties essential to satisfactory brush performance on heavy duty direct-current apparatus, the combination of materials possessing these necessary properties, and exact methods of production control to insure uniformity in both product and performance. The new series is to be known as the "SA" Series of National Pyramid Brushes, and consists of five grades.

Ferranti Increases Voltmeter Range.—According to a recent announcement, the Ferranti electrostatic voltmeter, introduced in this country some time ago, and originally available only up to 3,000 volts, is now supplied with full scales up to 18,000 volts maximum. These high range meters can be furnished in single, dual or triple range types and have numerous applications in present day testing. They consume zero current and the movement is protected with an over-voltage safety device. Electrostatic voltmeters are also now available in $3^1/_2$ and 4-inch dial patterns in full scales up to 3,500 volts. These meters are entirely independent of frequency, wave form, and temperature and may be used directly on either a-c or d-c circuits.

A New Cable Lug.—Supplementing its regular line of clamp type lugs, the Burndy Engineering Co., New York, has introduced a line of clamp wire and cable lugs, known as "Qiklugs," made by a forging process. The advantage claimed for the forged lug is a higher order of strength and conductivity than that possible in the cast lug. Qiklugs are quickly installed by simply inserting the wire or cable in the serrated gripping jaws and tightening a nut. This method of clamping destroys the "barrel effect" by forcing the outer layer of wires against the inner layers, particularly an advantage on the larger sizes of conductors having numerous layers of strands. An Everdur lockwasher, under the tightening nut of similar material, prevents loosening of the connection due to vibration. For temporary installations, the Qiklug can be easily disconnected, providing full salvage value to the terminal. The line of Burndy Qiklugs includes both the one-and two-hole types, of Durium alloy, in all sizes up to 500 mcm. They are approved by Underwriters' Laboratories.

Trade Literature

Air-Cooled Transformers. Bulletin GEA-897E, 20 pp. Describes air-cooled transformers for lighting and power service. General Electric Co., Schenectady, N. Y.

Watthour Meters.—Bulletin GEA-615C, 48 pp. Describes standard lines of watthour meters, supplies, and accessories. General Electric Co., Schenectady, N.Y.

Rigid Conduits.—Folder Series. Describes standard thread, protected enameled conduit, electrogalvanized and new hot-dip galvanized conduit with zinc-coated threads. Enameled Metals Co., Pittsburgh, Pa.

Transformers.—Catalog 152. Describes transformers for instrument and metering service; a complete line of current and potential transformers for all voltages as well as combined potential and current transformers or metering outfits. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Wires & Cables.—Catalog 302-E. A comprehensive brochure describing the processing and including the specifications of a wide range of electrical conductors of many types applicable in utility, industrial and general use. Installations in prominent structures are pictured. Crescent Insulated Wire & Cable Co., Trenton, N. J.

Demand Meters.—Bulletin GEA-612B, 56 pp. Describes the GE line of standard demand meters intended for the measurement of maximum demand (in kw, kv-a, and rkv-a, etc.), and its allied problems. Indicating, graphic, and printing types for all classes of service are included. General Electric Co., Schenectady, N. Y.

Convertible Motors.—Bulletin HM-1. Describes a new line of convertible squirrel cage and slipring induction motors, from $^1/_2$ hp, 600 rpm, to 125 hp, 3,600 rpm. A feature of these new motors is their ready conversion from open type to fan cooled, splash proof or totally enclosed construction. Harnischfeger Corp., Milwaukee, Wis.

Bakelite Varnish.—Bulletin, 40 pp., "Bakelite Varnish, Enamel, Lacquer, and Cement, Heat Hardenable." Describes characteristics, uses, and technic involved in the handling of these materials. In the electrical industry, the Bakelite baking-type liquid products are extensively used for armature and coil impregnation, the coating of paper wound tubes, covered enameled wires, etc. Other applications are illustrated. Bakelite Corporation, Bound Brook, N. J.

Gasoline-Electric Generating Plants.—Bulletin 251A, 4 pp. Describes semi-portable plants with direct current and 60-cycle a-c generators, in sizes from $^1/_4$ to 10 kw; also special lightweight portable plants rated from 650 to 800 watts for power and light supply, and ratings from 300 to 750 watts for furnishing power to the plate and filament circuits of portable radio transmitters. Electric Specialty Co., Stamford, Conn.

Pole Stubbing Clamps for Pole Salvage.—Circular, 4 pp. Describes and illustrates tests of various types of pole stubbing clamps. These clamps are used on poles that have become unsafe at the ground line and are then attached to stubs set in the ground directly adjacent to the original pole. The circular offers to operating companies, with salvage or replacement programs, a sample stubbing clamp set for actual field installation, without obligation. Malleable Iron Fittings Co., Pole Hardware Dept., Branford, Conn.

Thermostatic Bimetal.—Bulletin 301, 20 pp. Describes "Trueflex" thermostatic bimetal, a laminated material, made by fusing two sheets of metal, one having high thermal expansion and the other low. Charts are included for rapidly calculating the proper bimetal elements to accomplish a desired result and the characteristics of each type of material are outlined. General Plate Co., Attleboro, Mass.

Condensers.—Catalog, 24 pp. Describes industrial-purpose condensers or capacitors. One type (oil) utilizes for the dielectric a spacer consisting of two or more layers of paper impregnated with oil and hermetically sealed in cans filled with oil. A second type (electrolytic) utilizes for the dielectric thin films formed electrochemically on the surfaces of pure aluminum foil. The latter are designed for intermittent duty on a-c circuits. The oil condensers are particularly adaptable to continuous use in a-c circuits. Both types are made in a wide variety of standard shapes and sizes or adapted to meet individual requirements. Aerovox Corporation, 82 Washington St., Brooklyn, N. Y.

Battery Float Meter.—Bulletin, 4 pp. Describes the "Exide" float meter, a newly developed device for determining the average voltage of a battery or a direct-current circuit over a definite period of time. The meter operates on the principle of the electrolytic ampere-hour meter with an accuracy of about 0.25%, and draws a current of only 0.004 to 0.010 ampere, depending upon the time between resettings. A particular application of the float meter is in connection with floated batteries where it is desired to maintain a recommended average voltage; such applications include railway signal and interlocking, electric power control, telephone, emergency light and power, and other stationary services. The meter can be used either to determine the actual average voltage being maintained, or to assist the operator through the use of a special calendar scale in maintaining the desired average voltage from day to day. The Electric Storage Battery Co., Philadelphia, Pa.

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Front Cover

Arthur F. Huey generating station on Bell Isle Lake, Oklahoma City, Okla., near the scene of the Institute's forthcoming South West District meeting. This 30,000 kw station is the most modern in the southwest. Gas from the nearby Oklahoma City fields is used as fuel.

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Engineering Education as a Preparation for Any Life Work

By J. Allen Johnson, President A.I.E.E.

In our present day engineering civilization, is there a logical basis for the thesis that an engineering education is a good preparation for any life work? President Johnson says there is, and in this article gives strong supporting reasons for his contention. He concludes that a broad basic engineering education "which opens the mind and shows it how nature itself does its work, and teaches it to apply that knowledge through original thinking to the specific problems of one's life work, is a preparation for that life work which has, and in the very nature of things can have, no equal."

ON AN occasion of this kind* it seems clear that the proposition which I am expected to support in this brief talk is that an engineering education is a *good* preparation for any life work, possibly that it is superior to any other preparation or at least any other kind of education as such a preparation.

What is our criterion to be? Is the benefit of an engineering education to be assumed to inure to the individual concerned or to the social system as a whole? I think we must cling, in this discussion, to the criterion of advantage to the individual concerned. That is to say, the question the young man will ask and which we must try to answer is "Will an engineering education be the best preparation to help *me* accomplish *my* life's work?"

It now seems pertinent to inquire what we mean by "preparation" for a life work. Obviously there are many careers for which an engineering education could not be a *complete* preparation. In fact, no formal education can possibly be a *complete* preparation for any career, because every career is, in a very real sense, its own preparation for itself. All past experience is preparation for what is to come and education, in its broadest sense, is continuous from the cradle to the grave. So when we say "preparation" we must, I think, construe the word in the sense of "foundation."

"Education" and "Training" Not Synonomous

Here, I think, we must begin to differentiate clearly between "education" and "training." You will note that my subject says "engineering education" not "technical training." This differentiation, indeed, is implicit in the motto on the "Tech" seal, "Lehr and Kunst"—knowledge and skill—hence education for the acquisition of knowledge and training for the acquirement of skill, that is, the application of knowledge to the solution of practical problems. Both are necessary parts of the preparation for any life work. The 2 words are often loosely used synonymously, but they are far from synonymous. Education is a divergent or broadening process, while training is a convergent or narrowing process. Education is directed toward the attainment of a knowledge of many things *and of the relationships between them.* Training is directed toward the practical application of possibly only a single item of knowledge with no consideration whatever of its relationship to others. Education may be likened to a climbing up on a high mountain whence the surrounding terrain may be observed as a whole. Intellectually it implies the loosening and casting off from the mind and spirit of the shackles of tradition and dogma and prejudice and habit, and helping the mind to expand and grow and encompass ever widening and deepening comprehensions of the unity of the universe, and of the relationships between its component parts and processes.

In this world where each of us must make a living as well as live a life, training for the performance of some specific task is a practical necessity. One can, indeed, earn a living with training alone. Millions do so. Indeed, many highly trained specialists in our modern industrial society make good livings, but training without education can never result in the highest achievement.

I am entirely aware that there is nothing new or revolutionary in what I have so far said. The idea that an "education," in the sense above defined, should constitute the foundation upon which to build one's life work is not new. In fact, 35 years ago, when I was preparing for college, it used to be urged that a liberal arts education ought to precede technical training, and this argument may still be advanced in some quarters for aught I know. Here and now, however, the shoe is on the other foot and we are investigating the thesis that an *engineering* education should constitute the base for *any* kind of training. Is there a logical reason for this change? I think there is.

An Engineering Civilization

The civilization in which we are now living is an engineering civilization. Scientists, inventors, and engineers have made it, and engineers keep it going. From our first breath to our descent to the grave we are in almost continuous contact with some product or process of engineering. This was not always so. In simple and more primitive times such machines as were used were fashioned largely by trial and error. It is only within the last 100 years that mechanical, electrical, and chemical engineering have really existed at all and only within the last 50 years that they have become the overwhelmingly dominant

* One of the 4 addresses comprising a symposium on engineering education delivered at the annual joint meeting of New York and New Jersey alumni of Worcester (Mass.) Polytechnic Institute held in New York, N. Y., Dec. 6, 1934; published by the Alumni Association of the Worcester Polytechnic Institute in a supplement to the *Journal* of W.P.I., Jan. 1935.

factors that they now are in our daily lives. In view of this revolutionary change it is not only proper but imperative that we reconsider the question of what is the best preparation for a life work.

How does this changed situation affect, let us say, the other professions? Take, for instance, the law. A large proportion of the civil cases in our courts involve the many technical devices of this engineering civilization. I have listened to lawyers trying such cases whose ignorance of the simplest natural laws and physical relationships was pitiful; and on the other hand I have read judicial decisions proclaiming such a clear and exact knowledge of fundamental engineering facts and relationships on the part of the judges who wrote them that their mere perusal by an engineer was an intellectual treat. Is it possible that the *engineering education* possessed by these judges—however attained—was the reason for their elevation from the bar to the bench? I think it highly probable that it was at least an important factor.

Or take the ministry. In this technical age a minister who is ignorant of the fundamental laws of physical nature is surely under a severe handicap. The minister who is not accurately informed on such matters and attempts to interpret the scriptures today without benefit of modern scientific knowledge is likely to find himself greatly embarrassed. Indeed, when a modern scientist like Sir James Jeans says, as he does in his "The Mysterious Universe," "Today there is a wide measure of agreement—that the stream of knowledge is heading toward a non-mechanical reality; the universe begins to look more like a great thought than like a great machine. Mind no longer appears as an accidental intruder into the realm of matter; we are beginning to suspect that we ought rather to hail it as the creator and governor of the realm of matter"—and again "We discover that the universe shows evidence of a designing or controlling power that has something in common with our own individual minds"—when, I say, a great scientist makes such a statement as this, it appears that modern science and modern religion are not so far apart, and the modern minister surely cannot get along without a pretty accurate knowledge of modern science.

Obviously, in the short time at my disposal, I cannot take up one at a time every possible "life work" and individually argue the value of an engineering education as a foundation for it. Somewhere we must start to generalize. Now, if there is one thing that the progress of scientific knowledge has demonstrated it is the *unity* of nature. I like to think of it in these terms, that no matter where you may dip into nature's ocean of information or just what set of simultaneous equations you may find in your net, *you will always get the same value of X*. For instance, the velocity of light in free space, whether approached from the optical or from the electrical angle, yields the same answer. Planck's constant, *H*, keeps bobbing up, always with the same value. Newton's laws of motion are all-embracive. Nature's fundamental ways of doing things are universal. They may appear in different guises, but the same old fundamental laws and processes and relationships bob up serenely, and may be recognized by those who have learned to understand nature's language wherever they appear.

Same Fundamental Laws Govern Both People and Things

All "life works" have to do with things and people. Some, like engineering, have to do more with things; others like the law and the ministry, more with people. But if it is true that nature's ways of doing things are universal, then must it not be true that the same fundamental laws which govern the behavior of *things* also govern the behavior of *people?* Admittedly it is difficult to prove this for 2 reasons: first, because there is no way of accurately measuring the magnitude of the spiritual forces which act on people, nor of their effects; and second, because of the multiplicity of such forces which act simultaneously, thus making it difficult to identify the forces with their effects. But, nevertheless, qualitatively human forces and their effects can often be identified, and their operation interpreted and more clearly understood by comparison with analogous physical laws. For instance, suppose we observe that if some one criticizes some task which we have performed we get angry in proportion to the degree of imperfection in our performance of the task. In other words, the poorer the job we have done the madder we get when any one criticizes it. We might express this in an equation something like this:

$$\text{Anger} = (f)\,\frac{\text{criticism}}{\text{excellence of performance}}$$

Now if in order to illuminate and better understand this observation we seek a physical analogy for this expression, we may find it in the thermal realm in the expression

$$\text{Temperature rise} = (f)\,\frac{\text{heat added}}{\text{specific heat}}$$

or in the electrical realm we may similarly write

$$\text{Potential} = (f)\,\frac{\text{charge}}{\text{capacitance}}$$

Thus it appears by analogy that "excellence of performance" might be defined as "ability to absorb criticism," and "anger" as merely the index of the relationship. Further study would doubtless reveal even more interesting implications. Perhaps all emotion is merely the statistical index on the consciousness plane of the activities of molecules of mind which perhaps constitute the subconscious. The thought has intriguing possibilities.

I do not claim that this is a good example of what I mean, or that this relationship is either true, or if true that it is universal. I have merely used it in an attempt to illustrate how an understanding of the exactly evaluable relationships of physical science and engineering may illuminate and clarify the understanding of human reactions even though the human forces and reactions cannot be evaluated in arithmetical terms.

The example just cited relates to an individual human reaction. In the field of mass human be-

havior, such as may be studied through the use of human statistics, much more consistent and universal relationships may be discovered. In many cases, in fact, such relationships may be evaluated and quite accurate predictions made therefrom. The life insurance business is founded on human statistics and many other businesses make use of similar records of average or mass human behavior. The method is analogous to certain aspects of thermodynamics, for instance, where temperatures and pressures of gases appear as statistical averages or summations of individual molecular velocities and impacts. The magnitudes relating to the individual molecules (or persons) cannot be measured and would probably be of little significance if they could, but the statistical summations or averages are significant and are found to obey certain laws or relationships by means of which correct conclusions can be drawn and useful predictions made. Thus the scientific method may be applied even to human behavior, and relationships found analogous in many ways to those governing the behavior of inanimate things.

The point I am trying to make is this, that if natural laws are universal in their operation though they can be exactly evaluated only in their physical manifestations, a knowledge of these physical relationships such as must result from an engineering education cannot but be of immeasurable value in interpreting observations of either material or human reactions in whatever walk of life one may be placed.

Up to this time I have not attempted to define exactly what I mean by an engineering education. Perhaps this hesitation has been due to my realization that there are those present much more capable of doing this than I. However, it seems my thesis can hardly be complete without such a definition, so I shall now attempt it.

A Definition of Engineering Education

Such an education, as I see it, will comprise a content and a method, of which the latter is the more important. As to the content, it would start of course with the study of the characteristics of pure abstract numbers, that is, arithmetic, the algebra, and the calculus. It would then advance to the study of the characteristics of Euclidean space, namely, geometry. It would then proceed logically to the study of the matter which occupies space and its behavior on the mass plane, namely, the physics and mechanics, thus introducing the concepts involving time and energy. The next logical step would seem to be the study of the behavior of matter and energy on the molecular plane, namely, thermics and thermodynamics. This might logically be followed by the study of the behavior of matter and energy on the atomic plane, that is, chemistry and electrochemistry and, finally, with a study of the behavior of matter—energy on the electronic plane, namely, electricity and magnetism, and of energy on the vibratory plane, namely, optics and radiation.

Perhaps these technical phases of a purely *engineering* education should stop here, but if time permits, at least a glimpse should be taken of subatomic physics, relativity, and the wave mechanics, because although these subjects may not be understood and have little engineering significance, enough of their import can be gained to emphasize the oneness of the universe. For instance, the statement that in certain concepts of the wave mechanics an electron may be defined as "the one spot in the universe where a multiplicity of waves fail to completely neutralize each other" conveys a sense of identity between the electron and the universe in a manner challenging to thought. Along with these subjects there must of course be some language, some history, some economics, some finance, and some art.

Now as to methods, what is fundamental is the need to stress all through the educational process, the interrelationships between all these seemingly dissimilar subjects, the reappearance in them all of the fundamental laws, and the dual nature of many of the phenomena. Whenever, in any one of these subjects, a fundamental law lifts up its head it ought to be tagged. Of course, my memory may be at fault and much has been learned in 30 years, but I cannot recall that when I was at Worcester any one ever told me, when I was studying algebra, that I was learning the mysteries of pure numbers, the foundation of all exact knowledge; or when I was studying geometry that I was investigating the properties of pure Euclidean space; or suggested to me that physical space could possibly be other than Euclidean; nor when I was studying thermodynamics do I recall that any one took the trouble to point out that the temperature and pressure values with which we dealt were merely the statistical indications on the mass plane in which we worked, of purely mechanical phenomena which were taking place on the molecular plane; that temperature, for instance, was merely a mass plane indication of average molecular velocity, and pressure a mere statistical summing up of molecular impacts. Of course, in those days the electron had hardly been discovered, and atomic structure was still a largely unknown subject; so it is not surprising, of course, that I never learned in my study of chemistry, of the intriguing story of the ordered sequence of the elements, atomic numbers, isotopes, and all the rest of that beautiful and fascinating tale. An engineering education certainly ought to embrace all those things and many more of similar nature, and I have no doubt that such an education, as now taught, does embrace them. From the standpoint of true "education," that is, of leading the mind out from its prison of inherited and acquired prejudices and its slothful acceptance of standardized thought forms into the free and open universe where it can receive the stimulation of truth impinging, like cosmic rays, from every direction, the comprehension of the relationships between these various elements of knowledge is of far more importance than the mere acquisition of the knowledge itself. Something like this is my conception of a real engineering education.

A Tree With Roots of Education

Perhaps it will serve to sum up my argument if we think of one's life work as a tree, with roots of education furnishing support and sustenance, trunk and

branches of training serving to keep its head firmly attached to the solid ground of practicality, with leaves of experience and flowers and fruit of accomplishment overtopping the whole. A tree, if it is to be strong and sturdy, must have its roots in soil both firm and fertile. What soil could be more fertile to nourish the tree of one's life work than the world's accumulated knowledge of the laws of nature which govern the universe, and where can such a soil be found more sound and firm than the clearly defined and exactly evaluated expressions of such laws in the realm of physical science and engineering? It seems difficult to believe that any significant life work so rooted could be other than strong and sturdy and capable of healthy growth and abundant and useful productivity.

Having now reached the end of my thesis it will doubtless have become apparent to my audience, as it has to me, that the engineering education of which I have been thinking is not a specialized civil, or mechanical, or chemical, or electrical engineering education and training. It seems to correspond most closely to a course in general science, and quite naturally so, I think, because it is such a course that would seem to constitute the most practical engineering education for any other than an engineering life work. Such an education would naturally not include all the specialized training required for an engineering career. In the terms of my tree metaphor it would include the soil, the root structure, and possibly the trunk of the tree up to the point where the first branch appears. Beyond that point, special training for the intended career would seem to be required.

In conclusion, I submit that an engineering education such as I have attempted so inadequately to suggest, which opens the mind, shows it how nature itself does its work, and teaches it to apply that knowledge through original thinking to the specific problems of one's life work, is a preparation for that life work which has, and in the very nature of things can have, no equal.

Some Features of the Boulder Canyon Project

A brief résumé of some of the principal features of the Boulder Canyon project is presented herewith. Included in the paper are: (1) a brief review of historical facts leading up to the project; (2) an outline of principal features of the Boulder Dam–Los Angeles power transmission system, which includes a 270-mile 275-kv line; (3) a description of the distributing system in Los Angeles, which this line will feed; and (4) brief discussion of the flood control and water supply features of the project.

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MEN OF VISION serving the City of Los Angeles, Calif., in 1905–07, when the city had a population of 160,000, realized that the limited supply of water from local streams would not provide for a population in excess of possibly 350,000 people, and that for additional supply it would be necessary to go a distance of 250 miles for water from the Owens River watershed along the eastern slopes of the Sierra Nevada Mountains. The possibility of such a supply was studied, together with the possible power developments along the aqueduct resulting from bringing water from an elevation of 4,000 feet to that of the city near sea level, and careful studies were made respecting the project's justification from the standpoint of community benefits and self-liquidation. As a result, bonds were approved in 1907 for the construction of the aqueduct, and additional bonds were approved in 1910 for the construction of the first permanent power generating works along the aqueduct.

The first announcements of the proposed project to the people of Los Angeles, in July 1905, clearly set out that the possibility of developing large blocks of power at low cost would constitute the economic justification for a city of only 160,000 population to attempt constructing a project of such great magnitude. A $24,000,000 project was noteworthy in those days even for large centers of population. The blocks of cheap power have been developed by the city through its Bureau of Power and Light and have been utilized, as visualized and recommended by the management of the Power Bureau more than 20 years ago, for the purpose of establishing industries and of making electricity a convenience in domestic and commercial life, available to all.

During the first 10 years following the beginning of operations by the municipal system in Los Angeles in the fall of 1916, the encouragement of industry by the bureau and through the lowering rates of the Southern California Edison Company, Ltd., adja-

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cent to the city, resulted in increasing gross output for the metropolitan area from $167,000,000 for the first year to $1,250,000,000 for the eleventh year; the total invested wealth of the community threefold; the business of the private electric companies of the community fourfold; and the value of their stock an average of approximately ten points upward.

Of the 3 formerly-existing privately-owned distributing systems within the city, 2 were purchased and effort is being made to purchase the third. Through the establishment of low rates for electric service, but not unduly low, and through the purchase of existing distributing systems, results have been accomplished for the benefit of the community, without harm to invested capital, incomparably greater than could have been accomplished through paralleling or through undue lowering of rates which would have curtailed expansion at times for want of funds.

Los Angeles and southern California have become recognized as an important industrial community. It was manifestly a duty to the community on the part of the Los Angeles Bureau of Power and Light

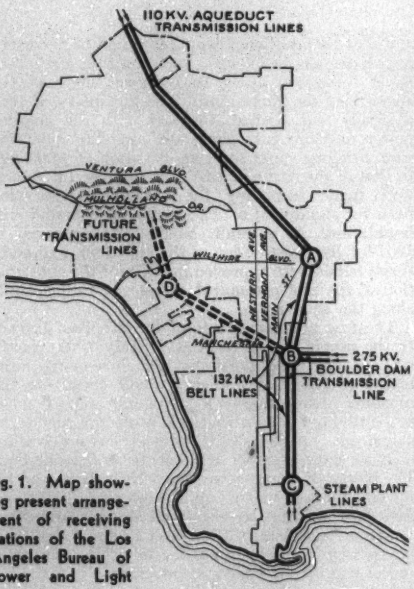

Fig. 1. Map showing present arrangement of receiving stations of the Los Angeles Bureau of Power and Light

to take the lead in bringing to the city additional large blocks of low cost power for the encouragement of additional industrial expansion and the maintenance of an approximation to an industrially and commercially balanced community. Exhaustive investigations showed that the largest block of power, and the lowest in cost, could be obtained, and community welfare otherwise served best, through the construction at Boulder (or Black) Canyon on the Colorado River of a high dam for the development of hydroelectric power, flood control, and storage of water for irrigation and domestic use—thus solving for many years to come the 2 most pressing problems, namely, a large permanent supply of low cost power and domestic water for future generations. On the strength of these investigations, the Bureau of Power and Light was instrumental, in coöperation with Arthur P. Davis, Director of the United States Bureau of Reclamation, in furthering national legislation authorizing the Boulder Canyon project and in furthering appropriations for its construction.

Careful and extensive surveys of the Southwest made in 1925 show the need for the waters that may be conserved by the Boulder Canyon project and for the block of low cost power that may be developed and transmitted to points of use. It is believed from such studies that the complete utilization of the power over a period of possibly 6 or 8 years and corresponding utilization of water for irrigation and domestic use as required will result in doubling the total invested wealth of the Southwest and in more than doubling the total gross annual output of all industry.

By providing flood protection, the project will enable farmers to secure necessary loans or to extend them in areas heretofore threatened by destructive floods, and thus greatly will benefit the metropolitan centers as well as the areas protected from flood and benefited by a more reliable water supply through seasonal and yearly stream regulation.

Boulder Canyon power will be delivered in Los Angeles at low cost and will assist in community development; its purchase was essential to the financing of the Boulder Canyon project and of great value to the Southwest. The Bureau of Power and Light, through the Department of Water and Power, has contracted with the United States government for a portion of the power privileges created through the construction of the project dam in the Black Canyon, and accordingly now is constructing a system for the transmission of power from the power plant below the dam to a central receiving station in the City of Los Angeles, for general distribution and use within the city.

Construction of the power transmission system, approximately 270 miles in length, is being financed through a loan of $22,800,000 by the Reconstruction Finance Corporation on the basis of repayment in full within 20 years, with interest. The loan will result in actual profit to the federal treasury because of the high interest rate charged. The transmission system will consist of 2 275 kv circuits, each divided into 3 equal parts by 2 switching stations along the way. The system will deliver, reliably, 240,000 kw at the receiving station in the city.

The Secretary of the Interior has required the Power Bureau, under the terms of the Boulder Canyon Project Act, to generate and transmit power allocated to and contracted for by the cities of Pasadena, Glendale, and Burbank, Calif., and those municipalities have contracted for the right of use of a portion, totaling 37,368 kw, of the 240,000 kw of

reliable operating transmission capacity on the basis of costs of installation, operation, maintenance, and replacement, with reasonable allowance for overhead percentages.

Research work conducted over a period of 5 years by the Bureau of Power and Light, in its laboratories; at the Harris J. Ryan high voltage laboratory at Stanford University; and on the part of leading manufacturers of electrical machinery, cables, and insulators in their laboratories, made possible the following developments: (1) copper conductors suitable for 275 kv, which did not exist previously; (2) clamps and other hardware suitable for supporting the particular conductor contracted for, which is 1.4 inches in diameter and consists of a hollow copper tube made up of 10 interlocking segments; (3) oil circuit breakers for 287 kv, and 2,500,000 kva interrupting duty, with necessary relays, which will clear any section of either transmission circuit that may be in trouble within approximately $^1/_{10}$ second from the instant of short circuit; and (4) main generating units in the plant with only 17.5 per cent inherent reactance. This and other pioneering work has made possible the provision of generating units, transmission lines, and receiving station equipment at a total cost of $30,000,000 while the investment cost using the best standard machinery, transmission equipment, and construction practice now in use would approximate $42,000,000 and would afford less flexibility and reliability.

The total estimated cost of the transmission line and receiving station facilities is $22,800,000. Of this amount, the transmission line, including right of way and communication facilities will cost $13,700,000; the intermediate switching stations including operators' cottages and permanent camp facilities $2,000,000; the autotransformer step-down station $1,000,000; the receiving station facilities including synchronous condensers $4,400,000; and the transmission line extension from receiving station *B* to receiving station *D* (see figure 1) $1,700,000.

Receiving Stations and Distributing System

Preliminary Studies. Engineers of the Bureau of Power and Light realized that the amount of power that could be supplied to a solidly interconnected system for distribution must be limited. The limitation might be controlled by ability to provide successful control equipment, but the actual limiting features are combined economy of investment, maintenance, and replacements coupled with reliable operating conditions.

In order that over-all economy and reliable service may be realized, the main power supply for Los Angeles, which comes from distant hydroelectric plants in large blocks, must be delivered in blocks thus limited in capacity at separate receiving stations in different sections of the city; and from the rceiving stations it must be distributed over moderately high voltage lines to numerous local distributing stations in each of the respective sections.

It is true, also, that in the interest of economy and reliability the required steam auxiliary and stand-by capacity must be generated at some advantageously located center and made available by means of interconnecting lines to each of such central receiving stations for auxiliary purposes and for stand-by in emergencies. The alternative of having separate steam auxiliary and stand-by for each block of hydroelectric power would be exceedingly costly in itself and, furthermore, there would be no provision for profiting by diversity through interchange between

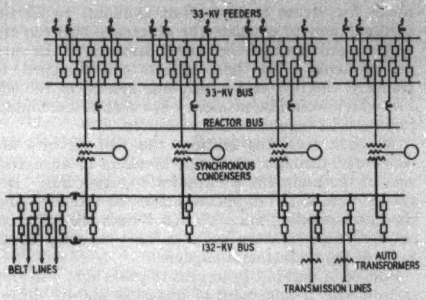

Fig. 2. One-line wiring diagram of a typical receiving station

such central receiving and distributing stations, nor for the greater reliability afforded by such interconnecting lines.

General Plan of Distributing System. Saturation of the area when fully developed in and immediately around Los Angeles probably will require a power supply of 1,500,000 kw. This area and load will be supplied ultimately from 5 or possibly 6 independent power systems, each with its central receiving and distributing stations located more or less centrally within one of the respective load sections of the city. Each system ultimately will have a load with a peak demand commensurate with 250,000 kw. At the present time 3 such receiving stations are in operation and are designated as stations *A*, *B*, and *C* (see figure 1).

A fourth central receiving station, to be known as station *D*, is projected and will be constructed in conjunction with the Boulder Canyon power transmission system, the main terminus of which will be at Station *B*, located in the east central part of the city, with station *A* at the north and station *C* in the harbor district to the south, as shown in figure 1. Figure 2 shows a one line diagram of a typical central receiving and distributing station. The transmission circuit voltage of 275 kv is transformed to the 132 kv bus voltage by means of autotransformers, which, technically speaking, are part of the transmission lines.

Power is distributed from each receiving station to the local distributing stations of the respective districts at 33 kv. The circuits are radial from the receiving station and generally tandem from one local station to another. The main 33 kv receiving station bus is sectionalized into 4 independent sections, each

bus section having its own 132–33 kv transformer bank. Each bus section also is connected to a reactor bus through rather large 33 kv reactors. Under normal operating conditions there are practically no energy losses in these reactors.

The various receiving stations are tied together by duplicate 132 kv belt circuits, the purpose of which is to hold the several systems in synchronism, to supply power to any one system from the other systems in event of transmission circuit failure, to make the steam reserve plant available to all the systems, and to equalize the difference between the power available and the power demands of the various systems. The belt circuits are designed to transmit the full load of any one system of 250,000 kw, which would be necessary in event of a complete failure of its regular source of supply.

At each receiving station, the belt circuits are connected through oil circuit breakers to an extension of the main 132 kv duplicate station bus. Between each of the duplicate busses so extended and the corresponding main station busses are large reactors. Each reactor has a current capacity equal to $^1/_2$ of the total station capacity.

Station *A* was put in service 18 years ago. In this station, the arrangement of busses is slightly different from that described and the high voltage bus is operated at 110 kv, the transmission voltage from the aqueduct plants, instead of 132 kv. The tie between station *A* and the belt circuits is the same as described except that transformers incorporating the necessary reactance are installed between the 110 kv station bus and the 132 kv belt circuits.

Each local distribution station supplies an area of from 3 to 7 square miles depending upon load density. Three sizes of stations are standard, 3,000, 10,000, and 50,000 kw. These stations are all of the indoor type and a great deal of attention is given to the architectural details of the stations and to the appropriate landscaping of the grounds. Figure 3 shows a one line diagram of a typical local distribution station.

Large industrial consumers having loads of 1,000 kva or greater are generally supplied directly from the 33 kv system. Each consumer has connections to 2 independent 33 kv circuits. These circuits are entirely separate from the 33 kv circuits supplying the local distribution stations.

When developed to a peak load of $1^1/_2$ million kw, the system as described will have a short-circuit duty in its various parts as follows: The 132 kv belt circuits, being the common tie between the various systems, will have a short-circuit duty not to exceed 3,500,000 kva. The duty at any receiving station will not be more than 2,500,000 kva on the 132 kv bus, and 1,500,000 kva on the 33 kv bus. The duty on any 33 kv distribution station bus will not be more than 1,000,000 kva.

Boulder Canyon Project

The Colorado River Boulder Canyon storage and power project, which now is nearing completion, will provide needed flood protection in the Imperial Valley and other agricultural areas in California and Arizona along the lower reaches of the river; will regulate the flow and conserve the flood waters for the benefit of irrigation and domestic supply; and will provide large blocks of low cost electric power.

The flow of the Colorado River varies greatly through seasons of the year and through periods of low and high annual precipitation in the river basin and run-off. The average flow through Boulder Canyon site under present conditions of water use in the upper basin states equals 22,000 cubic feet per second, which corresponds to an average yearly run-off measured at the Boulder Canyon site of 15,915,000 acre-feet.

During the months of May, June, and July the annual flood run-off takes place, and during early fall the river flow reaches its low mark for the year. At this period the flow is often less than the amount of water required for irrigation below in California and Arizona. During the year 1934 the low flow was but 1,570 cubic feet per second, while the usual total requirement for irrigation during the early fall months is approximately 5,000 cubic feet per second. This shows the great necessity for conservation of flood waters and regula-

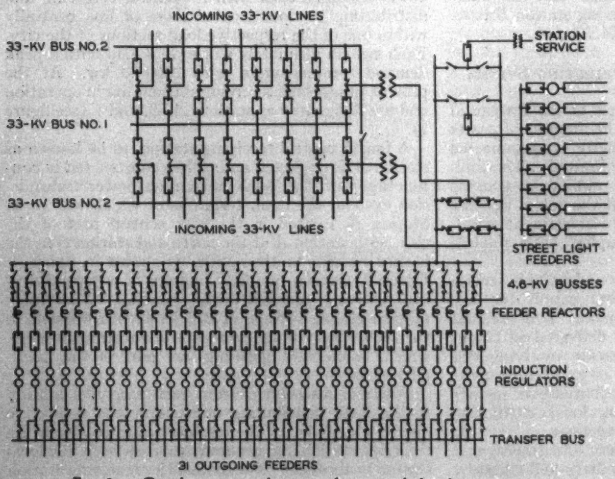

Fig. 3. One-line wiring diagram of a typical distributing station

tion of the stream for the benefit of agriculture and in order to make possible the needed additions to the domestic supply of cities of southern California.

Great benefit will result from the storage project through the elimination of silt amounting to a yearly average of something in excess of 100,000 acre-feet now passing the Boulder Canyon site. The great reservoir will provide ample capacity for intercepting the burden of silt for centuries to come. The storage capacity is equivalent to the silt of 300 years, but future storage at Glenn Canyon will intercept more than half the silt and reservoirs above Glenn Canyon, which will be provided for power development, will help regulate the flow and reduce the capacity requirement at the Boulder Canyon storage for flood protection and conservation purposes.

Imperial Valley lies from 100 to 300 feet below the level of the river as it passes southward between its dykes to the east, and the valley is nearly that distance below sea-level. The danger of floods has been a continual menace to this great valley. Millions of dollars have been spent for construction and maintenance of levees thus seeking to protect the region from overflow, with only partial success. Several breaks of magnitude in the levees occurred during 1905–06 and 1907, causing inundation of much of this rich valley floor and untold damage to crops and homes. To complicate the situation further, the reaches of the river where breaks in the levees generally occur are in Mexico and are thus under foreign jurisdiction.

Through the sale of the leases of power privileges the United States government will receive, in addition to full reimbursement for its investment with interest within 50 years and in addition to funds for yearly payments to the states of Arizona and Nevada in lieu of taxes, estimated surpluses or profits amounting to $63,000,000 for the period, together with further profits over the period amounting to the difference between 4 per cent interest on an average of $60,000,000 and the percentage of interest actually paid by the government.

The solid concrete dam rises 587 feet above the natural water level of the river creating a storage capacity of 30,500,000 acre-feet or more than 4 times the capacity of Gatun Lake along the Panama Canal. When filled, the reservoir will extend 115 miles up the canyons of the Colorado between the states of Arizona and Nevada and 35 miles up the valley of the Virgin River to the north in Nevada.

The ultimate installed capacity of the power plant will be approximately 1,400,000 horsepower at minimum operating head, and will consist of an equivalent of 16 main generating units of 65,000 kw rated capacity each, with a maximum capacity of 82,500 kw each. The machinery and equipment at the power plant will be installed by the federal government and paid for by the allottees of power as advanced rentals in full with interest within 10 years. Title to the complete project, including machinery, will rest permanently with the United States government.

The project will be operated under the direction of the Secretary of the Interior: first, from the standpoint of flood control; second, from the standpoint of water conservation and use for agriculture and domestic purposes; and, third, for the benefit of power. It is declared that the firm or reliable power will equal 4,330,000,000 kilowatt hours at the plant for the first year of operation and will decrease by the amount of 8,760,000 kilowatt hours each year on account of the increased use of water in the upper basin states. In addition to firm power there will be for many years in excess of 200,000 horse power of secondary power available on an average of 70 per cent of the time.

The Bureau of Power and Light of Los Angeles has been designated the generating agent for itself and all public allottees and the Southern California Edison Company, Ltd., as agent for itself and other privately owned power companies. The Metropolitan Water District of Southern California, which was formed for the construction of an aqueduct from the Colorado River for delivering domestic water to 13 cities of southern California, including the City of Los Angeles, was allotted 36 per cent of the firm power and the first right of secondary power for pumping water in and through the aqueduct in order to lift it over the divide; the Bureau of Power and Light of Los Angeles and 3 other municipalities were allotted 19 per cent; the private power companies 9 per cent; and the states of Arizona and Nevada each have an option, which they may use any time during the 50 year period in part or in whole, on 18 per cent of the firm power. The power allotments enumerated are made under firm contracts requiring the allottees to pay for the right of use of the falling water whether utilized or not; and each of the 2 principal lessees or generating agents are obligated to pay for half of the power not used by the states of Arizona and Nevada under their options.

Payments to the federal government for the right of power privilege, that is, the right to use the falling water below the dam for the generation of power, are based upon 1.63 mills per kilowatthour for firm power and 0.5 mill for secondary power, a rate that may be changed at the end of 15 years and every 10 years thereafter, and that is intended to be based upon the cost of power otherwise available in competitive centers.

Justification for the development of a great water and power project like the Boulder Canyon project on the Colorado River depends upon 2 principal factors: (1) the engineering feasibility and the reasonableness of cost of the project itself in proportion to the amount of resources made available; and (2) the sufficiency and permanency of demand for such resources and the actual need for them in the upbuilding of the community affected. These resources may consist of conserved water, developed power, or increased wealth resulting from flood protection or navigation.

The Boulder Canyon project is wholly self-liquidating, including the cost of protection against disaster from floods to large agricultural areas below it, and will result in the creation of resources that will make possible opportunity for livelihood and happiness of an increasing multitude of people in the Southwest.

Circuit Breakers for Boulder Dam Line

Because of its length, 270 miles, the 275 kv transmission line from Boulder Dam to Los Angeles, Calif., requires extremely high speed switching for stability. To meet the requirements, a high voltage impulse circuit breaker, extending the oil blast theory to cover a multibreak construction with double cross-blast ports, has been built. It provides over-all switching times consistently less than 3 cycles (3/60 second). Approximately 10 per cent as much oil is used as in a comparable breaker of conventional design, and only 1/10 of this is exposed to arcing. Large factors of safety are provided over and above the interrupting rating of 5,000 amperes, 287 kv, or 2,500,000 kva.

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THE 275 kv transmission line under construction from Boulder Dam to the City of Los Angeles, Calif., a distance of 270 miles, is the highest voltage transmission line yet undertaken, and the longest line without branch circuits. Because of the distance covered and the amount of power to be transmitted, the line may be required to operate near the stability limit. To secure the maximum through power under fault conditions, the 2 parallel tower lines are united and sectionalized at 2 desert switching stations located respectively 90 miles from each end of the line. At each switching station and at sending and receiving stations 4 2,500,000 kva circuit breakers are to be installed, so connected that in the event of a fault anywhere on the line, only one 90 mile circuit need be cut out. Power then will be transmitted over the remaining 90 mile single circuit and 180 miles of 2 circuit line.

Even with this amount of sectionalizing, stability studies have indicated that a reduction of switching time from 8 cycles to 3 cycles may be expected to produce a substantial increase in the maximum power limit. In an extreme case, this increase might approach 50 per cent. Three cycle operating time, therefore, has been specified for the high voltage circuit breakers to be installed both at terminal and intermediate switching stations.

Circuit breakers designed along conventional lines for this high voltage would be enormous and would require a tremendous volume of oil, very heavy foundations, and special oil handling equipment; such breakers thus would be particularly inconvenient for a desert location. Considerable time would be required to drain such a circuit breaker, even for inspection. In fact, all the operations of service and maintenance would be complicated, especially at the remote points where some of these circuit breakers are to be installed. The requirements, therefore, appeared to indicate the desirability of a new type of breaker; the breaker developed to meet these requirements is described in this paper.

The principal novel features of this circuit breaker are: its high speed operation, 3 cycles from initiation of tripping impulse to interruption of circuit; and its small oil volume, about $^1/_{10}$ that of an equivalent breaker of conventional design. Furthermore, the design of the breaker is such that the oil exposed to arcing is only about 1 per cent of that exposed in an equivalent conventional breaker. Its high speed operation results in:

1. Improved system stability.
2. Reduced damage to line conductors and insulators from dynamic current following faults.
3. Reduced maintenance. One cycle or less of arcing produces negligible burning on contacts. Oil deterioration is very slight.
4. Improved service. A voltage dip is hardly noticeable even with sequential operation.

Advantages of the small oil volume are:

1. No special oil handling equipment required.
2. Negligible fire hazard.
3. Unusually short time to drain and refill.
4. Interior parts available for inspection in short time.
5. Large saving both in first cost and replacement of oil.
6. Low weight simplifies foundation problem and difficulties of transportation and erection. All parts are light in weight, giving easy handling.

Theory

The oil blast theory was enunciated in 1931 and has been described and amplified in various publications since that time (see references at end of paper). In brief it has been shown that the behavior of an oil blast circuit breaker is explained by the equation:

$$\frac{\frac{v}{t}}{\frac{v}{d}} = \frac{d}{t} \qquad (1)$$

where

v = voltage
t = time
d = distance
v/t = rate of rise of recovery voltage
v/d = oil dielectric strength
d/t = oil velocity

If the oil velocity is greater than d/t, the arc can-

Full text of a paper recommended for publication by the A.I.E.E. committee on protective devices, and scheduled for discussion at the A.I.E.E. summer convention, Ithaca, N. Y., June 24–28, 1935. Manuscript submitted Jan. 9, 1935; released for publication Feb. 4, 1935.

not restrike after a current zero; if less, it may restrike. In this equation, the dielectric strength of the oil has been shown by experience to be approximately 55 kv for 0.1 inch, a value not sensitive to oil condition. The reasonableness of this value has been demonstrated by impulse tests on new and on used oil.[1]

Where pressure and not velocity is measured, the 2 are related by equation 2, which expresses the well-known law of flow of hydraulics:

$$v = \sqrt{2gh} = 12.8\sqrt{p} \qquad (2)$$

v = velocity in feet per second
g = gravitational acceleration, 32.2 feet per second per second
h = head in feet
p = pressure in pounds per square inch
The constant is for oil of density 0.9.

For the original form of contacts, a single wall of oil formed at substantially the velocity of linear oil flow as shown in figure 2*a*. Later the cross blast arrangement was developed for higher voltages as shown in figure 2*b*. In this form the gas bubble is separated from both contacts by oil walls which must be punctured to reëstablish the arc. In the most recent development 2 ports are provided, as shown in figure 2*c*. The gas bubble is divided into 2 parts, giving a total of 4 oil walls forming at the linear velocity of oil through the ports.

1. For all numbered references see list at end of paper.

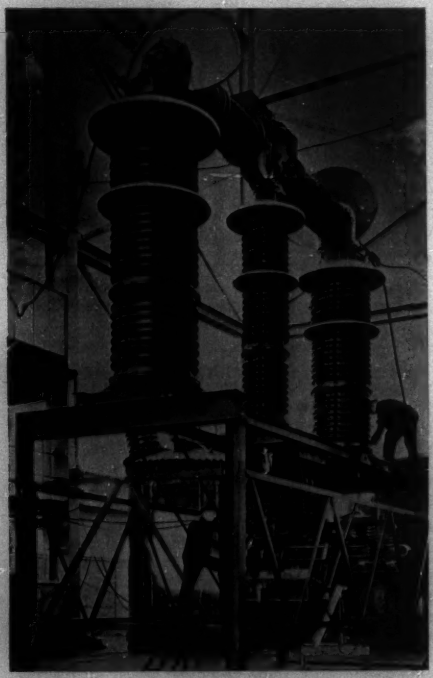


Fig. 1. One of the 287-kv single-phase high-speed impulse oil circuit breakers set up for test

The form of oil blast circuit breaker most suitable to meet the present requirements is the impulse breaker, in which a positive and definite oil flow is produced by a spring driven piston.[2] This form of circuit breaker has 2 important advantages: Since the oil is driven mechanically, it is not necessary to wait for the formation of an arc before oil flow is available to interrupt the circuit. This is important in securing high speed operation. Since the full oil velocities are available at light currents as well as heavy, it is not necessary to provide a long stroke. This makes possible the design of a circuit breaker of moderate proportions for this extreme voltage. The impulse theory has the further advantage that as a quantitative theory, it permits the quantitative design of this very high capacity breaker. Otherwise, the design would be dependent entirely upon the trial and error method, which becomes rapidly more cumbersome and expensive as the size of the apparatus increases.

Previously published studies have indicated the desirability of multiple breaks for high voltage, provided a structure is available that gives reasonably uniform distribution of potential between the various breaks.[3]

An oil flow should be maintained for a conservative length of time, say 4 or 5 cycles. The amount of oil required to keep up this flow is directly proportional to the velocity, and the pressure is proportional to the square of the velocity. The work done per operation is the product of these 2 and, therefore, is proportional to the cube of velocity, as shown in equation 3.

$$p = Kv^2$$
$$d = kv$$
$$e = pd = Kkv^3 \qquad (3)$$

p = pressure
v = velocity
d = displacement
e = energy
n = number of breaks
K = constant
k = constant

By using several breaks, provided the recovery voltage is divided equally among them, the oil volume required to pass through several breaks is proportional to their number, but the required oil velocity is inversely proportional to the number of breaks. Therefore, the energy is inversely proportional to the square of the number of breaks, as shown in equation 4.

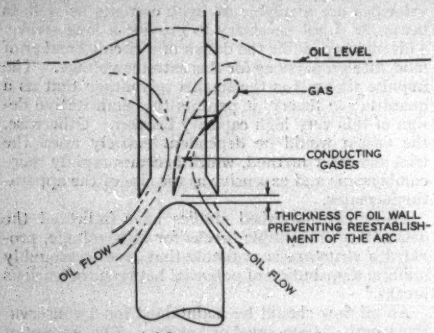
For n breaks providing the same aggregate velocity:

$$p = K\left(\frac{v}{n}\right)^2 \qquad d = kn\left(\frac{v}{n}\right)$$
$$e = Kk\frac{v^3}{n^2} \qquad (4)$$

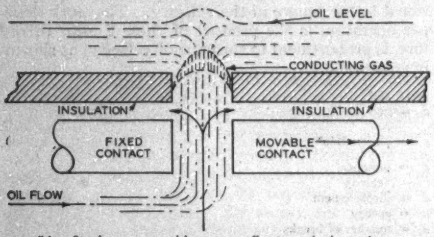
This relationship holds only so long as the division of recovery voltage among the breaks is equal.

Where the division of recovery voltage is unequal, the voltage appearing across the most highly stressed break would appear a logical choice instead of the total voltage divided by the number of breaks. On a line-to-ground fault on a multibreak tank type breaker, as much as 90 per cent of the total voltage may appear across the break on the ungrounded side.[4] A good deal of careful design work is necessary, therefore, if the relationship expressed in equation 4 is to be utilized to advantage.

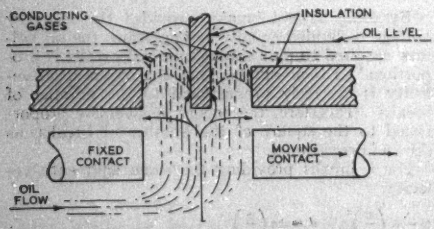
As a preliminary to building the first 287 kv circuit breaker, a 138 kv breaker was constructed.



(a). Original radial flow most suitable for high current low voltage circuits



(b). Single port cross blast, more effective at higher voltages



(c). Double port cross blast most effective for high voltages. Further multiplication extends time required to uncover ports

Fig. 2. Cross sections of contacts for 3 types of oil blast circuit breakers

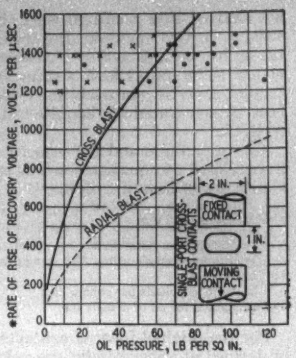


Fig. 3. Experimental verification of relation between oil pressure and rate of rise of recovery voltage for one of 4 single-port cross-blast breaks

* Plotted recovery rate is calculated recovery rate times 0.48 where entire breaker was used, and times 0.63 where grounded half of breaker was short-circuited

× Pressure at next to last current zero

⊙ Pressure at last current zero

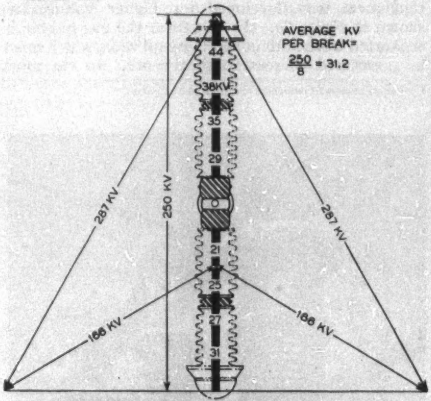


Fig. 4. Potential distribution across breaks of 8-break 287-kv impulse circuit breaker under worst field conditions

This circuit breaker had 4 breaks,[5] the individual breaks being as shown in figure 2*b*. Potential distribution measurements were made on this breaker to determine what fraction of the total voltage would appear across the most highly stressed break; figure 3 gives an analysis of these tests. In determining the rate of rise of recovery voltage which is used as the ordinate, the total rate of rise appearing across the circuit breaker was divided in accordance with the measured potential distribution, and only the value that appears across the most highly stressed break was used. The plotted test points, indicated by circles, represent the pressure and rate of rise at the last current zero, that is, at the time the circuit was interrupted. The crosses indicate the oil pressure and rate of rise at the previous current zero, eliminating only those tests for which at the previous current zero the contacts were too close together to uncover the oil port. The broken line

Table I—Test Data on 287-Kv 600-Ampere Single-Phase Impulse Oil Circuit Breaker, 60 Cycles

Test Volts, Kv	Initial Current in Arc, Amp (Effective)	Rate of Rise of Recovery Voltage, Volts per μSec	Cycles From Auxiliary Relay Trip to Interruption	Contact Separation, In. At Interruption	Contact Separation, In. At Previous Current Zero	Test No.
Full Breaker—8 Breaks						
	6,100	1,070	2.30	0.4	0	34
22	6,700	1,000	2.45	1.1	0.2	35
	7,700	1,130	2.60	1.0	0.1	36
	9,300	990	2.80	1.3	0.2	37
	4,100	2,000	2.75	1.3	0.2	18
	4,400	1,870	2.30	0.5	0	19
44	4,000	2,200	2.55	0.9	0	20
	6,800	1,560	2.40	0.8	0	21
	2,500	2,400	2.65	1.2	0.3	30
66	2,600	2,500	2.60	1.2	0.2	31
	3,100	2,200	2.45	1.0	0	32
	2,900	2,300	2.50	1.0	0	33
	3,100	2,500	2.35	0.8	0	26
88	2,000	2,900	2.35	0.9	0	27
	2,300	2,600	2.40	0.8	0	28
	2,100	2,800	2.60	1.2	0	29
	720	4,300	2.45	1.4	0.2	85
	760	4,700	2.45	1.2	0	86
264	760	4,500	2.55	1.5	0.3	87
	760	4,900	2.45	1.3	0.2	88
Half of Breaker—4 Breaks						
88	2,500	2,100	2.65	1.5	0.8	89
	2,500	2,300	2.85	1.8	0.8	90
	1,350	2,900	2.45	1.0	0	7
132	1,460	2,800	2.45	1.0	0	8
	107	660	2.45	0.7	0	16
	67	410	2.25	0.4	0	17
154	1,230	4,400	2.55	1.3	0.3	91
	1,350	4,200	2.65	1.4	0.8	92
176	1,140	4,500	2.70	1.8	0.9	93
	1,070	4,800	2.60	1.5	0.5	94
	990	4,300	2.85	1.9	0.9	95
220	970	4,400	2.50	1.1	0.3	96
	830	4,400	2.50	1.4	0.4	97
264	730	4,900	2.45	1.2	0.1	98
One Single Break						
33	1,690	1,190	2.75	1.9	0.2	99
66	3,800	2,100	2.40	1.2	0	100
	3,200	2,300	2.80	2.3	0.6	101
88	2,300	2,500	2.65	2.1	0.4	102
	2,400	2,400	2.60	1.6	0.1	103
110	1,850	2,400	2.45	1.2	0	104
	2,300	2,100	4.15	5.2	4.5	105

marked "radial blast" corresponds to an impulse dielectric strength of 55 kv for $^1/_{10}$ inch of oil, determined in the first work on the impulse breaker, figure 2*a*. This data merely has been replotted in terms of oil pressure instead of velocity. The full line of figure 3 has twice the ordinate of the broken line, to take account of the fact that the flow of oil is across the contact instead of radially, as in figure 2*b*. The fact that this line separates the region of all circles from that of mixed circles and crosses proves not only that the cross blast is, as expected, exactly twice as effective as the radial blast in terms of recovery voltage cleared for a given oil pressure, but also that the behavior of a multibreak breaker of this type can be predicted by determining the rate of rise appearing across the most highly stressed break and then applying the single break formula for the rate of rise so found.

Figure 4 shows the potential distribution determined for the 287 kv circuit breaker. The sides of the triangle represent the line voltage vectors. When the first phase clears, in the event of a 3 phase fault, the recovery voltage appearing across the phase is 0.866 times the full line voltage, and this is distributed across the 8 breaks of this circuit breaker, as shown in the diagram. Using this method of determining the recovery voltage rate across the most highly stressed break, figure 5 has been prepared. The lowest broken line is repeated from figure 3. Since this cross blast proved twice as effective as the radial blast, it seemed possible to break up the arc space further and secure even more effective use of the oil blast by the construction shown in figure 2*c*. Accordingly, in the new design 2 ports are employed instead of one for each pair of contacts. In the lower right-hand corner of figure 5 is shown a plan view of the arrangement. Oil carries the gas bubble into these 2 ports where it is broken up twice as much as with the single port arrangement of figure 2*b* and 3. On the assumption that the effectiveness in terms of recovery voltage should be twice as great in this arrangement as in that of figure 2*b*, the full line of figure 5 has double the ordinates of the full line of figure 3. So far, the data taken have not yielded any crosses, that is, there have been no "next to the last" current zeros at which the 2 ports have been uncovered. In all tests the circuit has been interrupted at the first current zero after the moving contact has uncovered the 2 ports, although in many of the tests the recovery rate was considerably higher than would have been cared for by the single port arrangement in figure 3. Additional tests are to be made to determine the limitation of this new arrangement and establish quantitative factors. The tests made so far, however, have established a considerable advantage in the double port for a high voltage circuit breaker.

Construction

Figure 1 shows one pole of the circuit breaker developed to meet the severe requirements of the

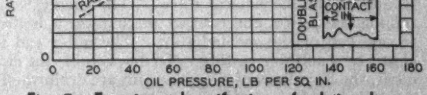


Fig. 5. Experimental verification of relation between oil pressure and rate of rise of recovery voltage for one of 8 double-port cross-blast breaks

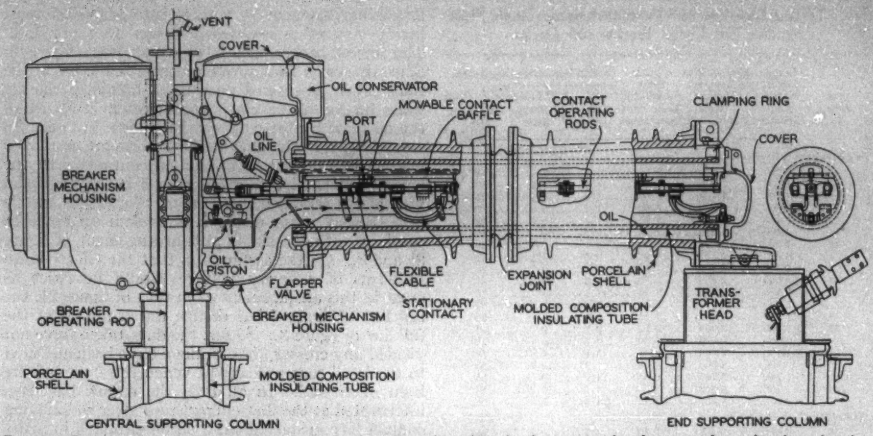


Fig. 6. Cross section of one element of the Boulder Dam–Los Angeles line circuit breakers; each single phase breaker consists of 2 elements

Boulder Dam–Los Angeles line, incorporating the structure indicated by the preceding theory. Instead of the single interrupting element of the 138 kv design, 2 have been provided, each containing 4 breaks and a piston to furnish the oil blast. These 2 interrupted elements are mounted through hinged joints upon a central column made up of a tube of molded insulating material protected from the weather by a porcelain shell. Through this tube the wood operating rod passes to the spring charged mechanism below. The outer ends of the interrupting elements are supported on cascade type current transformer columns by a roller joint to permit freedom of expansion and relative movement resulting from vibration, misalignment, or other causes. The pole is mounted upon a steel framework so as to provide adequate clearance from live parts to ground. A complete 3 phase unit of this design weighs approximately 110,000 pounds, as compared with 290,000 pounds for a breaker of conventional tank type design. It contains a total of 2,500 gallons of oil, compared with 23,000 gallons for the conventional design, or approximately $^1/_{10}$ as much total oil. The oil actually exposed to arcing is only 210 gallons, or somewhat less than one per cent of the oil exposed in the conventional breaker.

The construction of one of the interrupting elements is shown in figure 6. The interrupting element is built upon a tube of molded insulating material, which is protected from the weather by porcelain shells. These shells, however, are not subjected to any of the mechanical forces. The casting containing the piston and contact mechanism is bolted to one end of the molded tube. The other end is closed by a suitable casting. To disassemble the element, the 35 gallons of oil in one unit are drained off; the circular plate at the end of the unit then is unbolted, permitting the withdrawal of the diaphragm with all of the contact parts attached to it.

Detailed construction of this unit is shown in figures 7 and 8. Figure 7 shows the top of the diaphragm with the rib that braces it to the center of the top of the molded insulating tube. It also shows the exit ports through which the oil flows during operation. The central fin separates these ports so as to prevent the gas bubbles from coalescing after they have been driven through the ports. Figure 8 shows the lower side of the interrupting assembly. The 4 moving contacts are carried on crossheads which bridge the parallel wood rods. The circuit is completed to the moving contacts by means of heavy flexible cable, and each contact is provided with its separate spring to insure uniform pressure on all contacts. The contact surfaces themselves are made of a silver-tungsten alloy. The particular contacts shown have been through 30 or 40 short-circuit operations and show practically no burning. All of the spaces between molded insulating tube and porcelain shell are filled with oil, each space having its separate expansion chamber or conservator.

Each pole is operated by a spring charged mechanism providing positive high speed operation with

Fig. 7. Top of baffle showing discharge of double ports separated by longitudinal fin to prevent breakdown between hot gas bubbles

A—Motion of wood operating rod and piston: each step represents 1/8 inch of travel of rod; 3/8 inch of piston

B—Short circuit current

C—Piston pressure: (1) at interruption, 80 pounds per square inch; (2) maximum, 135 pounds

D—Current in opening trip coil

A—Arc voltage

B—Short circuit current

C—Motion of contacts: each step represents 1/8 inch of travel; (1) contacts separate

D—Current in high speed opening relay coil

A—Total control current

B—Short circuit current

C—Pressure at end of tube: (1) at interruption, 110 pounds per square inch; (2) maximum, 143 pounds

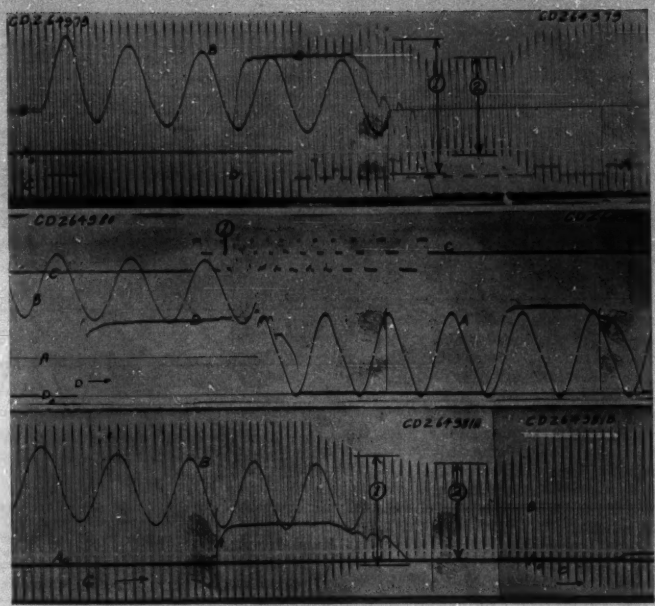


Fig. 9. Oscillograms showing 1/3 of 287 kv impulse oil circuit breaker interrupting a 132-kv 1,200-ampere short circuit

Time from trip impulse to contact separation, 2.0 cycles; to interruption, 2.5 cycles. Contact separation at interruption, 1.0 inch per break. Rate of rise of recovery voltage, 2,900 volts per microsecond

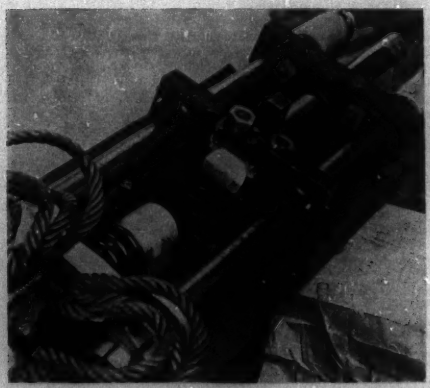


Fig. 8. Lower side of baffle showing contact and operating rod assembly and entrance of double ports. Contacts are in excellent condition after extended tests

small drain on the station battery. A permanent magnet trip of the flux shifting type gives highest speed response with no steady drain on the station battery.

Tests

The 287 kv rating carries with it a one-minute high-potential test of 650 kv. This test was made successfully with the circuit breaker open and one side grounded. After this, the voltage was raised to a flashover value corresponding to 780 kv under standard conditions. At this point the flashover occurred across one of the current transformer columns to ground, rather than across the interrupting elements. High voltage impulse tests also were made, in which the circuit breaker was flashed over by a 1×5 microsecond wave having a crest of 1,900,000 volts. As before, the flashover occurred across the outside of the current transformer columns. An extended series of interrupting tests was made, from which representative tests are given in table I. Of all other tests made but not shown in the table, none exceeded 3 cycles over-all from the trip impulse. In this table tests are shown for currents as high as 9,300 amperes, or nearly twice the interrupting rating of 5,000 amperes. The whole breaker has interrupted 264 kv, compared with 250 kv which is 0.866 times the line voltage. This same voltage has been handled successfully by half of the breaker without increased arcing time; 88 kv has been interrupted by a single break without increased arcing

time. A voltage as high as 110 kv has been interrupted by one break; this latter voltage, however, appears to indicate the ultimate capacity of one break, as in one of the 2 tests at that voltage the arcing time was extended. The average total time for all tests except the single break tests was 2.54 cycles, of which 0.54 cycle was arcing time. In 17 of the tests shown in table I, the contacts had not separated at the current zero previous to the one at which interruption occurred. The maximum arc length of all the full breaker tests was 1.5 inch per break, while for $^1/_2$ breaker tests the arc length was 1.9 inch per break. During 47 tests, including the high current tests in the table, oil dielectric strength fell from 28 to 20.5 kv for 0.1 inch.

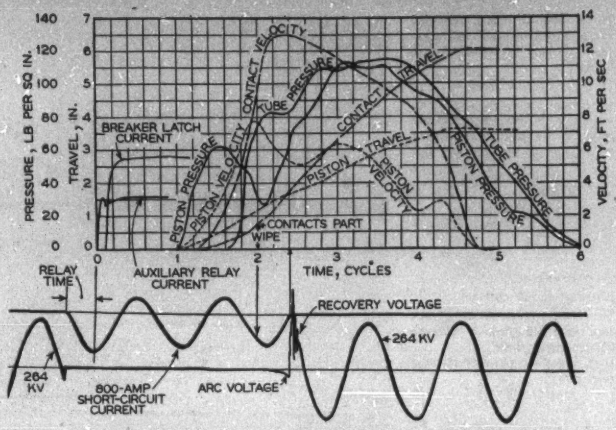


Fig. 10. Time diagram of operating characteristics of 287 kv impulse circuit breaker; time in cycles is based upon a 60 cycle system

The interrupting rating of this 287 kv circuit breaker is 2,500,000 kva. The highest single phase capacity in any of the tests of the whole breaker in table I is 300,000 kva. However, in test 100 made on one break at a voltage 50 per cent higher than one break can receive in service, 3,800 amperes was interrupted; this is equivalent to a 3 phase interruption of 1,890,000 kva on the whole circuit breaker. A further analysis of the basis of extrapolation with this type of breaker appears in the appendix.

Figure 9 shows oscillograms of a typical test showing an interruption of the circuit in $2^1/_2$ cycles. These oscillograms show the measurement of pressure and the travel of various parts. These data have been analyzed to make up the composite chart shown in figure 10, on which all of the various events have been plotted. It appears that after the trip impulse has been impressed upon the auxiliary relay, the current begins to flow in the main trip coil after 0.1 cycle. At the end of 1 cycle, motion of the major parts is observed. At 2 cycles the contacts separate, and at the next current zero, occurring in this test at 2.4 cycles, the circuit is interrupted.

Appendix—Extrapolation of Test Results

In general, the larger circuit breakers of today cannot be tested at rating in any of the existing testing plants. It is necessary, therefore, to use some basis of extrapolation, just as is done with other large equipment. The basis of extrapolation is not the same for different types of circuit breakers. Two methods of extrapolation are available for the high voltage impulse breaker which prove its high power performance with certainty, but which would not be applicable to other types without special proofs.

The potential distribution has been determined. The highest voltage appearing across one break is known. Test 100 (table I) at a voltage 50 per cent higher than the highest voltage in service was equivalent to nearly 2,000,000 kva on the whole 3 phase breaker. If there were only a few breaks, or if the voltage actually appearing across one break were not ascertainable, this method of extrapolation would not be available.

The impulse breaker has another property helpful in extrapolation that is only approached by a few other types. Arc length is constant over a wide range of test voltage. The distress in a circuit breaker is caused by electromagnetic forces, contact burning, and gas formation with the pressures incident thereto. These are determined by the arc length in time and inches. If a circuit breaker has a sufficiently positive arc extinguishing process to operate at full voltage and recovery rate, but at light currents, the question remains: Would the arc interrupting function be modified at heavy currents, and if it is not modified will the circuit breaker stand the additional punishment accompanying the heavy full rated current?

The high voltage tests of table I prove that the interrupting element will take care of the highest voltages and recovery rates with a safety factor of at least 100 per cent. At lower voltages, arc length in cycles and inches remained substantially the same, as did the oil pressures and oil velocities. Therefore, the ability to handle high voltage and high recovery rate was present even though not used. At lower voltages the current was increased to nearly double rating without altering these voltage interrupting conditions. The 9,300 amperes in test 37 is equivalent on this basis to 4,600,000 kva. It is concluded therefore, that all the distress elements were present and that the simultaneous appearance of voltage and recovery rate would have made no difference. Under these conditions, extrapolation is justified where it would not be if arc length, pressure, and other factors were variable with voltage.

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Direct Measurement of Surge Currents

A new instrument, called the surge crest ammeter, based upon the principle of magnetic retentivity has made available a direct and simple method of measuring surge currents. A study of the behavior of 2 magnetic links under the influence of oscillatory surge currents has made this instrument useful in measuring the per cent oscillation as well as crest values of surge currents. Specimen measurements included in this paper show briefly one application of this instrument.

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TO PROVIDE for a high standard of power service a great many problems related to transient or surge conditions must be met successfully. These problems concern insulation and mechanical strength and involve a great variety of circumstances. The designer must have adequate information concerning the nature of the existing transient conditions and reliable data pertaining to the surge performance of materials and apparatus arrangements. Instruments and methods of measurement adapted to the study of surge voltages and surge currents are necessary.

Throughout the early years of the era of electric power suitable surge instruments were not available. For many years the sphere gap[1–4] for measuring crest values of surge voltages was the only practical surge measuring apparatus in the hands of the engineer. Within recent years surge voltage recorders of the Lichtenberg figure type,[5–7] surge indicators,[8] and the cathode ray oscillograph[9–15] have been introduced in the form of practical working instruments applicable to surge measurements. Good progress in the field of surge measurements has been made since the introduction of these tools.

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1. For all numbered references see list at end of paper.

In studies of lightning strokes on transmission lines[16,17] recent developments have made it vitally important to have available a simple arrangement for the direct measurement of crest values of surge currents. A measuring instrument that would permit the location of hundreds of current measuring stations with a minimum of attention and give reasonable accuracy was required. For this purpose a surge crest ammeter based upon the principle of magnetic retentivity was conceived; it has been made practical through a series of laboratory tests and calibrations extending over a period of 3 years. Field work pertaining to measurements of surge currents was continued in progress along with this laboratory work.[16] As rapidly as instruments and methods were worked out in the laboratory, measuring stations were established in the field. Preliminary surveys of progress in the design of this instrument have been published previously.[18,19] In this early work, which pertained particularly to unidirectional polarity surges, the principles involved and technique were obvious in their simplicity and directness. Later work with oscillatory surges introduced principles and methods that are not understood quite so readily. This paper presents these recent developments including important material not published heretofore.

The principal features of the surge crest ammeter that make it ideal for measuring surge currents are:

1. It is a direct method of measurement; when properly installed the links respond only to the magnetic field present when a current flows through a conductor.
2. It is simple, and because of this a great many measuring stations can be operated at small cost per station.
3. It can be installed easily without disturbing in the least the current carrying circuit.
4. It measures current amplitude and per cent oscillation, and shows current polarity.
5. The same measuring apparatus is used repeatedly.

Principle of the Surge Crest Ammeter

Two small pieces of magnetic material having high retentivity are placed adjacent to the surge current carrying conductor at different distances as shown in figure 1. These are called the inner and outer magnetic links. When the surge current passes through the conductor the links are well within the surrounding magnetic field and are acted upon by a magnetizing force proportional to the current magnitude and inversely proportional to the distance from the conductor. The retained magnetization depends upon the magnetic properties of the link and the wave shape of the surge. However, it has been shown previously[18] that with a properly constructed magnetic link the retained magnetization using direct current is equal to that obtained with a $^1/_2 \times 5$ microsecond wave of the same crest amplitude. Time is therefore not a factor for surges slower than a $^1/_2 \times 5$ microsecond wave.

The magnetization of the links, of course, may be measured by a ballistic galvanometer, but this method is applicable to laboratory work only. Consequently, a simple compact portable instru-

ment was designed for general field and laboratory measurements.[19]

Laboratory Current Calibrations

In making the surge crest ammeter available for general use, a series of interesting and important laboratory calibrations were made. A surge current generator[20] was used as a source from which surges of various wave shapes were obtained.

A symmetrically constructed discharge circuit as shown in figure 2 was arranged. The use of such a circuit with the links mounted on the central vertical member eliminated the necessity for any corrections of link magnetization due to currents in the bus structure.

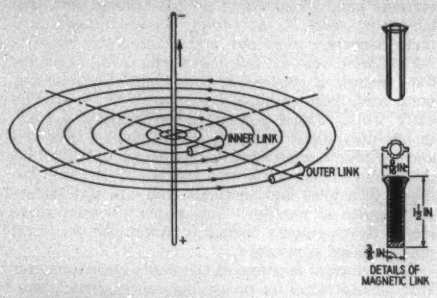


Fig. 1 (above). Principle of operation of surge crest ammeter and details of magnetic link

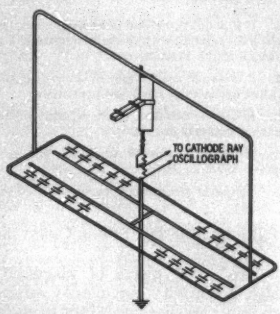


Fig. 2 (right). Connections of surge current generator and apparatus for calibrating magnetic links

The surges used varied from impulses of unidirectional polarity through a series of damped oscillations ranging up to 50 per cent oscillation. The per cent oscillation is the ratio of amplitude of the second half cycle to that of the first half cycle expressed as a percentage. Wave shapes were recorded and amplitudes measured by cathode ray oscillograph. Sample oscillograms are reproduced in figure 3. For each wave shape, current amplitudes were varied over a wide range. Several magnetic links each placed at a different distance from the current carrying conductor were exposed to each wave shape and current amplitude, and thereafter measured on the surge crest ammeter.

A specimen of test results using the waves of figure 3 at various current amplitudes is shown in figure 4. These data pertain to link positions such as shown in figure 1, wherein the inner link is 2.6 inches and the outer link 8.6 inches from the center of current. The ratio 8.6/2.6 is called the "distance ratio." In the upper curves, which show surge crest ammeter readings plotted against crest magnetizing currents, those for both inner and outer links for unidirectional surges are straight lines, showing direct proportionality between magnetizing current and surge crest ammeter readings for such surges. Readings for the outer link of course are less than those for the inner link, the ratio between the 2 being numerically equal to the distance ratio.

For oscillatory surges the curves for both inner and outer links have downward curvatures. Examination of figure 4 will show that this downward curvature is decidedly more pronounced for the inner link, which is in a more intense magnetic field. Curves for the outer link do not show downward curvature of appreciable degree over the range of currents on the abscissas until a surge of 20.2 per cent oscillation is used. For oscillatory surges, therefore, the ratios of readings for the inner link to corresponding readings for the outer link are less than the distance ratio and decrease as the percentage oscillation and current amplitudes increase. The ratios are plotted on the middle part of figure 4. Combining these ratio curves with the inner link curves gives a convenient surge measurement chart. This is done by locating and connecting points of equal ratio on the inner link curves. The inner link curves of the upper part of figure 4 are reproduced in the lower part. Points of equal ratio for each percentage oscillation are located as illustrated by the dotted lines for the 2.4 ratio. For other ratios similar points are located and lines drawn.

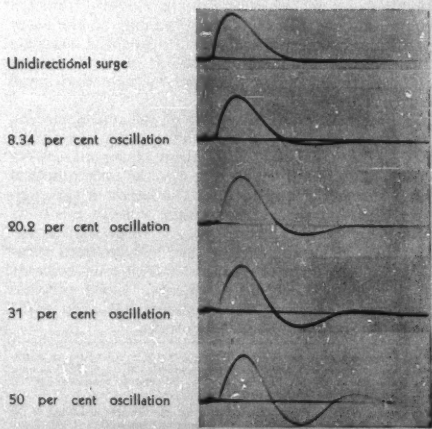


Fig. 3. Cathode ray oscillograms of surges used for calibrating magnetic links

A complete calibration chart built up exactly as just described is shown in figure 5, which is described later under the heading "Use of Calibration Charts."

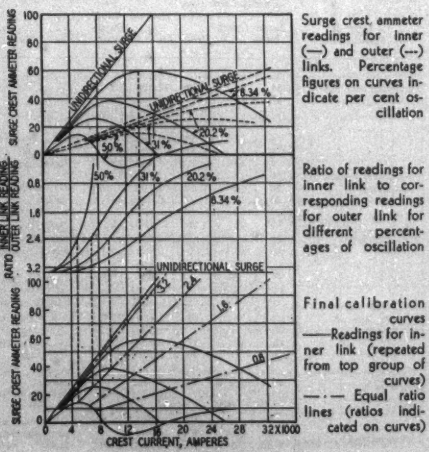
Experimental Study of Magnetic Links Under Various Surge Conditions

The magnetic-retentivity phenomenon upon which the method of measuring surge currents by means of the surge crest ammeter depends are demonstrated clearly by a few very simple laboratory experiments. One such experiment will be described. Eight magnetic links were mounted as shown at the lower left of figure 6 at 8 different distances from the current carrying conductor. Six unidirectional current surges with amplitudes as illustrated immediately above the bracket were used in the experiment. These surges were passed through the angle iron conductor in various combinations and surge crest ammeter readings taken after each combination, as follows:

1. Surge A applied and all links measured. Results are plotted at the top left immediately above the wave illustration. Surge crest ammeter readings are related to distance to current center, for each link. The familiar hyperbolic law of inverse proportionality of magnetizing force to distance is illustrated. A surge crest ammeter reading of 100 is obtained with a fully magnetized link. Surge A therefore gave the innermost link practically the maximum residual density it would retain. All other links obtained lower degrees of magnetization. The surge crest ammeter reading for each link was plotted also on the ordinate axis of the graph at the right of figure 6.

2. Surge A applied and immediately followed by surge F; then surge crest ammeter readings of all 8 links taken. Surges A and F were equal in amplitude, but opposite in polarity. These readings are plotted on the right hand graph of figure 6 above AF. All links were left with a magnetization practically equal to that obtained by surge A alone, but opposite in polarity.

3. Surge A applied and immediately followed by surge E, which had an amplitude of 80 per cent of the amplitude of surge A and was opposite in polarity; then surge crest ammeter readings of all 8 links were taken. These readings are plotted above AE on the right hand graph at the 80 per cent amplitude value on the abscissa.



Surge crest ammeter readings for Inner (—) and outer (---) links. Percentage figures on curves indicate per cent oscillation

Ratio of readings for inner link to corresponding readings for outer link for different percentages of oscillation

Final calibration curves
——Readings for inner link (repeated from top group of curves)
—·— Equal ratio lines (ratios indicated on curves)

Fig. 4. Specimen calibration of a 2-link arrangement

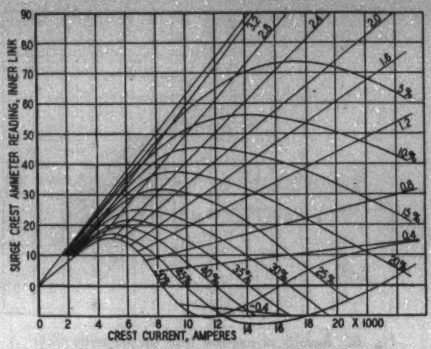


Fig. 5. Calibration chart drawn as illustrated in figure 4 for 4 inch angle iron with magnetic links at 1 and 7 inches from vertex of angle

Curves show surge crest ammeter readings for inner link for various percentages of oscillation as indicated
Straight lines are lines of equal ratio between readings for inner link and corresponding readings for outer link, for various ratios as indicated

4, 5, 6. Surge combinations AD, AC, and AB applied just as in combination 3. Surges D, C, and B had amplitudes of 60, 40, and 20 per cent of the amplitude of surge A, respectively, but were opposite in polarity. Similar points were plotted on the graph for each.

Study of the smooth lines drawn for each link position shows very clearly that the links in the outer positions away from the conductor and operating in a weaker magnetic field require a second surge of opposite polarity of higher percentage of the first surge for the same per cent demagnetization. For instance, the link in the extreme outer position required a reversed polarity surge of 67 per cent amplitude to reduce its residual magnetization resulting from surge A to zero, while the innermost link required a reversed polarity surge of only 33 per cent for the same result. These relations are cumulative for complete oscillations of several half cycles and are responsible for the variable inner link-outer link ratios illustrated in figure 4.

If an oscillatory surge passes through the conductor the relation of magnetizing forces to link magnetization are as illustrated in figures 7 and 8. These are illustrations of hysteresis loops under oscillatory surge conditions. A magnetizing force H_m when reduced to zero leaves the inner and outer links with residual flux densities of B_r and b_r, respectively, at the end of the first half cycle. The second half cycle H_m' leaves the 2 links at B_r' and b_r'. Such a cycle follows for each half cycle of the wave. The loops for the inner and outer links finally center about particular points on the ordinate axis which are the resultant residual magnetization points after the surge has passed. In figure 7 amplitude and per cent oscillation were just right to leave both links with the same residual magnetization. This gives an inner link-outer link ratio of 1. In figure 8 the inner link was left with a reversed polarity magne-

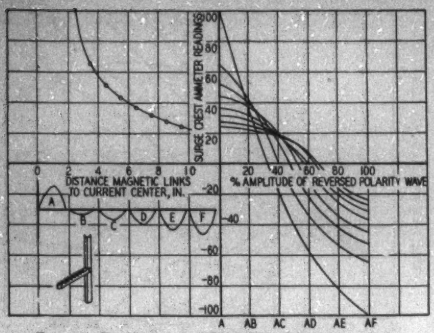


Fig. 6. Results of impulse tests on magnetic links

Lower left. Impulses applied, and sketch showing arrangement of the 8 links. Inner link 2.6 inches from center of current; distance between links 1 inch

Upper left. Surge crest ammeter readings for the 8 links after application of surge A

Right. Surge crest ammeter readings for the 8 links after application of various impulses as explained in text

tization while the outer link still retained the polarity of the first half cycle. This gives a negative inner link-outer link ratio.

Use of Calibration Charts

Keeping in mind the magnetic phenomenon illustrated, it is apparent that the resulting magnetizations for any link at any distance from a conductor will depend upon 3 factors: (1) the current amplitude, (2) the per cent oscillation, and (3) the distance from link to current center. For each link of the standard 2-link installation these 3 factors also determine the residual magnetization, but their relative influence on the 2 links is different as has been shown.

The third of these factors always is known, being deliberately chosen to permit readings over the range of currents to be measured. Provided the surge has a constant per cent oscillation, the current amplitude and the per cent oscillation may readily be read from the calibration chart of figure 5 in accordance with the following example: Assume an inner link reading of 36 and an outer link reading of 15; the ratio is 2.4. Reading at 36 on the surge crest ammeter ordinate scale across horizontally to the sloping ratio line marked 2.4 gives the reference point. Reading directly below on the abscissa scale gives a crest current of 9,000 amperes. Interpolation between the curved per cent oscillation lines gives an oscillation of 22 per cent. The second half cycle therefore has a crest value 22 per cent of 9,000 or 1,980 amperes. Each succeeding half cycle is 22 per cent of the preceding one.

Field Records

Use has been found for this direct method of measuring crest values of surge currents in the factory, field (see reference 16, Part IV), and laboratory. A total of approximately 10,000 magnetic links, constituting 5,000 measuring stations were in operation during 1934. The greatest number of records have been obtained on transmission line structures under lightning current conditions. Measurements have been obtained of lightning currents in tower legs, tower top lightning rods, counterpoise cables, and tower arms. Specimen records from each of these are given in table I.

The value of such records is revealed in the samples given. The single-leg currents in adjacent towers at the top of the table show lightning currents flowing through 5 adjacent towers. The currents in the legs are shown to be oscillatory with a second half cycle averaging about 27 per cent of the first.

The 4-leg readings next below show a current of 30,000 amperes dividing into 7,000 amperes per leg quite evenly. Below this set of readings is given a 4-leg reading for a case in which 2 of the legs were connected to parallel counterpoise grounding cables. The counterpoise legs carried 12,000 amperes against 7,000 for the free legs.

Samples of direct counterpoise cable readings for both radial and parallel counterpoise cables are given in the center of the table. For the radial counterpoise it may be noted that the 150 foot cable carried more than twice the current of the 40 foot cable. For the parallel counterpoise, with measuring stations located along the cable, measurements of currents at different distances from the towers give information on the effectiveness of the counterpoise in reducing tower potentials. The tower arm measurements give information pertaining to insulator flashover and, when coupled with readings in other parts of the

Table I—Records of Some Typical Measurements Made in the Field With the Surge Crest Ammeter

Types of Installations		Surge Crest Ammeter Readings: Inner Link	Outer Link	Ratio	Current in Amperes	Per Cent Oscillation	Remarks
Single-leg currents in adjacent towers		25	12	2.08	8,600	33	
		44	20	2.2	12,900	18	
		17	10	1.7	7,800	44	
		42	17	2.47	10,900	17.5	
		32.5	15	2.17	10,200	25	
4-leg single-tower readings	Tower 1	18	11	1.64	7,200	39	Radial counterpoise: 4 50-ft cables
		16	11	1.45	7,800	40	
		27	12	2.25	7,500	28	
		20	12	1.67	7,700	36	
	Tower 2	20	11	1.82	7,700	37.5	No counterpoise
		20	10.5	1.9	6,900	38	
		54	22	2.46	12,100	10.5	Parallel counterpoise
		75	23	3.26	12,100	1	
Radial counterpoise		32	11	2.91	2,600	11	40 ft, 223 ohms
		75	23.5	3.19	5,700	0	150 ft, 118 ohms
Parallel counterpoise		32	5		2,400		From 4 legs of tower in one direction
		21	T		1,600		
		11	T		800		
		T	0		400		
		23	9	2.56	2,400	27.5	From 4 legs of same tower in opposite direction
		20	1		1,500	27.5	
		11	8	1.37	3,200	44	
		14	9	1.55	3,100	42	
Tower arm		56			18,000		Approx. currents Indications of flashover
		100			32,000		
Lightning rod		−58	−68	*	13,500	*	*Both links at same distance from current center
		−60	−56	*	12,400	*	
		+64	+64	*	13,800	*	
		−68	−68	*	17,000	*	

structure, show whether the conductor or tower structure was struck.

The lightning rod measurements at the bottom of the table I were not obtained by the method that permits per cent oscillation to be determined, and therefore may be in error if the stroke current in the rod was oscillatory.

Accuracy

The accuracy of a current measurement by the surge crest ammeter-magnetic link method depends upon 3 things as follows:

1. **The magnetic link. How much does the magnetizing force-retentivity curve for the particular links used in the measurement depart from the average curve on which the calibration curves were based?**

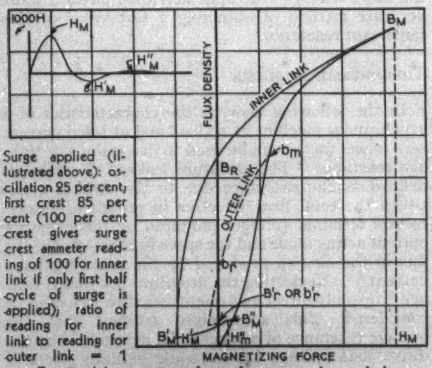
2. **The surge crest ammeter. How much do the scale readings of the particular surge crest ammeter used depart from the true magnetizing force-scale deflection relation arbitrarily chosen to make scale reading proportional to magnetizing current?**

3. **The magnetic link field installation. How greatly do the dimensions such as link distances depart from those distances on which calibrations used were based?**

When these 3 questions are answered the degree of accuracy of measurement is known. The dimensional characteristics of the field installation referred to in question 3 are believed not to introduce inaccuracies greater than 3 per cent except where links are located inside 2 inches from a conductor. Discrepancies in distance may be eliminated readily by the use of bracket arrangements giving precise spacings.

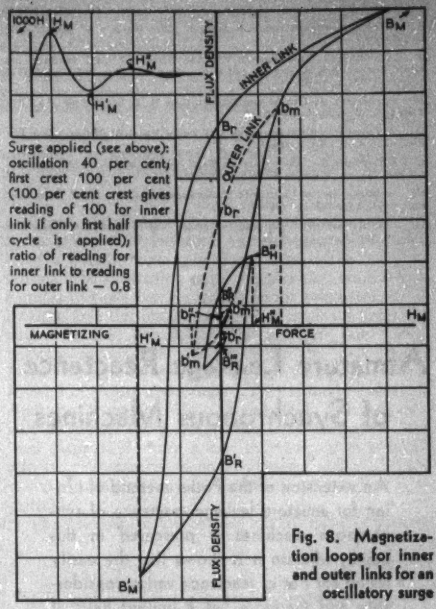
The maximum tolerance for the surge crest ammeter deflection at calibration referred to in question 2 is 3 scale divisions between 10 and 80 and 5 scale divisions between 80 and 100. Two links always are measured for every standard reading. This gives a 2 point reading, usually a midscale and an end-of-scale reading both of which influence the final accuracy.

The principal factor governing accuracy is referred to in question 1—variations in the magnetic link. Magnetizing force-retentivity curves are not the same for all magnetic links. Considerable progress has been made in controlling this characteristic, and by selection links can be obtained having the same curves.



Surge applied (illustrated above): oscillation 25 per cent; first crest 85 per cent (100 per cent crest gives surge crest ammeter reading of 100 for inner link if only first half cycle of surge is applied); ratio of reading for inner link to reading for outer link = 1

Fig. 7. Magnetization loops for inner and outer links for an oscillatory surge



Surge applied (see above): oscillation 40 per cent; first crest 100 per cent (100 per cent crest gives reading of 100 for inner link if only first half cycle is applied); ratio of reading for inner link to reading for outer link — 0.8

Fig. 8. Magnetization loops for inner and outer links for an oscillatory surge

For general field work, particularly in lightning measurements where hundreds of stations are used, it is agreed that efforts to measure to accuracies better than 10 per cent are of questionable value. Magnetic links therefore are selected by test to achieve over-all results within this range, and present control of the steel characteristic makes this possible without serious loss.

If greater accuracies are required, continued link selection will permit an improvement of the accuracy down to that of the surge crest ammeter. If still greater accuracies are required, a precision ballistic galvanometer may be used to measure links. Working accuracies in the order of 1 per cent are possible through the use of precise links and measuring methods.

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Armature Leakage Reactance of Synchronous Machines

An extension of the Potier method of testing for armature leakage reactance of synchronous machines is presented in this paper, wherein it is shown that the easily tested for Potier reactance varies considerably and therefore has a limited field of usefulness. It is further shown that if the Potier reactance is measured at high values of field current, the armature leakage reactance is closely approximated and a more valuable test results.

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An accurate knowledge of the armature leakage reactance of synchronous machines is essential to the designer who must calculate the flux densities in the various magnetic paths of a synchronous machine. It is also of interest to the operating engineer who must determine the operating characteristics, such as the short-circuit currents and the increasingly important steady-state stability limits,[6] which are appreciably affected by synchronous machine saturation. To meet the need of the designers, P. L. Alger[3] presented in 1928 formulas for armature leakage reactance. In 1931, L. A. Kilgore[4] proposed other formulas. These formulas provided a rational method by which the leakage reactance could be calculated. No matter how important a knowledge of this leakage reactance is for the proper determination of machine characteristics, this reactance could not be fully utilized generally as long as there existed only a method of calculating it from design data and there did not exist a practical method of testing for it. As a result, the easily tested for Potier reactance[1,5] at normal voltage has been used generally instead of leakage reactance to calculate the performance of machines, notwithstanding the fact that Potier reactance at normal voltage may differ considerably from the armature leakage reactance as defined by Alger and Kilgore.

The purposes of this paper are: first, to show that Potier reactance varies considerably with magnetic loading and consequently when measured by the standardized method[5] at normal voltage has a very limited field of usefulness; and second, to show that, if Potier reactance is measured at high values of field current, it gives a value which closely corresponds to armature leakage reactance and thus offers a more accurate method of obtaining a test value of this important reactance.

Theoretical Analysis

In the following analysis the characteristics of a synchronous machine at no load and at rated current zero power factor will be used to determine the leakage reactance. The armature leakage reactance is defined as the reactance due to the difference between the total flux (effective in producing fundamental terminal voltage) produced by the armature current acting alone and the space fundamental of the flux in the air gap produced by the same armature current.[3,4] Neglecting the armature resistance voltage drop, only direct axis quantities therefore need be considered. This accordingly assumes that the leakage reactance of a machine is determined by the direct axis leakage fluxes, while actually there is some difference, though generally small, in the amount of armature leakage flux (due chiefly to a

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The authors acknowledge the assistance given by J. M. Lyons and L. P. Shildneck.

6. For all numbered references see list at end of paper.

change in the tooth tip leakage flux) depending upon whether the armature magnetomotive force is acting along the direct or quadrature axis.

Nomenclature. The nomenclature used in this paper is as follows. All quantities are expressed in per unit (instead of per cent) of the machine normal kilovoltampere and voltage base and correspond wherever possible with established nomenclature.

e_d = voltage corresponding to direct axis field magnetomotive force
e_l = voltage corresponding to the air gap flux (behind leakage reactance)
e_p = voltage behind Potier reactance
e_t = terminal voltage
i = armature current
$k = 1 + \frac{\text{iron magnetomotive force}}{\text{air gap magnetomotive force}}$
x_d = direct axis synchronous reactance
$x_{ad} = x_d - x_l$ = direct axis armature reaction reactance
x_l = leakage reactance
x_p = Potier reactance

Assumptions. Following are the assumptions which have been made for the theoretical analysis of this problem.

1. The armature reaction magnetomotive force is proportional to a reactive voltage drop equal to $(x_d - x_l)i_d$.

2. The difference between the armature reaction magnetomotive force at zero power factor and the magnetomotive force due to the field current is a magnetomotive force which is proportional to k times the voltage behind the leakage reactance drop. Where,

$$k = 1 + \frac{\text{iron magnetomotive force}}{\text{air gap magnetomotive force}}$$

3. Armature leakage reactance is independent of saturation. This assumption is generally justifiable as an appreciable part of all of the armature leakage flux paths are in air.

In accordance with the above assumptions the following expression can be written for the field magnetomotive force at zero power factor.

$$e_d = (e_t + ix_l)k + (x_d - x_l)i \qquad (1)$$

Figure 1 presents a no-load saturation curve a and a zero power factor normal current saturation curve b for a synchronous machine. The curve c represents a load saturation curve constructed from curve b and a triangle having synchronous reactance x_d, as its base and the leakage reactance x_l as its altitude, with one side parallel to the air gap line. This triangle corresponds exactly with the well-known Potier triangle except that leakage reactance is used instead of Potier reactance. This triangle expresses equation 1 graphically. Hereinafter, this triangle will be called the leakage reactance triangle. The load saturation curve c has, therefore, iron plus air gap magnetomotive force as abscissa and a voltage corresponding to the fundamental air gap flux e_l as ordinate.

The load saturation curve c has the same or greater

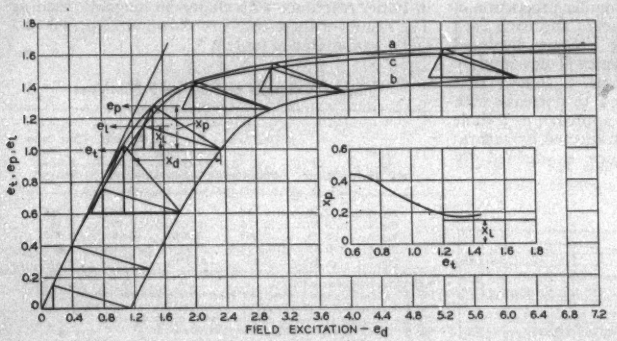

Fig. 1. Calculated saturation characteristics for a machine with very little pole body saturation at low field currents

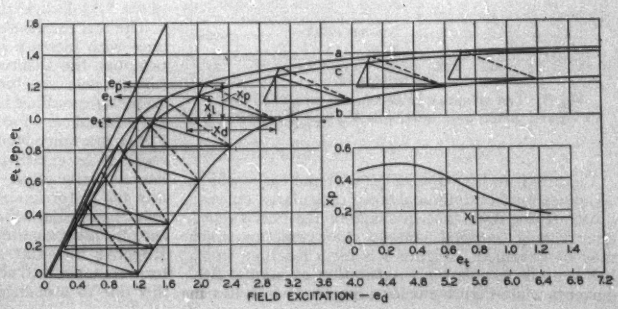

Fig. 2. Calculated saturation characteristics for a machine with an appreciable amount of pole body saturation at low field currents

magnetomotive force than the no load saturation curve *a* for the same air gap voltage, as the iron magnetomotive force necessary to obtain the same fundamental *air gap flux* is greater with increased armature reaction and field current. That is, the saturation factor k is not only a function of the air gap flux e_i but also of the total field current e_d.

This difference between the load saturation curve as constructed by the leakage reactance triangle and the no-load saturation curve can be attributed mainly to 2 effects: (1) increased rotor saturation due to the increase in field leakage flux with increase in armature reaction for the same useful air gap flux; and (2) any change in the air gap flux wave form due to armature reaction which changes the final required magnetomotive force.

As the field current increases, on open circuit, the voltage rises more and more slowly (curve *a*) until at very high field currents the voltage becomes nearly constant, the flux being limited by saturation. If now full load zero power factor armature current is maintained while the field current is again increased (curve *c*), the additional field leakage due to the increment in field magnetomotive force equal to a magnetomotive force $i_d\ x_{ad}$ is at first important, causing curve *c* to dip well below curve *a*.

However, under saturated conditions as the field current is increased the additional field leakage flux, caused by the addition of a field magnetomotive force equal to $x_{ad}\ i_d$, becomes increasingly, (1) less in magnitude, as well as, (2) a smaller proportion of the total flux. Hence, the 2 curves approach each other vertically, although they become displaced horizontally. Since Potier reactance is measured by the altitude of the Potier triangle, it follows that Potier reactance can be expected to decrease with high values of field current and approach as a limit (if leakage reactance itself is not affected by saturation) armature leakage reactance as defined by Alger and Kilgore.

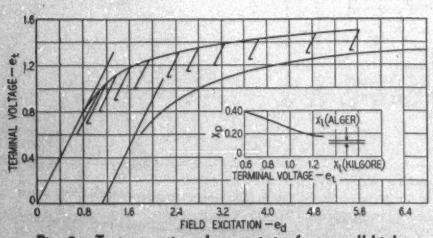

Fig. 3. Test saturation characteristics for a small high speed salient pole water wheel driven generator

Figures 1 and 2 represent 2 extreme cases which, although for fictitious machines (calculated curves), illustrate the difference in shape of the Potier reactance versus terminal voltage characteristics which may be obtained. Figure 1 is for a machine which has very little pole body saturation at normal field currents while Figure 2 is for a machine which has an appreciable amount of pole body saturation even at low values of field current.

In the case of figure 1, Potier reactance actually increases slightly after having decreased almost to leakage reactance. Also for the case of figure 1, Potier reactance approaches very closely to leakage reactance at a terminal voltage not much greater than normal (e_t = 1.0). It is evident from figure 1 that Potier reactance x_p should be measured well above the knee of the saturation curve, even when the load saturation is small.

Although both cases represent limiting conditions, they illustrate the tendency for Potier reactance to approach leakage reactance at the high values of saturation. If armature leakage reactance itself is reduced by saturation, Potier reactance will tend to approach a value less than the value of armature leakage reactance as calculated by the formulas of Alger and Kilgore. The value which it approaches under these conditions may be considered a saturated value of leakage reactance. However, based upon calculations, it is not expected that the ratio of the saturated value of leakage reactance to the unsaturated value will vary appreciably from unity except at extremely high values of saturation.

Test Results

Tests were made on 4 salient pole machines and on 1 cylindrical rotor machine to determine the variation in Potier reactance with change in magnetic loading. The results of these tests are shown on figures 3 to 7, and are tabulated in table I.

Table I—Results of Tests on 5 Machines

Type of Machine*	x_1 (Alger)	x_1 (Kilgore)	$x_1 = x_d - x_{ad}$ (x_d Tested, x_{ad} Calculated)	x_p (Lowest Value From Test)	x_p (Test Value Obtained at Normal Voltage)
Fig. 3	0.14	0.115	0.125	0.17	0.244
Fig. 4	0.16	0.155	0.175	0.16	0.19
Fig. 5	0.10	0.082	0.075	0.12	0.205
Fig. 6	0.10		0.08	0.168	0.216
Fig. 7	0.10	0.15	0.130	0.13	0.155

* Machine types are as follows:
Fig. 3. Small high speed salient pole water wheel driven generator.
Fig. 4. Large slow speed salient pole water wheel driven generator.
Fig. 5. Large 25 cycle salient pole water wheel driven generator.
Fig. 6. Small high speed salient pole synchronous motor.
Fig. 7. Small 2 pole cylindrical rotor steam turbine driven generator.

The test results show the variation in Potier reactance with increase in field current. All these tests bear out the theoretical conclusion for the case of salient pole machines that Potier reactance approaches, as a limit at high values of saturation, leakage reactance. For the cylindrical rotor machine Potier reactance is practically constant. This is the result to be expected as a cylindrical rotor machine has a comparatively small amount of field leakage flux and distortion of the flux wave shape. The test values of Potier reactance for this cylindrical rotor case lie between the values obtained by Alger's and Kilgore's formulas. Neither Alger's nor Kilgore's formula takes into account the change in end leakage flux due to a change in the relative position of the

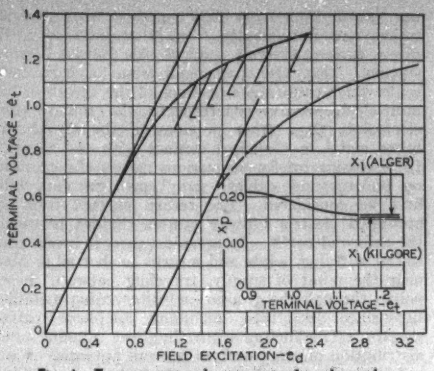

Fig. 4. Test saturation characteristics for a large slow speed salient pole water wheel driven generator

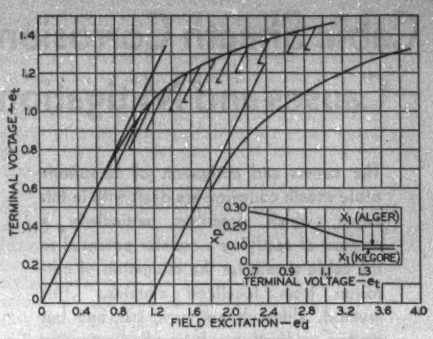

Fig. 5. Test saturation characteristics for a large 25 cycle salient pole water wheel driven generator

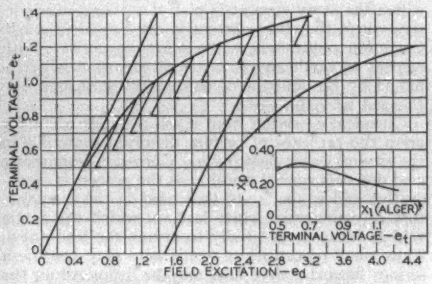

Fig. 6. Test saturation characteristics for a small high speed salient pole synchronous motor

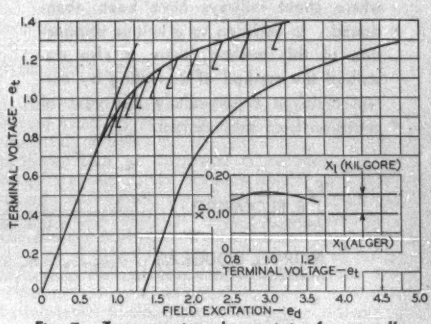

Fig. 7. Test saturation characteristics for a small 2 pole cylindrical rotor steam turbine driven generator

retaining ring and core. This relative position has been shown by tests to have considerable influence on the end leakage flux. Since in 2 pole turbine generators the end leakage reactance is relatively high compared to the total leakage reactance, it is not surprising that 2 formulas with arbitrary assumptions regarding end leakage should give such different results.

Summary

The following conclusions can be drawn from the above analysis and tests:

1. Potier reactance measured at normal voltage is not a true indication of leakage reactance and may be over 100 per cent too large. Potier reactance measured below normal voltage may be several times the leakage reactance.

2. Since Potier reactance more nearly approaches leakage reactance at high values of field current than at the normal voltage point, it is recommended that leakage reactance be measured by the Potier method at as high a value of field current as practical.

3. Because of the comparatively small amount of field leakage flux and distortion of the flux wave shape with increased armature reaction of cylindrical rotor machines which have a few number of poles, the Potier reactance of cylindrical rotor machines does not vary as much as that of salient pole machines of normal design.

4. Armature leakage reactance, for normal armature current, appears to be sensibly independent of saturation even for stator tooth densities well above practical operating values. This is evident since, with the exception of the cylindrical rotor machine, in no case does Potier reactance x_p drop below the calculated value of leakage reactance x_l.

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Cable Sheath Corrosion —Causes and Mitigation

The causes and mitigation of telephone cable sheath corrosion are dealt with in this paper, which describes particularly a method of applying a counter potential to the cable sheath for the mitigation of corrosion from localized currents. This method, although not new, has had but limited application. It may find extensive future use for controlling corrosion on intercity toll cables, and in localities where street railways have been abandoned. In addition to a unique application of this method, there is also described the method of correcting by current drainage a particularly bad case of corrosion from stray current.

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THE usual corrosion problem on telephone cables is the control of stray earth current from electric railways. The solution of this problem may be accomplished by limiting the stray current picked up and by providing drainage by means of metallic conductors from the cable to suitable points of lower potential. This quite frequently requires the coöperation of several utilities operating underground plants. Stray current from electric railways, if controlled, serves to protect the cable plant from corrosion. In the absence of stray current, localized current corrosion may become a serious problem. In this case the corrosion may be greatly reduced by a convenient and economical method of applying counter potentials.

Causes of Corrosion

Corrosion of lead cable sheath, and also corrosion of other metals, may be considered as an electrochemical process in which metals tend to go into solution at anodic points or areas. These anodic areas may result from stray direct current from electric railways or, infrequently, from other multigrounded direct current systems, such as the Edison 3 wire system. They also may result from localized currents which cause some portions of the sheath to be more electropositive with respect to the ground water electrolyte than other portions of the sheath or other metal in electrical contact with the sheath. In discussing briefly the various causes of corrosion on underground cables, stray earth currents will first be considered. The return current from a grounded electric railway system divides between the rails and earth. In a typical case, it leaves the rail at outlying points and returns to the rail or bus near the point of supply, traveling between these points through the ground and intervening metallic subsurface structures, including telephone cable sheaths. The factors controlling the amount and distribution of stray current are rail potential drop, rail insulation to earth, and earth conductivity. The last factor is influenced by the distribution and resistance of metallic subsurface structures. The sheath to earth potentials are negative in areas where the stray current is picked up, and are positive where the stray current is discharged to earth. Corrosion occurs where the sheath is positive with respect to earth and the rate of corrosion is determined by the amount of current per unit area discharged into the earth.

Chemical corrosion from a soil depends primarily upon the presence of certain dissolved materials in the ground water electrolyte. Corrosion from acetic acid deserves special mention as the process is regenerative and is similar to that used in the manufacture of commercial white lead, in which the acetic acid is released repeatedly to attack the lead anew. Thus small quantities of acetic acid may become a serious hazard. Free lime may be deposited on the sheath by water seeping through concrete used in the construction of manholes and duct lines. Lime water, which is somewhat corrosive to lead and sometimes results in considerable damage, may be present in a duct as a result of water seepage through new concrete used in the construction of manholes and duct lines. Under a comparatively rare combination of circumstances, corrosion may be caused by the presence in the soil of certain alkalies which may be deposited on the cable in locations where the potential to earth is highly negative. Lead may be corroded by the presence of water with dissolved carbon dioxide and oxygen.

Galvanic potentials causing corrosion may be set up between a metal and an electrolyte whenever the metal is immersed in the electrolyte. This potential varies with different metals and alloys and also with the character and concentration of the electrolyte. If 2 dissimilar metals in an electrolyte are electrically connected the resulting current flow will cause corrosion of the anode. If the ground water is alkaline, the lead cable may corrode as a result of the galvanic couple set up by contact with iron hangers, ladders, or loading coil cases. If the concept of galvanic potentials from contact of 2 dissimilar metals immersed in an electrolyte is extended to include potentials from variations in composition or

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condition of the sheath, then this condition is known as local action. Lead under mechanical strain, which may be caused by a scratch or dent in the sheath, may become anodic to the lead not under strain, with resultant corrosion of the anodic area. Corrosion also may be produced by variations in sheath compositions over minutely small areas.

Anodic conditions also may be set up by differences in dissolved oxygen content of the electrolyte. Portions of the sheath more or less shielded from the dissolved oxygen by contact with clay particles or other shielded portions, such as at the bottom of corroded pits, may become anodic with respect to other portions of the sheath, with resultant corrosion.

If different portions of the sheath are in contact with electrolytes which differ in character or concentration, a "concentration cell" will be formed with resultant corrosion in the anodic area. The "concentration cell" may exist over comparatively small distances, or, as in long cables or pipe lines,[1] the anodic and cathodic areas may be separated by several hundred feet.

It may be noted that the above causes of corrosion on lead sheath tend to localize the corrosion in small anodic areas and produce the phenomenon known as pitting. The metal at the bottom of the pit becomes more anodic to nearby areas by being shielded from oxygen and causes the corrosion to proceed more rapidly, at least for a period of time.

Indications of Corrosion Damage

There are no reliable methods which can be used universally to determine quantitatively the presence of corrosion damage on underground cables, except by actual inspection. This is, of course, impractical except for special tests, and therefore other means which give qualitative results are used. The usual electrolysis survey consists in making either indicating or 24 hour recording tests of the potential between the sheath and a lead electrode placed in the ground. Positive potentials generally are considered as indicative of the presence of conditions which may cause corrosion. Potential measurements are of considerable advantage in most cases of stray current electrolysis as the sheath to earth potentials usually are more than 0.1 volt. Where the potentials are less than this amount, particularly in the absence of nearby street railway systems, potential measurements may have practically no significance because the lead testing electrode has its own single potential, which is included in the measurement. In addition to potential tests, the usual electrolysis survey includes measurements of current flow along the cable sheath. This is particularly useful in the study of mitigation measures for stray earth currents. Over-all potential drop measurements are also of considerable value.

In the absence of stray direct currents, localized current on the cable sheath usually is too small to measure without special methods, and may be of little value even if known. Measurements of the current discharged into the earth and earth resistivity tests, made by means of an earth current instrument[2] are of value in special tests. However, this instrument seldom is used because of practical difficulties in its application on telephone plant.

Other indications of corrosion include the visual inspections of cables in manholes or cables withdrawn from the ducts for various reasons, or periodical examinations of short sections of cable inserted into the ducts as pilots.

Mitigation of Corrosion

The electrochemical theory of corrosion now is accepted generally as the one which best explains the multitude of facts concerning corrosion. This theory proposes that all corrosion is accompanied by a transfer of electricity between anodic and cathodic areas. This entails that there be an electrolyte and an electric potential to maintain the reaction. In the absence of any external influence, this potential is supplied entirely by the algebraic sum of the solution potentials of the anodic and cathodic areas, which net potential adjusted for the effects of polarization tends to drive the metal into solution. The solution potential of lead depends upon the character and concentration of the electrolyte. The rapidity and amount of corrosion depends, in addition to the solution potentials, upon numerous important secondary factors. The significant fact is that the solution potential, and consequently the rate of corrosion, may be either increased or decreased by the application, in the proper direction, of external potentials.

Thus 2 methods are available for the reduction of corrosion on underground cable. One is to maintain the cable free from moisture and contact with the ground water; the other is to maintain the cable slightly negative to the ground water with which it

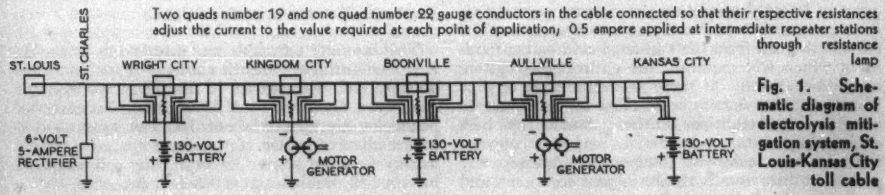

Fig. 1. Schematic diagram of electrolysis mitigation system, St. Louis-Kansas City toll cable

1. For all numbered references see list at end of paper.

is in contact. It is doubtful if it would be possible to prevent, absolutely, all corrosion under all circumstances by making the metal negative to the electrolyte. However, it is believed that if the underground cable sheath is maintained consistently negative to the surrounding earth, corrosion, under ordinary conditions, should be so reduced as not to shorten appreciably the life of the cable. This statement is well borne out by the fact that there is practically no evidence of anodic corrosive damage on cable plant maintained negative to earth by stray current.

All but a very small percentage of telephone underground cables are lead-antimony sheath cables installed in vitrified clay conduit so that they are protected from direct contact with the earth. The conduit system is constructed to drain, as completely as possible, water which seeps into the duct. In special cases protective coatings of insulating material may be used to provide additional insulation to the sheath, and in recent years there have been some installations of tape armored and jute covered cable buried directly in the earth. From a limited amount of experience with these types of cables, it appears that corrosion will be somewhat less for comparable conditions than for lead sheath cable in tile duct.

The reduction of stray current leakage from electric railways is an important detail of mitigative measures. If uncontrolled, stray direct current on cable systems may cause very serious electrolytic corrosion damage, but if properly controlled it becomes possible to maintain the cable system negative to earth and reasonably free from corrosion. The stray current picked up by the cable systems should be reduced to a minimum by avoidance of incidental or accidental contacts or close proximity of cable sheaths to other metallic structures from which current might be collected.

The stray current usually is drained from the cable system by means of a metallic bond to some point of lower potential on the railway negative return system, but preferably not to the rails. The current drained from the system should be the minimum which will maintain the entire cable system negative to earth. If there are other cable or pipe systems in the vicinity, care must be taken not to cause positive conditions on these plants. The best engineering solution in such cases may be a coöperative drainage scheme. Competitive drainage by several utilities usually results in poor economies and ineffective drainage.

Cable systems which cannot be maintained negative to earth by picking up stray current are subject to possible corrosion by localized currents. A practical and economical method of mitigating corrosion in certain of these cases is to apply a potential to the cable system to maintain it slightly negative to earth. This method has complications in its use in certain parts of cities where there is close proximity to the underground plants of other utilities and where the number of telephone cables is large.

The general method of applying counter potentials to a cable system is to ground the positive side of a suitable direct current source and connect the negative side to the cable sheath. The ground should have a low resistance at all times, being of such size and material as to withstand the resultant corrosive effects without appreciable deterioration over a reasonable period of time. The direct current source may be the central office battery, in which case the potential would be applied to the cable sheath using pairs in the cable brought out at suitable intervals, or the source may be local batteries, rectifiers, or generators installed at convenient intervals along the cable. Under favorable conditions the extent of the spread along the cable of the counteractive effect of negative current application to the sheath is remarkable. As an example, in actual practice a current of 0.75 amperes was found in a specific case to maintain about 8 miles of cable at least 0.1 volt negative to earth, whereas the previous potential ranged from 0.01 to 0.20 volt positive to earth.

As has been pointed out elsewhere in this paper, cable systems which are not influenced by stray direct current may exhibit small positive potentials to earth, which does not necessarily mean that corrosion is taking place. For such cases it has been the practice to observe conditions carefully and, if there is definite evidence that corrosion is taking place, the desirability of applying counter potentials is considered.

Two outstanding corrosion problems and their solutions will be cited to illustrate the methods described. The first involves the St. Louis-Kansas City toll cable on which some corrosion was noted in manholes soon after the cable was installed. A unique system of counter potentials was placed in operation and apparently has succeeded in stopping the corrosion. The description of the extensive electrolysis mitigation system placed in effect at Wichita, Kan., to correct a very bad condition resulting from stray earth current from the street railway system is then given.

St. Louis-Kansas City Toll Cable

This intercity toll cable was installed in 1930. It is a lead-antimony sheath cable, $2^5/_8$ inches in diameter, and was placed in vitrified clay conduit along the shoulder of U.S. highway number 40. Manholes are spaced about 750 feet apart and 4 intermediate repeater stations are spaced approximately 50 miles apart. Steel loading coil cases are installed in manholes at 6,000 foot intervals.

Several metallic drainage connections between the cable sheath and other points of lower potential were made in Kansas City and St. Louis to control the stray current from electric railways. This resulted in making the cable negative to earth for a few miles beyond the city limits of both cities. The remaining 225 miles of the cable was found to be positive to earth in nearly every manhole. The potentials ranged from 0.01 to 0.20 volt and were virtually constant at any point of test. A few scattered manholes tested slightly negative to earth. In most manholes the current on the sheath was only a few milliamperes, and there was no consistency in the direction of current flow. A few currents of

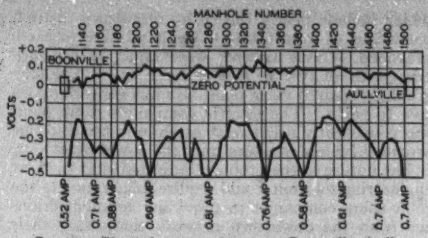

Fig. 2. Electrolysis conditions in Boonville-Aullville section, St. Louis-Kansas City toll cable

Upper curve positive to earth; lower curve negative to earth. Negative conditions result from applying negative direct current from repeater offices in amount shown at each point

magnitudes as high as 100 milliamperes were noted.

It appeared desirable to investigate the potential from cable to earth in the duct line. By means of a duct exploring electrode potentials of the same general magnitude as those noted in the manholes were observed. In several sections positive and negative conditions alternated every few feet and sometimes in less than one foot.

Several duct electrodes consisting of 6 foot lengths of lead-tin cable sleeving were installed in a duct adjacent to the cable and bonded to the cable by an insulated copper wire. The duct electrodes were removed for visual inspection 3 months after they were installed. All electrodes showed some evidence of corrosion. On some pits about $^1/_{32}$ inch in depth were found, while in others, particularly in drier locations, the corrosion was extremely slight. Earth resistivity tests were made near the manholes where the duct electrodes were installed and at numerous other points, but there seemed to be no relation to the potential of sheath to earth. It was noted, however, that at the point where the greatest damage occurred to the test electrode the lowest earth resistance also was shown. The cable was uncovered at 2 locations where it was believed corrosion might be found. From 15 to 20 feet of cable was examined and in both cases corrosion was found, but always on the bottom of the cable. Some of the pits were approximately $^1/_{32}$ of an inch in depth. All manholes were inspected and very little evidence of corrosion was found on the cables, but severe corrosion was evident on some of the spare lead-tin splicing sleeves which had been under water. The more severe corrosion on the splicing sleeves than on the lead-antimony cable sheath proper probably was caused by relatively large galvanic potentials set up on the sleeve because of its heterogeneity.

This toll cable represents a large investment and is extremely important from a service standpoint, so that in view of the evidence of corrosion along the cable it seemed desirable to install remedial measures as soon as practicable. It appeared that to obtain complete protection for this cable the most practical solution was to apply a system of counter potentials. Consideration was given to using low voltage rectifiers or wet batteries at intervals along the cable route, but because of the absence of power lines in certain localities, this plan was discarded. In the plan finally adopted 130 volt telegraph batteries or 130 volt motor generators at the repeater stations were used to supply current to the cable sheath by means of pairs in the cable, as shown in figure 1. Four number 22 and 8 number 19 American wire gauge conductors were used in such combinations that the current to each point was of the order of 0.5 to 0.9 ampere. Connections were made to the cable sheath at 4 points in each direction from each intermediate repeater station and at 3 points near the Kansas City end. The distance between the points of contact varied from 3.12 to 9.08 miles, with an average of about 5.5 miles. In addition, about 0.5 ampere was applied to the cable sheath at each intermediate repeater station. In order not to corrode the regular central office ground at the repeater stations by the current used for counter potentials, special long-life grounds were installed at most of these points.

The results of this mitigation system have been very gratifying. The cable in each manhole from St. Louis to Kansas City is now negative to earth. The minimum potentials are slightly less than 0.1 volt and the maximums at points of application of the counter potentials range up to 1 volt. The system has been in operation for nearly 3 years with no evidence of additional corrosion on the cable, and all evidence indicates that the old pitting has definitely stopped. The potentials of the cable sheath to earth for a typical repeater section before and after completion of the preventive system are shown in figure 2. A representative picture of the pitting effects found on some 30 spare lead sleeves previous to the application of the counter potentials is given in figure 3.

The total direct current required to maintain the 225 miles of cable negative to earth is only 24 amperes, which means an average current density of about 30 microamperes per square foot of sheath. It is understood that this current value is very much smaller than is required for other installations of forced drainage.

Approximately 88 per cent of the total length of the cable, or 225 miles, is protected by the facilities described at an annual cost which is very low for insurance against the effects of corrosion with the inevitable replacement from time to time of sections of cable. Such replacements always are costly and are accompanied, especially in case of comparatively heavy cable fills, by adverse service reactions.

The outstanding features of this protective method are its stability and the very small amount of maintenance required. It is necessary only to check the current output occasionally in the connections to each point of application, which is done at the repeater stations by the regular attendants.

Wichita Electrolysis Mitigation System

The corrosion problem on the telephone cable plant at Wichita, Kan., has been very serious, dating back to the advent of the street railway system more

than 30 years ago. The condition became progressively worse as the underground plants of the various utilities grew. Finally, in 1931, an extensive mitigation system involving the coöperation of the Kansas Gas and Electric Company and the Western Union Telegraph Company was placed into effect. Some of the important features of the problem will be reviewed.

Wichita has a single local exchange located in the business district which is about 0.25 square mile in area, and underground is a grid of telephone, telegraph, and power cables, and gas, water, and steam pipe lines. The drainage of stray current from the district was complicated by the fact that the street railway's power was supplied from the electric company's generating plant, which was located nearly a mile from the telephone central office. The only stray current drainage from the district to the power plant was by way of the railway company's negative returns, the water company's mains, and the electric company's cable system. The problem was the more difficult of solution because only 35 per cent of the total railway load returned over the negative feeders as a result of the inadequacy of this system.

Fig. 3. Representative pitting effects found on spare lead sleeves previous to the application of the mitigative scheme

The telephone cable plant was negative to earth in all the outlying districts, but at about 80 manholes which include nearly the entire downtown district, conditions of from 0.1 to 0.5 volt positive to earth prevailed. Cable failures were rapid in this district, with an average of 7 or 8 per year. The telegraph company's cable plant also was generally positive to earth. The electric company's cable plant was consistently negative to earth from the drainage provided by feeder cables from the power plant.

The nature of the problem indicated that the best engineering solution would require coöperation of the cable-using companies in providing common drainage from the downtown network comprising their respective plants. It was evident that competitive drainage by all 3 companies would be decidedly uneconomical and would be almost impossible in providing a satisfactory solution. The mitigation system which was installed consisted, in general, of bonding the 3 cable plants together in 15 locations to form a uniform grid, and then increasing the conductivity from the downtown district to the power plant by means of about one mile of 1,000,000 circular mil drainage cable. Several shorter drainage wires also were used.

A great deal of stray current on the telephone plant was eliminated by isolating the cables at the central offices from the station grounds and placing insulating splices in all lateral building and block cables in the downtown district.

The electrolysis mitigation program which was completed in 1931 has resulted in a great improvement and a satisfactory condition for all utilities concerned. The telephone cable system now has about 15 manholes which are positive to earth. The potentials are under 0.1 volt and are constant throughout the 24 hour period, which indicates that the potential is caused by local conditions and not by stray current. No method has been found for eliminating the remaining positive condition without damaging other underground plants.

In view of the great amount of corrosion damage done by stray current over a period of many years, it was expected that cable failures would continue to occur for a number of years after the drainage system was installed. The results have been pleasing in that only 6 failures have occurred in the past 4 years, compared to the previous average of more than 6 per year. Duct electrodes have been installed in numerous places and are frequently inspected for any evidence of new corrosion.

The localized current problem has received considerable attention in recent years and according to present trends will become increasingly important with the extension of intercity toll cables and the abandonment of street railway systems. While the experience with the counter potential system of preventing corrosion is somewhat limited, the results obtained indicate that this will frequently be a very satisfactory method.

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Speed Transients of D-C Rolling Mill Motors

In its introductory part, this paper explains why the transient speed changes of d-c motors under suddenly applied loads may affect the quality of the product rolled on a continuous rolling mill. In a later section, the paper analyzes the behavior of such motors driving a tandem tube mill, and points out the difference between the transient and the steady-state speed-load characteristics; the former greatly affects the product, while the latter, or the conventional speed regulation, is of only minor importance. The paper outlines the course to follow in choosing the most suitable motors and gives a mathematical study of the transient speed-load changes.

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THE MODERN TENDENCY in rolling mill design and practice is toward tandem mills, which consist of several sets of rolls, or stands, arranged in line as shown in figure 1. The majority of stands are driven by separate motors as this greatly simplifies the mechanical layout. For this purpose, d-c motors, furnished with power from one or several generators, commonly are used. The speed relationship between the several stands is not fixed, but should be adjusted from time to time to suit the product rolled. By varying the generator voltage, the speed of the whole mill may be raised or lowered as a unit. The speed relationship between the stands may be altered by field control of the several motors.

Figure 1 shows, in elementary form, the layout of a typical tandem mill. The metal passes from stand to stand. Ordinarily the bar is sufficiently long to be in several, or even in all, stands at the same time. Hence, the speed of each successive stand should be raised in proportion to the reduction of the cross-section area so that the product of the speed times the area is constant. This expresses the obvious fact that the same amount of metal passes through each stand in any interval of time. Once established, the speed relationship between the stands should be maintained accurately because otherwise there will be created a tendency to stretch or loop the metal between stands.

If the rolled material is flexible, such as strips or the like, a small amount of looping is not objectionable. In fact, a loop often is desired, as it gives a positive indication that the metal is not being stretched.

When the product is of such a nature that its bending or looping is impossible, the problem of proper speed control becomes more involved. There is no visible indication as to whether the relative speeds are set rightly or not. Presumably the bar may be pulled apart or pushed together by the adjacent stands, but it is impossible to say, by looking at the mill, what is the magnitude of force being transmitted through the metal from stand to stand. The motor loads, indicated by ammeters, serve as crude guides. By strengthening the fields of those motors that pull the heavier loads, or by weakening the fields of motors that are underloaded, the operator, in a measure, may hold the mill under control. In hot rolling, any excessive pull or compression exerted on the bar may ruin the desired cross section. Hence, the operators of such a mill require means of fine control of motor speed; vernier field rheostats for each drive become indispensable, in order to control the loop or load properly.

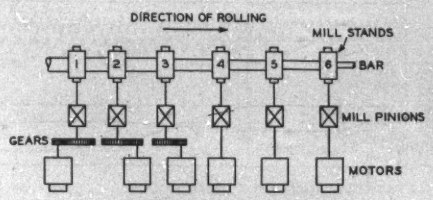

Fig. 1. Modern continuous, or tandem, rolling mill with individual drive for each stand

If the tube or the bar that is rolled were infinitely long, the relative speeds of the several driving motors would be adjusted once, and then these

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speeds would not change. Only such factors as uneven heating of motor fields, or change of motor loads resulting from variations in metal temperature, would require an occasional adjustment of one or several vernier rheostats. In metal rolling practice, however, particularly in hot rolling, the bars are of limited length, since they have to be reheated in furnaces in a straight form before going through the mill. Thirty foot furnaces constitute a practical limit. Consequently, several separate bars go through the mill each minute, usually separated by intervals when there is no metal in the rolls. Thus the motor load changes several times a minute from friction load to its maximum value.

The speed of a d-c motor varies somewhat with changes of load. When the load is applied suddenly, the motor speed dips down (the "impact speed drop"), then recovers part or whole of this speed drop, and finally settles down at some steady state value, which may be either higher or (usually) lower than the running light speed.

The load is not applied simultaneously to the several motors driving a tandem mill. Hence, the periodic change from load to no-load condition upsets the proper speed relationship even if such were established with all stands full. The bar or the tube may be stretched or compressed temporarily between adjacent stands before the transient speed changes are over and the steady state load conditions reëstablished. This may result in permanent damage to the product rolled.

It was natural, therefore, for the mill operators to call for motors that would not change their speed appreciably with changes of load. A very close speed regulation has been specified on many occasions. This requirement, however, was based upon a misunderstanding of this term. The speed regulation of a motor, as defined in the Standards of the A.I.E.E., is the ratio of change of motor speed from full load to no load, to the full load speed. Both values are taken under steady state conditions; transient phenomena causing the impact speed drop are not taken into account in this definition. A motor may have a small speed regulation and yet a large impact speed drop, and therefore not be as suitable for use in tandem mills as another motor with a reduced impact speed drop and a larger speed regulation. In fact, it will be shown in the following analysis that in certain instances a too-close steady-state speed regulation does not give the best results.

In the summer and fall of 1933, the authors were called upon to analyze the performance of several d-c motors driving a tandem mill producing thin walled tubes. This mill will be used as an illustration in this paper; the method used, but not necessarily the conclusions reached, are applicable, of course, to any other tandem mill where the problems are similar.

Problem of Tandem Tube Mill

Typical behavior of motors driving the stands of tandem tube rolling mills is represented by the curves shown in figure 2. The test shows the dip in speed occurring when the tube strikes the rolls.

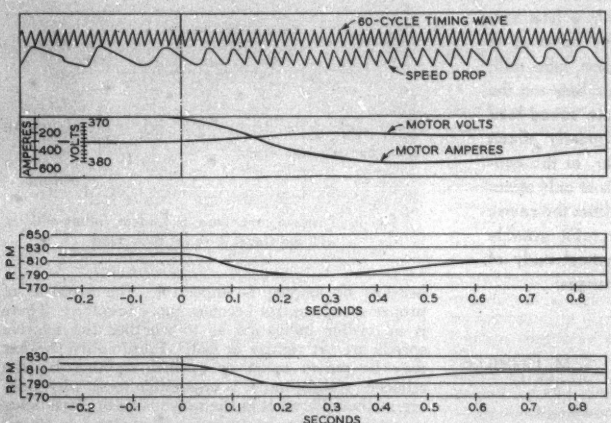

Fig. 2. Actual and calculated performance of a 325-horse power 815/1,630-rpm d-c motor driving one stand of a tandem tube mill

A—Test oscillogram taken during operation

B—Speed drop plotted from oscillogram

C—Speed drop calculated assuming constant flux

$$Rpm = 820 - 17.9 - 29.4e^{-2.99t} \times \sin(7t - 0.63)$$

If the motor of the preceding stand is running at normal speed, the length of tube between the 2 stands will undergo a compression stress until the motor of the second stand has recovered its speed. In common vernacular such "overfeeding" spoils a length of the tube, equivalent to the distance between stands, by causing it to "balloon." For this reason the percentage of scrap in tube rolling is frequently high.

Actually the length of tube between the 2 stands may undergo first a tension or stretching stress, and then the compression or "ballooning" stress. This will occur when the motor of the first stand has not

yet recovered its normal speed before the tube strikes the rolls of the second stand. This is the usual situation as the stands are placed as close together as possible. The motor of the second stand, running at normal speed when the tube strikes the rolls, stretches the tube until a balance is reached between its falling speed and the recovering speed of the first motor, after which the ballooning stress occurs. It is the latter stress that is especially responsible for spoilage.

The curves shown in figure 2 were taken on a motor rated: 325 horse power, 815/1,630 rpm, 375 volts. The motor was operating at 375 volts, 820 rpm, running light and taking about 5 per cent of full load current. When the load suddenly was increased to 63 per cent of full load (to about 440 amperes) the speed dropped from 820 to 790 rpm in 0.25 second, and then recovered to approximately the original speed in about 1 second. Thus, the oscillograph record shows that the tested motor had an impact speed drop of approximately 3.7 per cent with load changing from 5 to 63 per cent of full load. If the load were changed from 5 to 100 per cent the impact speed drop would be slightly greater than 6 per cent. These tests were made on an existing mill where operation of the old motors was not satisfactory.

In the following part of the paper, the proper characteristics of motors designed to reduce the ballooning effect are described.

General Analysis

Figure 3 has been prepared to illustrate the elementary case, which is to be discussed. Assume that the motor is running light, developing a small torque just sufficient to overcome the mill friction and its own losses. The counter electromotive force of the motor is only slightly less than the impressed voltage, the difference between the 2 values being just enough to circulate the small current required to develop the small torque.

Now assume that at the instant t_0 the external torque suddenly has been increased. The running light current which has been flowing through the motor armature does not produce enough torque to balance the external torque; therefore, the motor will slow down and its counter electromotive force will be reduced. Ultimately the difference between the line voltage and the motor electromotive force will be such that enough current (I_1) will circulate through the motor to produce a torque to overcome the external load torque T_1. The ultimate motor speed will change from n_0 to n_1; the ratio of the ultimate change of motor speed (s) to n_1 is the value conventionally defined as the speed regulation. However, all these changes do not take place at once, but the motor goes through a certain period during which several transient phenomena occur. These phenomena should be studied most carefully because they are the ones that produce the undesirable effect on tube rolling processes.

In this discussion the magnetic flux of the motor will be assumed to remain constant during the described period. This is not strictly so, as will be explained further, but the effect of the flux changes will be described later and will be fully considered. The behavior of the motor after the load has been applied suddenly will be analyzed next.

As has been mentioned already, the motor torque at the initial instant is not sufficient to overcome the

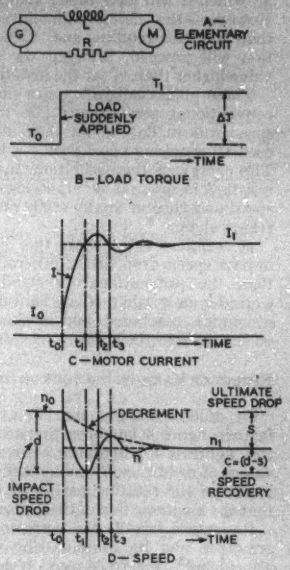

Fig. 3. Diagrams illustrating fundamental behavior of d-c motors driving individual stands of a continuous mill

load torque; therefore, the motor will slow down, the rate of deceleration depending in the first place on the moment of inertia of the rotating parts. It is quite obvious that the larger the moment of inertia, the lower will be the rate of deceleration. It may be seen from the speed-time curve of figure 3 that at the instant t_1 the motor speed drop has reached its maximum. This maximum is the impact speed drop designated as d.

As the motor slows down, the difference between its counter electromotive force and the impressed voltage increases and, therefore, the current flowing through its armature also increases. However, this current does not rise as rapidly as the difference between the 2 voltages increases; this readily is explained by the fact that the motor armature possesses inductance just as any magnet or solenoid does. Therefore, rise of current always lags behind the rise of applied voltage that causes this current to flow.

At the instant t_1 the drop of motor speed (d) is sufficient to cause enough current to flow through the motor armature to balance the external torque, and therefore the deceleration of the motor ceases; however, the motor current still rises because the drop of speed (d) is greater than the ultimate drop (s) which causes current I_1 to flow under steady

state conditions. The current-time curve in figure 3 shows, therefore, that the current still rises from the instant t_1 to t_2. In other words, the motor develops during this time interval more torque than the external load, and this causes the motor to accelerate.

At the instant t_2 the motor will reach the speed n_1, which it will have under steady state conditions. However, the motor still develops more torque than the load requires and, therefore, the acceleration will proceed, bringing the motor speed to a value higher than n_1 (at the instant t_3).

These phenomena are quite similar to those of a conventional pendulum. The motor current and speed will oscillate about their ultimate values, this oscillation taking place during a very short interval. The energy of the oscillation finally is absorbed in resistive losses and in other losses, and the motor speed and current finally settle down to their steady state values.

It is quite evident from this description that the impact speed drop (d) is, generally speaking, larger than the conventional or steady state drop (s). Consider now what effect various factors, such as resistance, reactance, and mechanical inertia, have on the value of the impact speed drop.

Effect of Various Factors on Speed Drop

In order to study the effects of these various factors, figure 4 has been prepared. Diagram A of this figure is for a motor with arbitrarily selected values of resistance R, inductance L, and moment of inertia of the rotating parts. It is assumed further that the magnetic flux of the motor remains constant.

Resistance R is the resistance not only of the motor armature and its commutating field winding, but also includes the resistance of the generator armature and its commutating field winding, as well as the resistance of the connecting cables, etc. The same remark applies to the inductance L, which should include the inductances of all parts comprising the complete electric circuit. Furthermore, the moment of inertia includes not only the inertia of the motor armature, but also the inertia of other rotating parts driven by the motor.

Effect of Resistance. Assume now that the resistance R of the circuit has been reduced. Diagram B illustrates this case. With a smaller value of R, the motor speed drop will be less in order to cause the same current to flow through its armature windings. Therefore, the ultimate speed drop s and the impact speed drop d are reduced. (As long as the motor flux remains constant, the only thing that produces the speed regulation is the resistance of the circuit.) The reduction of the resistance R reduces the resistive losses in the circuit, and, therefore the oscillations do not die down as rapidly as shown on diagram A. Summing up, it may be concluded that the reduction of the resistance R is highly beneficial, particularly when the inductance and moment of inertia also are changed in the manner to be described.

Effect of Inductance. Diagram C illustrates the case when the inductance of the motor and of other parts of the circuit has been reduced, the resistance and moment of inertia remaining the same as in diagram A. The effect of reducing the inductance is twofold: In the first place, oscillations die down more rapidly (the time decrement is higher); secondly, the frequency of the oscillations is higher. The ultimate speed drop s is not affected by the change of inductance, but the impact speed drop is reduced because of the higher damping effect. On the whole, the reduction of the circuit inductance is very desirable.

Effect of Moment of Inertia. Diagram D shows the effect of increasing the moment of inertia of the system, other factors like resistance and inductance remaining the same as in diagram A. The higher is the inertia of the system, the lower becomes the frequency of oscillation. The ultimate speed drop s remains the same, but the impact speed drop d is reduced. The latter feature may be understood readily because the maximum dip of speed is likely to occur when the damping effect already has reduced the amplitude of the oscillations. Thus, it is highly desirable to increase the moment of inertia of the system to minimize the impact speed drop.

Combined Effect. It is evident from the previous discussion that in order to obtain the best results, as far as the value of the impact speed drop is concerned, it is necessary to reduce as far as possible the resistance and inductance of the circuit and to increase the inertia of the rotating parts.

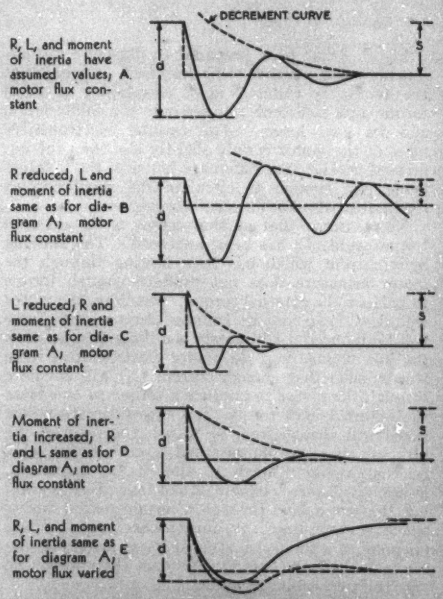

Fig. 4. Diagrams illustrating individual effects of principal factors influencing speed transients of a d-c motor as a heavy load suddenly is applied

Magnetic Flux. It has been assumed thus far that the magnetic flux of the motor remains constant when the load changes, and that the only thing that causes the motor to change its speed is the resistive (IR) drop in the system. Consider now what effect, if any, the change of the motor flux will have on the motor performance.

The current flowing through the motor armature produces the so-called "armature reaction" which tends to demagnetize the machine. Therefore, the motor speed tends to increase, counter-balancing in part the effect of the voltage drop in the resistance of the system. To put it differently, the armature reaction acts like a differentially wound series field.

The effect of the armature reaction is not instantaneous because anything affecting the main flux of the motor is delayed by the very appreciable time constant of the main field. Diagram E of figure 4 illustrates the effect of this armature reaction. The motor speed will not follow the dotted line (which corresponds to the speed-time line of the diagram D), but will follow the solid line which is somewhat higher than the dotted line. The ultimate speed drop s is obviously less than in the diagram D; the impact speed drop d also is reduced as compared with diagram D, which may appear to be rather desirable. Further analysis will show that this latter conclusion is not always correct.

Application of Results to Tandem Tube Mills

To illustrate the application of the theoretical results obtained to the practical case of the tandem tube mill drives, figure 5 has been prepared. On both diagrams A and B of this figure the solid line represents the speed-time curve of a motor driving *any mill stand*, while the dotted lines represent the speed-time curve of a motor driving the *following mill stand*. The speed-time curves of both motors are assumed to be identical. The curve of the following motor is merely shifted to the right by the time t_1 required for the tube to travel between these 2 stands.

The motor speeds, as plotted on these curves, do not represent the actual speeds, but the relative speeds of 2 motors. In other words, if these relative speeds are equal, then there is no stretching nor overfeeding between the 2 mill stands these motors are driving. On the other hand, if the motor, say number 10, is running relatively slower than motor 11, there is a stretching of the tube between the stands; likewise, when motor 10 runs relatively faster than motor 11, stand 10 overfeeds stand 11, and there is "ballooning" between these stands.

It is assumed that of the 2 evils, stretching and ballooning, the former is the less objectionable, particularly when very thin walled tubes are rolled. Therefore, while it is desirable to reduce as far as possible both the stretching and the ballooning, it is assumed that the latter effect should be minimized to the largest possible extent. This may or may not be true for other products rolled. Diagram A of figure 5 illustrates the case when the 2 motors under consideration have a relatively small "speed

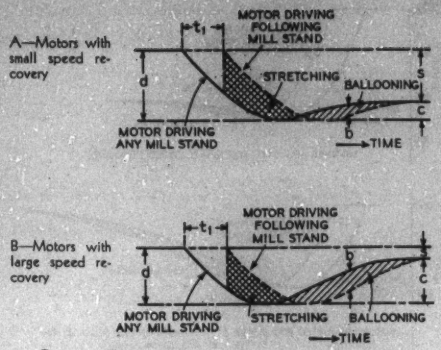

Fig. 5. Comparison of motors having large and small speed recovery

recovery." In other words, the motor flux remains more or less constant, the steady-state speed regulation is relatively large, but the speed recovery ($c = d - s$) is rather small.

The motors represented by diagram B have a rather large speed recovery. In other words, the conventional speed regulation has been reduced.

As long as the dotted speed-time curve is higher than the one drawn in solid lines, the tube between these 2 stands is being stretched. Therefore, this area is designated by the word "stretching." When the preceding motor is already on its way to recover while the following motor still is going through the early stages of the transient period, the solid line is higher than the dotted line, and therefore the ballooning effect takes place. The amount of this ballooning may be said to be proportional to the area marked "ballooning." The value b represents the maximum difference between the instantaneous values of the relative speeds of the 2 adjacent stands, and therefore this value should be held to the minimum.

Now from this viewpoint diagram A of figure 5 will be compared with diagram B. The motors with good (large) speed recovery, as represented by diagram B, have a small speed regulation and even the impact speed drop d is less than of the motors with small speed recovery, diagram A. One would be likely to conclude that the motors represented in diagram B, are the more desirable ones of the 2 combinations; however, this is not true. In order to reduce the amount of ballooning to a minimum, it is desirable to have the speed-time curves as flat as possible after they have passed their minimum values; the flatter are these curves, the less is the "ballooning" area and the smaller is the speed differential b. Thus, even though the motor combination of diagram B may look better because its speed regulation and its impact speed drop are less, from the practical standpoint the motor combination of diagram A should be preferred.

The conclusions reached may be summed up as follows: The driving motors should be designed

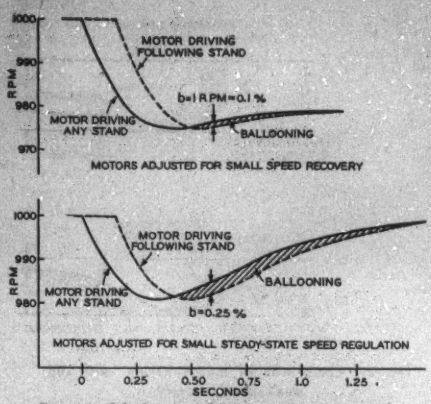

Fig. 6. Calculated performance of motors recommended for driving typical tube mill stands; motors rated 400 horse power, 1,000/1,500 rpm, 375 volts

Assumptions: Load changes suddenly from 5 to 100 per cent; tube travels 0.15 second from stand to stand. Allowance made for line drop and voltage regulation of generator

with as small a value of impact speed drop as possible. After this is done, their speed recovery should be held at the minimum, without too much attention being paid to the conventional or steady state speed regulation. In other words, after the motor speed is reduced, it is desirable to let it remain so rather than to recover while the tube rolling process goes on. In order to obtain these results, it may be desirable to equip the machines with a very light cumulative series field so proportioned as to offset in whole or in part the demagnetizing action of the armature.

Attempts have been made at various times to improve the steady state speed regulation of tandem mill drives, with the idea of improving the operating conditions. For instance, series exciters have been employed in order to control the degree of compounding of a d-c motor throughout its speed range and thus obtain a nearly flat speed-load curve. Mills are known where, at the insistence of the operators, special speed regulators have been provided, to hold the motor speed regulation (steady-state value, of course), within $^1/_4$ of 1 per cent. Quite obviously, this result, when obtained, did not have any effect on impact speed drop. In fact, a complete speed recovery would be detrimental to a mill like a tandem tube mill, as the foregoing analysis shows.

When the material rolled is flexible and can be looped between stands, the impact speed drop, creating a transient overfeeding, causes a small loop to form. After the motor speeds become stabilized under load, this loop ceases to grow and remains constant until the whole bar passes the mill. Here again, a flat steady-state speed-load characteristic may result in a larger loop than would have been obtained with a slightly drooping speed, everything else remaining constant.

In the appendix of the paper the analysis of the impact speed drop is given in more detail showing how the speed-time curve, when load is applied suddenly, may be calculated.

It is anticipated that the application of the results of this paper will result in improved performance of mills of the described type. New drives may be designed with such characteristics as have been pointed out. In some instances the operation of existing mills can be improved by equipping the motors with flywheels. This has been done with satisfactory results.

Tentative designs of motors for a proposed application have shown that the speed dip can be reduced to less than $^1/_3$ of the usual dip (see figure 6) without adding too greatly to the cost of the motors. This is accomplished by taking into consideration the effects of R, L, K_1, and M, as described in the appendix, and modifying the design to get desirable values for these factors. Of course, when the material can be looped between stands, as in strip mills, or when it can withstand considerable compression, motors of conventional design are well suited.

Finally, it is hoped that a clearer understanding of the transient speed-load changes will eliminate the numerous and expensive, but futile, attempts to correct the transient shortcomings of motors by improving their steady-state speed-load characteristics.

Appendix—Equations for the Motor Speed Characteristic

For the purpose of calculation, it is assumed that the torque is applied to the motor instantaneously, when the tube or bar being rolled strikes the rolls. The solution is obtained under the condition that the flux in the armature per pole, in both motor and generator, remains constant. Therefore, the speed disturbance is calculated without the demagnetizing or magnetizing effect of load, either for the motor or generator. However, this does not destroy the value of the solution as can be seen from succeeding paragraphs.

The demagnetizing or magnetizing action results from 4 causes: first, from the effect of magnetic saturation of the teeth and pole face due to the field distortion created by armature reaction; second, from the commutation, since the armature conductors short-circuited by the brushes, rotating in the commutating field and encircling the main axis of the machine, frequently give demagnetizing ampere turns as the load increases; third, from the direct effect of the commutating pole ampere turns if the brushes are set off neutral; and fourth, from the direct effect, either magnetizing or demagnetizing, of the series field. The first and second causes are inherent. The third and fourth are imposed and are adjustable within limits after the machine is built.

With the brushes set directly on neutral (equivalent to being directly under the center of the commutating pole) the third cause is eliminated. This is the normal position in commutating pole machines having a series field. Therefore, in the usual machine the change in the effective flux is entirely a change in the flux through the main poles, and is strongly resisted by the highly inductive main field winding. Actually the flux is substantially constant during the first portion of the speed dip. Thereafter, the calculated speed curve may be raised or lowered along its length in proportion to the change in flux. The total correction, if any, is known if the steady state speed regulation is known, or if it is assumed that adjustments will be made in test to obtain a specified steady state regulation. This total action takes place gradually over a relatively long period of time because of the slow decay of the induced field current. Furthermore, the correction easily is applied as the time constant governing the action is that of the field circuit, which is determined readily. With knowledge of these

facts, it is quite possible to calculate a highly accurate speed-time curve on the condition of constant flux. This method provides the simplest, quickest way of getting results.

Speed Equations

Consider a motor and generator with armatures connected together and with torque applied to the motor as shown in figure 3*A*. The current flowing in the circuit is:

$$i = \frac{E - e}{R + Lp}$$

where

E = voltage behind generator impedance
e = counter electromotive force of motor
R = total resistance of generator, motor, cables, etc.
L = lumped inductance of generator, motor, cables, etc.
p = d/dt

Inductance L is the total transient inductance of the armature circuit consisting of the total inductance of the armatures and commutating fields, minus twice the mutual inductance between those fields and armatures, plus the inductance of the cables. This is substantially a constant except on heavy overloads. The transient inductance of the series field is negligible. The total inductance, L, is only slightly less than the steady state inductance (flux linkages per ampere of sustained current) because the effect of the solid iron of the frame is to damp only a portion of the flux. It has been found that the steady state inductance may be calculated roughly by taking the unit resistance of the machine (equal to rated volts divided by rated amperes, or rated volts squared divided by rated watts) and dividing this by the rated angular velocity (πPn)/60 as though it were reactance (P is the number of poles and n is the speed in revolutions per minute). The steady state inductance is 0.6 of the resulting value for uncompensated machines and 0.25 for compensated machines. Such approximate estimates have given remarkably close checks in 11 cases for which elaborate calculations have been made.

The electrical torque of the motor with constant flux is the product of a constant times the current. Therefore, this torque may be expressed by:

$$Ki = \frac{K_0 - K_1 n}{R + Lp} \tag{1}$$

where

$$K = \frac{P\phi Z 10^{-8}}{2\pi a}$$

$$K_0 = KE = \frac{P\phi Z\ 10^{-8}}{2\pi a}$$

$$K_1 = KK_3 = \frac{P\phi Z}{2\pi a 10^8} \cdot \frac{P\phi Z}{60 a 10^8} = \frac{(P\phi Z)^2}{120\pi(a10^8)^2} = \frac{30}{\pi}\frac{e^2}{n^2}$$

n = speed in revolutions per minute
P = number of poles
a = number of armature paths
Z = number of armature conductors
ϕ = flux per pole (maxwells)

All of the foregoing coefficients are for the motor.

The electrical torque must balance the total mechanical torque consisting of: the suddenly applied torque ΔT; the initial torque T_0 (including the friction of bearings, brushes, windage, etc.); and the inertia torque Mpn where M is an inertia constant of the motor armature and is equal to $(2\pi/60)(WR^2/g)$ in which W is the weight of the armature in pounds, R its radius of gyration in feet, and g the acceleration due to gravity.

$$Ki = (\Delta T) + T_0 + Mpn \tag{2}$$

Substituting equation 1 gives:

$$K_0 - K_1 n = (R + pL)(\Delta T + T_0 + Mpn)$$

and expanding:

$$\left(p^2 + \frac{R}{L}p + \frac{K_1}{LM}\right) n = \frac{K_0 - RT_0}{LM} - \frac{(R + Lp)}{LM}(\Delta T)\,1 \tag{3}$$

where 1 is Heaviside's unit function.

The solution of this equation by the expansion theorem is:

$$n = \frac{K_0 - RT_0 - R(\Delta T)}{K_1} + \frac{(\Delta T)e^{-\frac{Rt}{2L}}}{2K_1}\left((R + \beta)e^{\alpha t} + (R - \beta)e^{-\alpha t}\right) \tag{4}$$

where

$$\beta = \frac{R^2M - 2LK_1}{2LM} \qquad \alpha = \sqrt{\frac{R^2}{4L^2} - \frac{K_1}{LM}}$$

For the oscillatory case let $\omega = \sqrt{\frac{K_1}{LM} - \frac{R^2}{4L^2}}$; then $\alpha = j\omega$

By this substitution:

$$n = \frac{K_0 - R(\Delta T + T_0)}{K_1} - \frac{(\Delta T)e^{-\frac{Rt}{2L}}}{\omega M}\sin\left(\omega t - \sin^{-1}\frac{R\omega M}{K_1}\right) \tag{5}$$

In the ordinary case the disturbance is a harmonic oscillation of the frequency $\omega/(2\pi)$ and amplitude $(\Delta T)/(\omega M)$. The axis of the oscillation is the final steady state speed at constant flux.

If n_0 is the initial speed and the torque is in foot pounds,

$$n = n_0 - \frac{1.36R(\Delta T)}{K_1} - \frac{1.36(\Delta T)e^{\frac{-Rt}{2L}}}{\omega M}\sin\left(\omega t - \sin^{-1}\frac{R\omega M}{K_1}\right) \tag{6}$$

Influence of R, L, and M

The influence of factors R, L, and M may be interpreted readily from the approximate equations following:
For values in the ordinary range

$$\omega = \sqrt{\frac{K_1}{LM} - \frac{R^2}{4L^2}} = \sqrt{\frac{K_1}{LM}}\ \text{(very nearly)}$$

Substituting this approximate relation gives:

$$n = n_0 - \frac{1.36R(\Delta T)}{K_1} - 1.36\sqrt{\frac{L}{K_1M}}\,(\Delta T)e^{\frac{-Rt}{2L}}\sin\left(\sqrt{\frac{K_1t}{LM}} - \sin^{-1}R\sqrt{\frac{M}{LK_1}}\right) \tag{7}$$

This result shows that the speed fluctuation, starting from an initial speed n_0, is a damped harmonic oscillation about the speed $n_0 - 1.36R(\Delta T)/K_1$ as an axis. The amplitude of the oscillation is $1.36\sqrt{\frac{L}{K_1M}}\,(\Delta T)$ and the damping exponent, or decrement factor, is $R/2L$.

These quite simple results led to the conclusions made earlier in the paper regarding the effects of R, L, and M. The effects of all factors, R, L, M, and K_1, may be summed up as follows:

1. The amplitude of the speed oscillation is $1.36\,(\Delta T)\sqrt{L/(K_1M)}$ and is, therefore, independent of R, proportional to $\sqrt{L}$, proportional to $\sqrt{1/M}$, and proportional to $\sqrt{1/K_1}$.
2. The offset of the axis of oscillation is $1.36\,R(\Delta T)/K_1$ and is proportional to R, independent of L, independent of M, and proportional to $1/K_1$.
3. The frequency of the oscillation is $\sqrt{K_1/(LM)}/(2\pi)$ and is independent of R, proportional to $\sqrt{1/L}$, proportional to $\sqrt{1/M}$, and proportional to $\sqrt{K_1}$.
4. The damping is $R/2L$ and is, therefore, proportional to R, proportional to $1/L$, and independent of M and K_1.

It is obvious that the least fluctuation of speed occurs when the values of R, L, K_1, and M are such that they result in: (1) small amplitude, (2) small offset, (3) low frequency, and (4) large damping.

The factor K_1 is fixed by the voltage and speed of the motor. On the face of the results, a large value of K_1 would be desirable indicating that high voltage and low speed should be chosen for the motor. However, K_1 is a design factor related to R and L in such a fashion that the 3 factors always move to exactly compensating values so long as the current density in the copper, the flux per pole, and the number of poles are not changed. Therefore, K_1 is not a basic value, and the best motor is one for which R and L are made as low as possible. It is beyond the scope of this paper to go into the details of the design except to note that considerable improvement can be obtained through the proper choice of speed, voltage, number of poles, and other design features. As expected,

the theory points to an overslzed motor and large inertia, especially the latter. A separate flywheel is advantageous.

References

The following articles, with their accompanying discussions, give an interesting background:

1. Speed Regulation of Main Roll Drives, L. A. Umansky. *Proc.* Assn. of Iron and Steel Elec. Engrs., 1927, p. 103–15.

2. The Drive of Tandem Rolling Mills, A. F. Kenyon. A.I.E.E. Trans., v. 47, 1928, p. 764–70.

3. 76-Inch Hot Strip Mill, Inland Steel Co. R. W. Davis. *Iron and Steel Engr.*, Dec. 1934, p. 486–94.

Definitions of Power and Related Quantities

Definitions of power, power factor, and related quantities in an a-c circuit have been prepared in an effort to provide definitions which will be generally acceptable. If such general acceptance is obtained, they will be published as a part of the revised report on "Definitions of Electrical Terms" which is being prepared by the Sectional Committee on Electrical Definitions. The authors were requested to prepare this paper to give to engineers an understanding of the principles which have guided the preparation of the proposed definitions and to provide opportunity for their discussion. The definitions cover the entire field of single-phase and polyphase circuits. The explanations start with simple circuits and lead to the more complex.

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THIS paper has been prepared to present the reasons which have influenced the selection of the names and definitions of a number of quantities which are related to the concept of power in an a-c circuit. The preparation of the definitions was undertaken as part of a program which has for its object the recording and clarifying of the present terminology in the electrical field. This program is being carried on by the Sectional Committee on Electrical Definitions under the sponsorship of the A.I.E.E. and under the rules of procedure of the American Standards Association. As part of this program, the present paper was prepared by the authors at the request of the Institute's committee on instruments and measurements.

In no part of the field of clarifying electrical terminology is there greater need of a logical set of definitions than in connecton with power. As the set of definitons which are accepted will soon be published as a part of the sectional committee's report on American standard "Definitions of Electrical Terms," a statement of the considerations which have led to the selection of this particular set is appropriate at this time in order that a wider discussion may lead to further improvements.

The definitions concerning power in single-phase and in balanced polyphase circuits with sinusoidal currents and potential differences have been universally recognized for many years. The extension of these definitions to the more complicated cases where the currents and potential differences are not sinusoidal and the circuits are unbalanced presents difficulties which were early recognized. To aid in solving these difficulties, the A.I.E.E. held, in 1920, a symposium on the subject. This symposium failed to clarify the situation, and 2 fundamentally inconsistent definitions of power factor have persisted in the A.I.E.E. standards for many years. The problem was again brought to the fore by the "Roumanian Questionnaire" of 1928, and much valuable discussion of it has been stimulated by the special subcommittee on reactive power of the A.I.E.E. standards committee.

A problem of this sort can never be settled by the fiat of any authority, but its solution must necessarily evolve with the growth of science. Because of the controversial nature of the subject, most of the definitions pertinent to it were omitted from the first report of the Sectional Committee on Electrical Definitions which was published in August 1932. So many comments on this omission were sent to the committee that it appeared that the proper evolution of the subject might be materially assisted by carefully naming and defining the principal concepts involved. Because of the fundamental nature of some of these quantities, the preparation of their definitions was referred to the subcommittee on fundamental and derived terms of the sectional committee, and in the autumn of 1933 the present authors were charged with the duty of preparing this group of definitions.

In preparing the definitions, advice and criticism were obtained from a large number of engineers. Before writing any definitions, correspondence was carried on with a number of persons who had given

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Publication approved by the director of the National Bureau of Standards of the U. S. Department of Commerce.

particular attention to this field. A set of definitions was then prepared and circulated to a rather large group and over 20 written criticisms were received from different individuals and groups. After all these suggestions had been carefully considered, those definitions concerning which there was a wide difference of opinion were revised and resubmitted to the same group for further criticism. The purpose of this paper is to bring out the reasons which have led to the selection of the definitions in their present form.

In the appendix are given those definitions which are essential for understanding this paper. In the complete report which the subcommittee on fundamental and derived terms has submitted to the sectional committee, the definitions are first stated in as concise English as is consistent with a definite and precise statement. Each quantitative definition is then repeated in mathematical symbols. The use of mathematical symbols should require no apology as it is the one method of expression concerning which there is no possible ambiguity. However, it has not seemed necessary to the authors to include the mathematical statements in the appendix of this paper.

The definitions of the report are stated in general terms assuming that in each case, unless otherwise stated, periodic (nonsinusoidal) currents and potential differences are present. The adaptation of the definitions to sinusoidal cases is readily accomplished by omitting the harmonic terms. This method of treatment has not met with universal approval. Some critics felt that additional definitions which would be applicable only to sinusoidal and to balanced conditions should also be included. This suggestion has not been followed because the increased space did not appear to be justified in view of the ease with which the simplified form can be derived from the more general. Other critics felt that the definitions for some of the more unusual cases were unnecessary. Although this criticism was given very careful consideration, the authors reached the conclusion that the formulation of a complete and logical set of definitions is more important than an attempt, on their part, to select only those quantities which, at the present time, have sufficient importance to justify defining.

Every definition necessarily is a statement that a particular word or small group of words is to be used as a name to designate the idea defined. The problem of choosing the names is a matter of fundamental importance and in many respects proved to be more difficult than that of formulating the precise definitions. After the authors' tentative choice of names had evolved some very vigorous criticism, a sort of preferential ballot was circulated, offering a number of alternative names for each of several of the disputed quantities. The results of this ballot (modified slightly as required to maintain consistency among the different quantities involved) are the names in the present edition. It is to be hoped that these names will find universal acceptance in order to strengthen the A. S. A. program of standardization.

In selecting names, extensive use has been made of qualifying adjectives to distinguish between quantities which belong to the same general class. It is expected that these adjectives will be omitted by writers when the context indicates sufficiently well the particular quantity that is under consideration. However, such an omission should be made only if there is no possibility of misunderstanding. Verboseness is preferable to indefiniteness.

I. Fundamental Concepts

There are several fundamental concepts which must be kept in mind in making definitions concerning electric power. The first is that power is the rate of flow of energy and hence that it is measured at a particular boundary through which the energy flows. It follows that before measuring power, the boundary at which the power is to be measured must be specified. The only method of specifying the boundary so that it is applicable to all kinds of electric circuits is to consider a closed surface which incloses a region into which, or from which, the flow of energy is to be measured. Within this region may be included a power house or a single generator; a factory or a single lamp therein; a bank of transformers or a single rectifier. In any case, the algebraic sum of all the currents entering and leaving the region is zero at every instant. To identify a region completely, it is sufficient to designate all the places where the circuit enters or leaves the region. For convenience, these places will generally lie along equipotential surfaces where the bounding surface cuts the conductors of the circuit and each such cross section is called "a point of entry of the circuit" or "a terminal of the circuit." Nearly all measurements of power and related quantities are made by connecting apparatus at such points of entry.

It will be noted that these statements specifically exclude consideration of the distinction between potential difference and electromotive force. To have introduced these distinctions would have greatly complicated the discussion.

It can be seen that when the circuit considered lies within a region so that the surface inclosing it cuts no conductors, the definitions do not apply directly. The power associated with such a closed circuit is, however, essentially indefinite unless the consideration is extended to cover not only the flow of electrical energy but also the transformations from or into other forms of energy. Usually it is possible to make assumptions which serve in effect to separate such a closed circuit into portions, to each of which the present definitions immediately become applicable.

II. Names for the Quantities Involved

Before giving definitions of power, it is necessary to decide the names to be used in designating the various quantities to be defined. In deciding on names, the most difficult question is to determine whether the name "power" shall be applied to all the quantities which have the dimensions of voltage

times current. This can be best illustrated by taking as examples 2 terms which are familiar to all engineers. The question that must be decided is whether "apparent power" and "reactive power" shall be used to designate certain quantities, or whether these quantities shall be designated as "voltamperes" and "reactive voltamperes." A preferential ballot indicated that engineers were nearly equally divided in their preference regarding these 2 pairs of terms. A number of letters have been received explaining why one or the other set of terms is not suitable. Very few have pointed out the advantages of the set of terms which they favor. Under these conditions, the authors have decided to use "apparent power" and "reactive power" for the reasons which follow.

The quantities "apparent power" and "reactive power" have the same physical dimensions as "power" and therefore can be used in the same equation as "instantaneous power" or "active power." In other branches of physics and engineering, this is often considered sufficient justification for continuing a generic name. Moreover, the present tendency of engineering usage appears to be away from "voltamperes" and toward "power." In recent years committees of the Institute have frequently used these expressions.

It is a general principle of nomenclature that it is not desirable to name a quantity by some particular unit which is used to measure that quantity. Hence, it is not desirable to use "voltamperes" as the name of a quantity. If the units are in any way to be connected with the name of the quantity, it should be called "voltamperage."

There has been considerable diversity of opinion concerning the adjectives to be used to designate the various types of power. Of the expressions concerning which there appeared to be enough difference in usage to warrant placing them on the ballot, only 2, "active power" and "distortion power," had substantial majorities. In 3 cases, "vector power," "fictitious power," and "nonreactive power," the vote was so close that the result was indeterminate, and final decision had to be made by the authors.

III. Power in Single-Phase Circuits When the Currents and Potential Differences Are Sinusoidal

While the definitions of the quantities relating to power in a single-phase circuit,* when the current and potential difference are sinusoidal, are well established, a consideration of the properties of these quantities is important before extending the definitions to nonsinusoidal wave forms and to polyphase circuits.

1. Instantaneous Power. The definition of instantaneous power follows directly from the definition of a potential difference and hence instantaneous power is equal to the instantaneous current times the instantaneous potential difference. The algebraic sign of instantaneous power is determined by the signs of the current and potential difference at that instant, with the result that instantaneous power is in most cases negative during a small part of each cycle. If both current and potential difference are sinusoidal, the instantaneous power can be represented as a constant plus a sinusoidal function of the time which has double the frequency of the current. In a single-phase circuit, the potential difference is usually measured from one conductor which is taken as having zero potential. However, that is not necessarily the case, since, if any other point is chosen, the increase in the instantaneous power attributed to one conductor is exactly offset by the decrease in that attributed to the other conductor. Hence, the instantaneous power has the following properties:

a. It is independent of the choice of the point which is taken as the origin from which the potentials of the points of entry of the circuit are measured.

b. The total quantity for a region, measured at its points of entry, is equal to the algebraic sum of the contributions of the parts into which the region may be divided, the measurement for each part being made at its respective points of entry.

2. Active Power. Active power is the time average of the values of the instantaneous power, the average being taken over a complete cycle of the fundamental frequency of the alternating current. Since it is simply a time average of the instantaneous power, it has the same 2 properties listed under instantaneous power.

3. Apparent Power. In a single-phase circuit, the apparent power at the points of entry is the product of the effective value of the current and the effective value of the potential difference between the 2 conductors which carry the current. Apparent power, as defined above, requires that one conductor be taken as the origin from which to measure the potential of the other conductor. The conception of apparent power can be so extended that it will have property *a* listed above; *viz.*, the potentials may be measured from any point as origin, provided apparent power is treated as a complex quantity or vector, the rectangular components of which are active power and reactive power. The total apparent power is then obtained by the vector addition of the apparent powers for the 2 conductors. It is then evident that apparent power does not have property *b* listed above, since this property involves an algebraic addition. However, it does have the following analogous property:

c. The total apparent power (vector power) for a region is equal to the *vector* sum of the contributions of the parts into which the region may be divided.

Apparent power also has the following properties:

d. Apparent power is numerically equal to the maximum active power that can exist at given points of entry with the given effective value of the sinusoidal current and potential difference and hence is directly related to the size of the required equipment and to the generating and transmitting losses.

e. Apparent power multiplied by the cosine of the angular phase difference between the sinusoidal current and potential difference is equal to the active power.

f. Apparent power is proportional to the amplitude of the cyclic fluctuations in the instantaneous power when the currents and

* The term "single-phase circuit" is used throughout this paper with the limited meaning of a 2-wire single-phase circuit.

potential differences are sinusoidal and hence indicates the tendency to produce vibrations.

4. Reactive Power. Reactive power in a single-phase circuit with sinusoidal current and potential difference is the product obtained by multiplying the apparent power by the sine of the angular phase difference between the current and potential difference. It may be treated as a vector which is always in quadrature with active power, or as the absolute value of this vector. From the above mathematical statement, it follows that reactive power in a sinusoidal, single-phase circuit has the following physical properties:

In this and the following diagrams, the reactive power has been drawn positive, indicating that the current leads the potential difference as is the case in a capacitative circuit

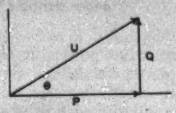


Fig. 1. Power diagram for a single-phase circuit under sinusoidal conditions

g. Reactive power is complementary to active power, since active power is equal to the apparent power multiplied by the cosine of an angle, whereas reactive power is equal to the apparent power multiplied by the sine of the same angle. From this, it follows that reactive power for sinusoidal conditions has 2 of the properties listed under instantaneous power and active power; *viz.* (*a*) it is independent of the point which is selected from which to measure the potentials of the 2 conductors; (*b*) it can be obtained by the algebraic summation of the reactive powers of the parts of the circuit.

h. Reactive power for sinusoidal conditions is proportional to the amplitude of the alternating component of the power resulting from the reactance of the circuit as distinguished from the pulsating component resulting from the resistance of the circuit.

i. Reactive power is equal to 4π times the frequency, times the amount by which the mean value of the stored electrostatic energy exceeds the mean value of the stored electromagnetic energy during a cycle.

The algebraic sign to be assigned to reactive power has presented a serious problem. In 1933, the U. S. national committee of the International Electrotechnical Commission sought for guidance concerning the conventional direction for plotting reactive power when treated as a vector. A careful survey of American opinion made by the special committee on reactive power of the A.I.E.E. showed that the negative (downward) convention for inductive reactive power (current lagging potential difference) was favored in about the ratio of 3 to 2. The committee on electrical and magnetic magnitudes and units of the International Electrotechnical Commission, meeting in Paris later in the year, formally adopted this convention. The authors therefore felt obliged to adopt the corresponding algebraic sign when reactive power is considered as a scalar quantity.

5. Geometric Power Diagram for Sinusoidal Conditions. The geometric power diagram in a single-phase circuit under sinusoidal conditions is shown in figure 1. It is a right triangle in which apparent power U is the hypotenuse, active power P and reactive power Q the 2 legs, and the angular phase difference θ the angle opposite Q. From this diagram the following additional relationship is immediately evident:

$$U^2 = P^2 + Q^2$$

The close analogy between this power diagram and the familiar admittance and impedance diagrams is evident.

IV. Extension of Power Concepts to Single-Phase Circuits With Nonsinusoidal Currents and Potential Differences

The commonly accepted method of dealing with problems involving nonsinusoidal quantities is to resolve each into its fundamental and harmonics by a Fourier analysis, and to treat each component separately. In extending power concepts, this method of analysis has been used as much as is feasible.

1. Instantaneous Power. In single-phase circuits in which the current and potential difference have harmonics, instantaneous power is necessarily defined in the same manner as for sinusoidal conditions. However, in this case, its variation is not a simple sine function of the time, so that the instantaneous power is given by an expression which includes the product of each harmonic term of the current by every harmonic of the potential difference.

2. Active Power. The averaging of the instantaneous power over a complete period of the fundamental component gives the active power for that period. This leads to a relatively simple expression, as most of the terms in the expression for instantaneous power disappear in the averaging process. In this way, it is shown that the active power under periodic conditions is equal to the algebraic sum of the active powers corresponding to the fundamental and to each harmonic. This extended definition to periodic conditions retains for active power the same properties as were given by the sinusoidal definition; *viz.* (*a*) it is independent of the point from which potentials are measured; (*b*) the total for an entire region is the algebraic sum of the parts into which the region may be divided.

3. Apparent Power. Apparent power also is defined in the same manner for periodic conditions as for sinusoidal conditions; *viz.*, it is the product of the effective (root-mean-square) current in one conductor by the effective potential difference between the 2 conductors. Apparent power as thus defined for periodic conditions has only 1 of the 3 special properties of apparent power as defined for sinusoidal conditions; *viz.*, that one given as *d* (in a previous paragraph) which states that the apparent power is the maximum possible active power for the given effective values of the current and potential difference. This property is generally considered as the most important of the 3. The relation between the apparent power and the active power depends not only upon the angular phase differences of the fundamentals and harmonics as indicated under *e* for sinusoidal conditions, but also upon their relative magnitudes. Also the extreme variations of the instantaneous power are not pro-

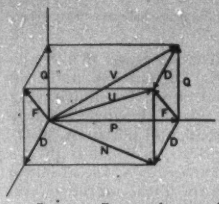
portional to the apparent power as given under *f* for sinusoidal conditions.

4. Reactive Power. Reactive power in a single-phase circuit with periodic current and potential difference is defined as the algebraic sum of the reactive powers corresponding to the fundamental and to each harmonic component. This definition retains the properties *g*, *a*, and *b* of the definition for sinusoidal conditions; *viz.*, that reactive power is complementary to active power, and like it, is independent of the point from which potentials are measured and the whole is the sum of the parts. It does not retain *h* and *i*, the close relation to reactance and to the storage of energy in the electromagnetic and electrostatic fields. Some engineers have suggested that the definition be modified by multiplying the reactive power of each harmonic component by its number for the purpose of retaining property *i* which relates reactive power with the rate of storage of energy in the electrostatic and magnetic fields. Such a multiplication destroys the parallelism with active power (property *g*). Other critics suggested limiting the concept of reactive power to sinusoidal conditions, except as it might be applied to the individual harmonics separately. If this were accepted, there would be, in a periodic circuit, no term complementary to active power, and hence the possibility of the further extension of power concepts would vanish. Neither of these proposals seemed to warrant changing a definition that has been in the A.I.E.E. standards (polyphase circuits) for many years.

5. Geometric Power Diagram for Periodic Conditions. With the definitions that have been chosen, the square of the apparent power is, in general, greater than the sum of the squares of the active power and reactive power when there are harmonics in the current and potential difference. Under these conditions the triangular diagram which is applicable to sinusoidal conditions must be modified. One method of doing this is to introduce a new quantity, distortion power, which is so defined that the square of the apparent power is equal to the sum of the squares of the active power, the reactive power, and the distortion power. Instead of representing these quantities in one plane, a more convenient diagram is obtained by a figure in 3 dimensions, as shown in figure 2. This diagram has the advantage that it gives a mental picture of the interrelations of all the power concepts that have been proposed in connection with single-phase circuits.

6. Distortion Power. This term was defined above in connection with the geometric power diagram. Its name appears to some extent in the literature and seems appropriate because the distortion power differs from zero only when the current or potential difference has harmonics (is distorted).

7. Fictitious Power. Fictitious power is defined as the square root of the difference of the squares of the apparent power and the active power. From the diagram, figure 2, it is seen that the square of the fictitious power is equal to the sum of the squares of the reactive power and distortion power. It is identical with the quantity which was defined as



This diagram is drawn to represent the vector addition, in 3 dimensions, of active power, P, reactive power, Q, and distortion power, D. The vector sum of P and Q is the vector power, V, the vector sum of Q and D is the fictitious power, F, the vector sum of P and D is the nonreactive power, N, while the vector sum of all 3 is the apparent power, U

Fig. 2. Power diagram for a single-phase circuit under periodic (nonsinusoidal) conditions

reactive power in the A.I.E.E. standards (single phase) in 1921. Some change in the name was required because the A.I.E.E. standards had 2 conflicting definitions for "reactive power."

8. Vector Power. Vector power is defined as the square root of the sum of the squares of the active power and reactive power. It has the property *a* above; *viz.*, it is independent of the origin from which potentials are measured; and also property *c*, *viz.*, the whole is the vector sum of the parts. In addition to forming a rational part of the power diagram for periodic conditions in single-phase circuits, it is particularly useful in polyphase circuits. The concept was formally defined for such circuits by the A.I.E.E. in 1920, the name "vector voltamperes" being applied to it at that time. It will be seen that if there are no harmonics, vector power in a single-phase circuit becomes identical with apparent power.

9. Nonreactive Power. Nonreactive power is the square root of the sum of the squares of the active power and distortion power. This term has been introduced to complete the naming of the edges of the power diagram. The name was chosen to indicate that it is the residue when reactive power is subtracted vectorially from apparent power.

V. Balanced Polyphase Circuit Under Sinusoidal Conditions

The extension of power concepts to a balanced polyphase circuit with sinusoidal currents and potential differences, both of which form symmetrical sets, follows directly from the single-phase definitions under sinusoidal conditions. Because of the symmetry, such a circuit may be considered as divided into a group of single-phase circuits, each having the same effective current and potential difference, with the same phase difference, as every other. The manner of separation into equal single-phase circuits is immaterial, but the customary method is to consider the single-phase circuits as the arms of a star network, with the currents those in the line conductors and the potential differences those from each line conductor to neutral. Each power quantity for the balanced polyphase circuit is defined as the sum of the corresponding quantities for the single-phase circuits. However, the instantaneous power in a balanced polyphase circuit under sinusoidal conditions does not change during a cycle as is the case in a single-phase circuit. All

the power concepts connected with a single-phase circuit under sinusoidal conditions, *viz.*, active power, apparent power, and reactive power, are thus extended to a balanced polyphase circuit under the same conditions. They have the same properties that they have in the single-phase circuits, except that, since there are no fluctuations in instantaneous power, apparent power cannot be correlated with such fluctuations.

VI. Balanced Polyphase Circuit Under Nonsinusoidal Conditions

The extension of power concepts to a balanced* polyphase circuit with harmonics in the currents and potential differences may be accomplished by considering the circuit either as separated into a group of single-phase circuits each of which has the same current and potential difference as every other or as divided into an assemblage of balanced sinusoidal polyphase circuits in which the frequencies of the currents and potential differences are those of the fundamental and the harmonics of the currents and potential differences of the balanced circuit. If the first method is employed, "active power," "reactive power," "apparent power," "distortion power," "vector power," "fictitious power," and "nonreactive power" are all obtained by multiplying the values for one single-phase circuit under periodic conditions by the number of circuits. The properties of the various quantities when summed in this way are the same as they are in a single-phase circuit. Hence, apparent power has the property *d* previously outlined; i. e., it is the maximum possible active power for the given effective currents and potential differences. However, the instantaneous power of the circuit is obtained by an algebraic summation of the instantaneous powers of the component single-phase circuits. It is, in general, not a constant but shows a cyclic variation with time.

If the second method is employed for each member of the assemblage of balanced polyphase circuits, values can be determined for the quantities "active power," "reactive power," and "apparent power," as is the case with any balanced polyphase circuit under sinusoidal conditions. Active power and reactive power of the circuit are obtained by the algebraic addition of the contributions of the successive members of the assemblage. The vector power of the circuit is obtained correspondingly by the vector addition of their vector powers each of which is identical with its apparent power because each component is sinusoidal. The arithmetic sum of the apparent powers of the successive members of the assemblage does not give the same value for the apparent power of the circuit as was obtained by the first method. Because the apparent power as defined by the first method is generally recognized as the apparent power of a balanced polyphase circuit, and has the important property *d* noted above, that definition has been preferred to one that might have been formulated from the second method.

VII. Unbalanced Polyphase Circuit Under Sinusoidal Conditions

The extension of power concepts to an unbalanced polyphase circuit with sinusoidal currents and potential differences, all of which have the same frequency, can be made either by separating the polyphase circuit into a group of single-phase circuits, in which the currents are those in the conductors at the points of entry and the potential differences are measured from a common point, or by resolving the unbalanced polyphase circuit into an assemblage of balanced polyphase circuits in which the characteristic angles of the symmetrical sets of currents and potential differences of the members of the sequence are integral multiples of a common angle.

The customary method of separating into single-phase circuits is to choose an origin from which to measure potentials and to consider that the single-phase component circuit corresponding to each point of entry carries the current in the corresponding conductor with a potential difference equal to that between the origin and the given point of entry. Since instantaneous power, active power, and reactive power are independent of the point chosen as an origin, their values are the same for every possible separation into single-phase circuits. Also, their properties are identical with those which they have in single-phase circuits and in balanced polyphase circuits.

It is to be noted, however, that although the insertion in the usual manner of a set of wattmeters at the terminals of an unbalanced polyphase circuit gives a theoretically correct measurement of the active power in the polyphase circuit, the corresponding method for measuring reactive power will not give a correct result if both the currents and the potential differences form unsymmetrical sets. A theoretically possible but impracticably complicated sequence network is required for a correct measurement of reactive power in this case.

There is no one quantity in an unbalanced polyphase circuit which possesses the properties of apparent power in a single-phase or a balanced polyphase circuit. To meet this situation, a number of different quantities have been suggested, each of which is in some respects analogous to apparent power, with the result that, in an unbalanced polyphase circuit, apparent power must be considered as a generic term. Four of these quantities which appear to have the greatest significance, practical or theoretical, have been formally defined as extensions of apparent power to unbalanced circuits. Each of these extensions postulates some particular manner of separating the polyphase circuit into component single-phase circuits, and each defines the total apparent power by a suitable combination of the apparent powers of the component circuits.

1. **Arithmetic Apparent Power.** Arithmetic apparent power in an unbalanced polyphase circuit is defined as the sum of the apparent powers obtained by multiplying the effective current in each line

* The term "balanced polyphase circuit" is here used to indicate a circuit in which all the potential differences of the polyphase set are symmetrical, and that the currents are also symmetrical but do not necessarily have the same wave form as the potential differences. See definition of a symmetrical set in the appendix.

conductor at the point of entry by the effective potential difference between it and the actual neutral, when one exists, or, if one does not exist, then an artificial neutral arbitrarily defined by the potential of the junction of a star of equal impedances connected to the line terminals.

Although this extension corresponds to the one which is commonly employed in extending the definition of apparent power from single-phase circuits to balanced polyphase circuits, yet in the unbalanced circuit, arithmetic apparent power, unfortunately, has none of the properties of apparent power in either of the simpler types of circuit. Because of this lack of definite properties, the A.I.E.E. did not, in 1920, include this definition in their standards. However, a number of engineers have urged its inclusion, possibly because it can be readily obtained from measurements with ammeters and voltmeters. The name has been chosen because it is the *arithmetic* sum of the contributions of the different component circuits.

2. Limiting Apparent Power. Limiting apparent power, in the case of an unbalanced circuit which is intended to be supplied with power from a symmetrical polyphase source, is equal to the maximum power which could exist at the points of entry of the circuit without loading any one of them more heavily than the actual load does at the most heavily loaded one. Like arithmetic apparent power, it is simple to measure; but unlike the former, its value is determined from a single current and a single potential difference.

3. Algebraic Apparent Power. Algebraic apparent power in an unbalanced polyphase circuit is so defined that it possesses property *d*, previously outlined, of single-phase and balanced polyphase circuits; *viz.*, it is equal to the maximum active power that can exist at the given points of entry with the given effective values of the currents in, and the potential differences between, the points of entry. This is the Lyon-Lienard concept of apparent power and requires that the common point of the group of component single-phase circuits be chosen in a particular manner. The determination of the common point for the purpose involves the various values of current as well as of potential difference. If the common point is located by a star of resistances, there may be required, in extreme cases, one or more arms having a negative resistance. When this is the case, the contributions from the corresponding component circuits must be considered negative, hence the name *algebraic* apparent power.

4. Vector Power. Vector power in an unbalanced polyphase circuit under sinusoidal conditions is defined as the square root of the sum of the squares of the active power and reactive power. As in the previous use of this term, it has properties *a* and *c*; *viz.*, it is independent of the point of measuring potentials and the whole is the vector sum of the parts.

It is to be noted that the distinction between vector power and apparent power arises from the unbalance of the circuit. In a balanced polyphase circuit, vector power, arithmetic apparent power,

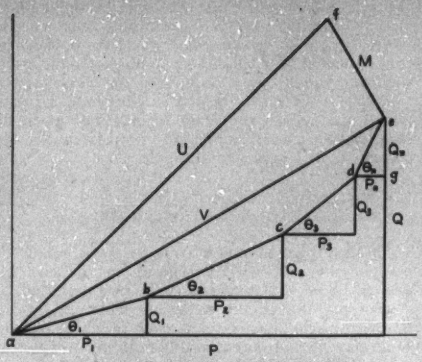


Fig. 3. Power diagram for an unbalanced 4-wire polyphase circuit under sinusoidal conditions

This diagram represents in one plane the vector addition of the contributions, corresponding to a particular origin from which potentials are measured, from each of the 4 points of entry. The vector, M, representing the mesh power, is drawn perpendicular to the vector power, V, and of such length that the vector sum of V and M has the magnitude of the apparent power, U

and algebraic apparent power all have the same value and are called apparent power in the same way as, in a single-phase circuit, vector power and apparent power become identical when there is no wave distortion and are similarly called apparent power. Another feature of vector power is its identity, under sinusoidal conditions, with algebraic apparent power in a circuit with 3 points of entry.

5. Mesh Power. Mesh power has been suggested (see reference 1 at end of paper) as a quantity to connect algebraic apparent power with vector power in an unbalanced polyphase circuit under sinusoidal conditions in the same manner that distortion power is used to connect these quantities in a single-phase circuit when harmonics are present. Hence, a definition of mesh power comes from the relationship that the square of the algebraic apparent power is equal to the sum of the squares of the active power, reactive power, and mesh power. A similar definition can be formulated to connect vector power with arithmetic apparent power, so that adjectives may be required to distinguish the 2 possible kinds of mesh power.

6. Geometric Power Diagram for a Sinusoidal Unbalanced Circuit. A geometric power diagram for an unbalanced 4-wire circuit under sinusoidal conditions is shown in figure 3, the length of the sides being numerically equal to the value of the corresponding power quantities. In this case, the diagram has been made in one plane, since there are no harmonics and hence no distortion power. The length *af* has been chosen equal to the algebraic apparent power *U*, and *fe* is drawn at right angles to *ae* so that *M* represents the mesh power. This diagram shows the vectorial nature of the sum-

mation which gives the straight line *ae* as the vector power of the entire circuit.

If the separation of the 4-wire circuit into single-phase component circuits has been made by measuring the potentials from the actual neutral, or, in its absence, an equal-arm artificial neutral, the triangle *deg* will reduce to a point. The arithmetic power is then equal to the arithmetic sum of the hypotenuses of the remaining 3 triangles; i. e., the length of the broken line *abcd*. This shows that arithmetic apparent power is greater than the vector power unless the angular phase differences of the component circuits are identical.

For each point which may be chosen as the origin from which to measure the potentials, there is a corresponding power diagram. If this point is determined by a resistance star having the properties required for measuring algebraic apparent power, then the length of the broken line *abcde* is the algebraic apparent power. However, in obtaining the length of the broken line, those parts of the line corresponding to those arms of the star in which the resistance has a negative value must be taken as negative. This broken line will be longer than *ad* except when all the phase angles are equal. With only 3 points of entry the phase angles of the separate circuits which determine the algebraic apparent power are necessarily equal, but this may not be the case with 4 or more points of entry. When the phase angles are not equal, mesh power must be introduced to account for the difference between the length of the broken line *abcde* and the straight line *ae*, in that diagram in which the potentials are measured from the point required for determining algebraic apparent power.

7. Symmetrical Components. The method of resolving an unbalanced polyphase circuit in which the currents and potential differences are sinusoidal into a group of balanced circuits, in each of which the currents and potential differences form symmetrical sets, furnishes an alternative procedure for treating power problems in such circuits. This method of separating an unbalanced polyphase circuit into a group of balanced polyphase circuits instead of into a group of unequal single-phase circuits avoids some of the difficulties which have been noted in the preceding paragraphs. When such a resolution is made, the various definitions of power as extended to a balanced polyphase circuit under sinusoidal conditions are directly applicable. The active power and reactive power of the separate balanced polyphase circuits can be added algebraically to obtain the total active power and reactive power respectively of the unbalanced circuit. The vector sum of the apparent powers of the symmetrical components is, for the unbalanced circuit, identical with the vector power as obtained by separating into a group of single-phase circuits.

VIII. Unbalanced Polyphase Circuit Under Nonsinusoidal Conditions

The extension of power concepts to the general case of an unbalanced polyphase circuit, with harmonics in the currents and potential differences, may be accomplished as in the preceding cases by considering the circuit as separated either into a group of single-phase circuits, in which the currents are those in the line conductors and the potential differences are those between a common point and the line conductors, or as divided into an assemblage of unbalanced sinusoidal polyphase circuits in which the frequencies are those of the fundamental and harmonics.

The method of separating into single-phase circuits permits the immediate application of the analysis of each circuit by the extension already given for a single-phase circuit under periodic conditions. There is no unique division of an unbalanced polyphase circuit into component single-phase circuits, since no possible separation will give a group of identical circuits. The method generally employed is the same as was outlined for an unbalanced sinusoidal circuit; *viz.*, choose a common point from which to measure potentials and consider the component circuits as characterized by the current in each conductor and by the potential difference from the point of entry of the conductor to the common point. As in the unbalanced sinusoidal case, the instantaneous power, the active power, and the reactive power of the entire circuit can be obtained by the algebraic summation of the corresponding quantities for the single-phase circuits as defined for a single-phase circuit under periodic conditions. Also, a vector summation of the vector power of the component circuits gives the vector power of the entire circuit. These 4 quantities have all the properties that they possessed in a single-phase circuit, so that they are independent of the point from which the potentials are measured, and are additive. All the other power quantities need to be separately considered. All excepting arithmetic, algebraic, and limiting apparent power can best be considered in connection with the geometric power diagram for this type of circuit.

1. Arithmetic and Limiting Apparent Power. Arithmetic and limiting apparent power are respectively defined in the same manner for a circuit under unbalanced periodic conditions as under unbalanced sinusoidal conditions. Since they depend only upon the effective values of currents and potential differences, a knowledge of the wave form is not required in the measurement of either. As in the unbalanced sinusoidal case, arithmetic apparent power has none of the properties associated with it in single-phase circuits.

2. Algebraic Apparent Power. Algebraic apparent power is also defined in the same manner for a circuit under periodic conditions as under sinusoidal conditions. This requires the selection of a particular point from which to measure potentials. With 3 points of entry, it may not be the same as vector power, as was the case with an unbalanced sinusoidal circuit. In other respects, the statements made for a sinusoidal unbalanced circuit are directly applicable.

3. Geometric Power Diagram of a Periodic Unbalanced Circuit. The geometric power diagram for an unbalanced, 3-wire circuit under periodic

conditions is shown in figure 4. In the diagram is shown the vector summation in space of the active powers, the reactive powers, and the distortion powers of the component circuits. If the potentials used in obtaining the quantities for this diagram were all measured from the neutral (either the real neutral or an artificial neutral obtained as indicated in the definition for arithmetic apparent power), the length of the broken line *abcd* is equal to the arithmetic apparent power. On the other hand, if the point from which the potentials are measured is determined by the star of resistances required by the definition of algebraic apparent power, the length of the broken line *abcd* is equal to the algebraic apparent power, unless the star of resistances contains one or more negative resistances, in which case an algebraic sum of the lengths of the lines *ab*, *bc*, etc., is required, the sign of each term depending upon the sign of the resistance. In either case, the vector power is not equal to the vector sum of the lines *ab*, *bc*, and *cd*, which is the line *ad*, but to the projection of *ad* on the *PQ* plane.

The algebraic sum of the active power and of the reactive power is the same for each of the power diagrams that can be constructed for a given set of conditions. Hence, the vector power of the unbalanced circuit is independent of the point from which potentials are measured. However, the sum of the distortion powers is not the same in the different diagrams. It follows that distortion power is not definite unless the particular point from which potentials are measured is specified. In any case, the broken line *abcd*, which represents apparent power, is equal to or larger than the straight line *ad* which represents the vector summation of active power, reactive power, and distortion power. Hence, another quantity, mesh power, is introduced which is equal to the line *df* drawn perpendicular to *ad* and of such length that the hypotenuse of the right triangle *adf* is equal to the apparent power.

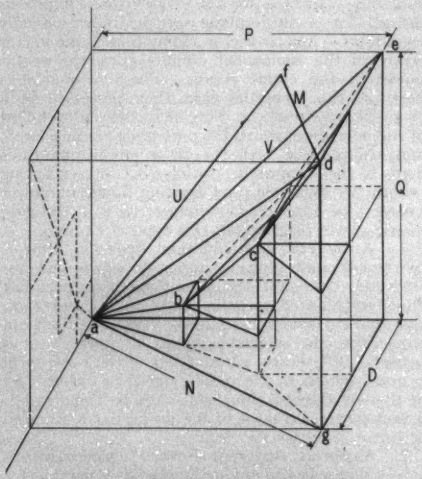


Fig. 4. Power diagram for an unbalanced 3-wire polyphase circuit under periodic conditions

This diagram represents, in 3 dimensions, the vector addition of the contributions, corresponding to a particular origin from which potentials are measured, from each of the 3 points of entry. The projections are shown on each of the 3 coordinate planes. The mesh power, *M*, is drawn perpendicular to the diagonal *ad*, and of such length that the hypotenuse of the resulting triangle equals the apparent power. For the origins which give arithmetic and algebraic apparent power, respectively, the corresponding adjectives should be applied to distortion power and mesh power

4. Distortion Power. Distortion power for any given division of an unbalanced periodic circuit into single-phase circuits is the sum of the distortion powers of the separate circuits. If the division is that required for obtaining arithmetic apparent power, the sum of the distortion powers is the arithmetic distortion power; if that required for algebraic apparent power, the sum is algebraic distortion power.

5. Mesh Power. Mesh power is defined from the relationship that the apparent power is equal to the square root of the sum of the squares of the total active power, the total reactive power, the total distortion power, and the mesh power. It is definite only when the point from which potentials are measured is specified. Hence, in specific cases, the terms "arithmetic mesh power" and "algebraic mesh power" may be employed.

6. Symmetrical Components. The second method of treating power concepts in unbalanced polyphase circuits under periodic conditions is to resolve the harmonic component sets of both the currents and the potential differences into symmetrical components. This method is carried out in 2 steps. First, the polyphase sets of the currents in the points of entry and the potential differences to any convenient origin are resolved into a series of harmonic components. Next, the resulting unsymmetrical sinusoidal sets for each frequency are separated into their symmetrical components. Such a resolution is unique, so that the value of each symmetrical component of each harmonic component is independent of the point from which potentials are measured. The total active power is obtained by the algebraic summation of the active powers of all the symmetrical components of every harmonic component. The total reactive power is similarly defined. The vector power is the vector sum of the vector powers of the component parts. It is interesting to note that the arithmetic sum of all the individual vector powers gives a definite quantity which might be called symmetrical apparent power. However, this is not directly related to arithmetic apparent power, algebraic apparent power, or limiting apparent power.

IX. Circuits in Which the Effective Values of the Currents and Potential Differences Vary With Time

An extension of power concepts to circuits in which the effective values of the currents and potential

differences vary with the time is theoretically possible by literally applying the preceding definitions to each individual cycle separately, and suitably combining the results. In only a few cases is such an analysis useful. Only 2 cases will be considered.

The first case arises in connection with the sale of electrical energy because the charges are sometimes made to depend upon the average values of power quantities during a "demand" interval. Active power and reactive power, being scalar quantities, can be averaged by adding algebraically the respective values for each cycle and dividing by the number of cycles, or by some equivalent process. Vector power, however, is logically averaged by taking the vector sum of the values for each cycle and dividing by the number of cycles. The numerical value obtained by this vector averaging is equal to the square root of the sum of the squares of the average active power and the average reactive power. The average values of other power quantities do not appear to be required.

The second case arises in circuits in which there is persistent "hunting" or in which the load varies periodically with a period much longer than that of the alternating current. The average value of the active power is obtained by averaging over a period of the hunting or of the periodic load. The extension of the preceding definitions of other power quantities to this case is too specialized for standardization at the present time.

X. Power Factor

Power factor is a term which arose in connection with single-phase circuits to designate the numerical factor by which the value of apparent power is multiplied to give the value of active power. This is a definite factor in all single-phase and balanced polyphase circuits. Also, in these circuits, apparent power is identical with vector power. However, in the extension to unbalanced polyphase circuits, power factor becomes a generic term, requiring adjectives to distinguish the different relationships that may be required. Hence, vector power factor, arithmetic apparent power factor, algebraic apparent power factor, and limiting apparent power factor are all numerical factors by which the values of the similarly designated power quantities must be multiplied to give the value of active power.

Appendix—Extracts From Proposed A.S.A. Definitions

Points of Entry of an Electric Circuit (A Set of Terminals). The points of entry (or exit) for delimiting an electric circuit where it enters or leaves a region are the group of surfaces, one cutting each of the conducting paths where the path enters or leaves the region, each of which is individually an equipotential surface and each of which is also a part of the single surface that constitutes the boundary of the region. It follows from this definition that the algebraic sum of the instantaneous currents through a complete set of points of entry is zero at every instant.

Instantaneous Power. Instantaneous power at given points of entry of an electric circuit is, at any instant, the rate at which electrical energy is then being transmitted by the circuit through the boundary of the region which corresponds to the given points of entry.

Instantaneous Power of a Single-Phase 2-Wire Circuit. The instantaneous power at the 2 points of entry of a single-phase 2-wire circuit is equal to the product obtained by multiplying the instantaneous current in one conductor by the instantaneous potential difference between the 2 points of entry. The value of instantaneous power is given in watts when the instantaneous current is in amperes and the instantaneous potential difference is in volts.

Active Power of a Single-Phase 2-Wire Circuit (Power) (Actual Power). Active power at the points of entry of a single-phase 2-wire circuit is the time average of the values of the instantaneous power when the average is taken over a cycle of the fundamental frequency of the alternating current. The value of active power is given in watts when the effective current is in amperes and the effective potential difference is in volts.

Reactive Power of a Single-Phase 2-Wire Circuit. Reactive power at the 2 points of entry of a single-phase 2-wire circuit is, for the special case of a sinusoidal current and a sinusoidal potential difference of the same frequency, equal to the product obtained by multiplying the effective value of the current by the effective value of the potential difference, and by the sine of the angular phase difference by which the current leads the potential difference; and is, for the more general case of a periodic current and a periodic potential difference of the same fundamental frequency, the algebraic sum of the reactive powers corresponding to the sinusoidal harmonic components. The value of reactive power is given in vars when the effective current is in amperes and the effective potential difference is in volts.

Vector Power of a Single-Phase 2-Wire Circuit (Combined Power) (Vector Voltamperes). Vector power is equal to the square root of the sum of the squares of the active power and the reactive power. Vector power is generally treated as a vector of which the components are 2 mutually perpendicular vectors that have the magnitudes of active power and of reactive power. It follows that the total vector power is the vector sum of the vector powers of the harmonic components. The unit of vector power is the vector voltampere.

Apparent Power of a Single-Phase 2-Wire Circuit. Apparent power at the 2 points of entry of a single-phase 2-wire circuit is equal to the product of the effective current in one conductor multiplied by the effective potential difference between the 2 points of entry. The unit of apparent power is the voltampere.

Distortion Power of a Single-Phase 2-Wire Circuit. Distortion power is equal to the square root of the difference of the squares of the apparent power and the vector power. The unit of distortion power is the distortion voltampere.

Fictitious Power of a Single-Phase 2-Wire Circuit. Fictitious power is equal to the square root of the difference of the squares of the apparent power and the active power. The unit of fictitious power is the fictitious voltampere.

Nonreactive Power of a Single-Phase 2-Wire Circuit. Nonreactive power is equal to the square root of the difference of the squares of the apparent power and the reactive power. The unit of nonreactive power is the nonreactive voltampere.

Symmetrical Polyphase Set of Potential Differences. A symmetrical polyphase set of potential differences is a set in which each potential difference has the same effective value and the same wave form as each other potential difference and in which the individual potential differences form a closed sequence such that successive members differ in phase by equal amounts.

Characteristic Angular Phase Difference. The characteristic angular phase difference of a symmetrical polyphase set of potential differences or currents is the angular phase difference between adjacent members of the sequence.

Instantaneous Power of a Polyphase Circuit. The instantaneous power at the points of entry of a polyphase circuit is equal to the sum of the products obtained by multiplying the instantaneous current at each point of entry by the potential difference between that point of entry and some arbitrarily selected origin from which all the potential differences are measured (which may be the neutral point of entry). The value of the instantaneous power is given in watts when the currents are in amperes and the potential differences are in volts.

Active Power of a Polyphase Circuit (Power) (Actual Power). The active power at the points of entry of a polyphase circuit is the time average of the values of the instantaneous power at the points of entry, the average being taken over a complete cycle of the fundamental frequency of the alternating current. The value of active power is given in watts when the effective currents are in amperes and the effective potential differences are in volts.

Reactive Power of a Polyphase Circuit. The reactive power at the points of entry of a polyphase circuit is equal to the sum of the products obtained by multiplying the effective value of each harmonic component of the current through each of the points of entry, by the effective value of the corresponding harmonic component of the potential difference between the point of entry and an arbitrarily-selected origin (which may be the neutral terminal) and by the sine of the angular phase difference by which that harmonic component of current leads the corresponding harmonic component of the potential difference. The value of reactive power is given in vars when the effective currents are in amperes and the effective potential differences are in volts.

Vector Power of a Polyphase Circuit (Combined Power) (Vector Voltamperes). Vector power at the points of entry of a polyphase circuit is equal to the square root of the sum of the squares of the active power and the reactive power.

Average Vector Power. The average vector power at the points of entry of any electrical circuit, averaged over a time interval which contains a large number of periods of the alternating current, is equal to the square root of the sum of the squares of the average active power during the interval and the average reactive power during the same interval.

Arithmetic Apparent Power of a Polyphase Circuit. The arithmetic apparent power at the points of entry of a polyphase circuit, is equal to the arithmetic sum of the products obtained by multiplying the effective current at each point of entry by the effective potential difference between that point of entry and the neutral point of entry or, if one does not exist, an artificial neutral, the potential of which is established by joining it to each of the line points of entry by a set of equal resistances. The unit of arithmetic apparent power is the voltampere.

Algebraic Apparent Power of a Polyphase Circuit. The algebraic apparent power at the points of entry of a polyphase circuit is the algebraic sum of the products obtained by multiplying the effective current at each point of entry by the effective potential difference between that point of entry and an artificial neutral, the potential of which is established by joining it to each point of entry by a resistance that has a value (positive or negative) such that the ratio of the effective current in a resistance to the current in the point of entry to which it is connected, is the same for each of the resistances. The unit of algebraic apparent power is the voltampere.

Limiting Apparent Power of a Polyphase Circuit. Limiting apparent power of a polyphase circuit at the points of entry at which it is intended that the currents and potential differences shall form symmetrical sets, is equal to the result obtained by multiplying the largest effective value of current in any line conductor, by the largest effective value of potential difference between any 2 adjacent line conductors, and by the number of line conductors, and dividing this product by twice the sine of $^1/_2$ of the characteristic angular phase difference of the symmetrical set of potential differences. The unit of limiting apparent power is the voltampere.

Distortion Power of a Polyphase Circuit. Distortion power at the points of entry of a polyphase circuit is equal to the sum of the distortion powers of the group of single-phase circuits into which the polyphase circuit may be considered to be divided. A convenient method of division is to choose an origin from which to measure the potentials of the points of entry, and to consider the single-phase circuit corresponding to each point of entry as having the current in the conductor at the points of entry and the potential difference between the point of entry and the origin. The value of distortion power depends on the choice of origin as well as on the circuit. The unit of distortion power is the distortion voltampere.

Mesh Power of a Polyphase Circuit. Mesh power at the points of entry of a polyphase circuit is equal to the square root of the result obtained by subtracting from the square of the apparent power, the sum of the squares of the vector power and the distortion power; the same origin being chosen for measuring potentials in determining distortion power as in determining apparent power. It follows that mesh power must be designated as arithmetic or algebraic corresponding to arithmetic or algebraic apparent power. The unit of mesh power is the mesh voltampere.

Fictitious Power of a Polyphase Circuit. Fictitious power at the points of entry of a polyphase circuit is the square root of the difference of the squares of the apparent power and the active power. It follows that fictitious power must be designated as arithmetic or algebraic corresponding to arithmetic or algebraic apparent power. The unit of fictitious power is the fictitious voltampere.

Power Factor. Power factor is the ratio of active power to apparent power. It follows that the power factor of a polyphase circuit must be designated as arithmetic or algebraic to indicate whether arithmetic or algebraic apparent power is used in the denominator.

Vector Power Factor. Vector power factor is the ratio of the active power to the vector power.

Reactive Factor. Reactive factor is the ratio of reactive power to apparent power. It follows that the reactive factor of a polyphase circuit must be designated as arithmetic or algebraic to indicate whether arithmetic or algebraic apparent power is used in the denominator.

Reference

1. Reactive and Fictitious Power, V. G. Smith. A.I.E.E. Trans., v. 52, 1933, p. 748–51.

Instantaneous Overcurrent Relays for Distance Relaying

Instantaneous isolation of faults on transmission and distribution lines is ever a problem of the relay engineer. The use of instantaneous overcurrent relays as applied to the system of the Oklahoma Gas and Electric Company is discussed in this paper. Relays of this type were applied in conjunction with already installed overcurrent time delay relays, giving a form of distance relay protection. Operating results have proved the scheme to be highly satisfactory. Economies realized in the better coördination between relays and fuses by using instantaneous relays also are discussed briefly.

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THE rapid isolation of faults on transmission and distribution lines today is more a problem of economics than a problem of relay design. High speed relays of various types, suitable for many applications, are available. A particular scheme of relay protection worked out for the system of the Oklahoma Gas and Electric Company, is described

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in this paper. This scheme consists essentially of the addition of an instantaneous overcurrent element which in most cases was mounted inside the case of the regular directional and nondirectional overcurrent time delay relays already in use. This scheme provides what is essentially distance relaying, and has greatly simplified problems of relay coordination. The time required for the isolation of faults has been greatly reduced and generally satisfactory operation has been secured at a comparatively low cost.

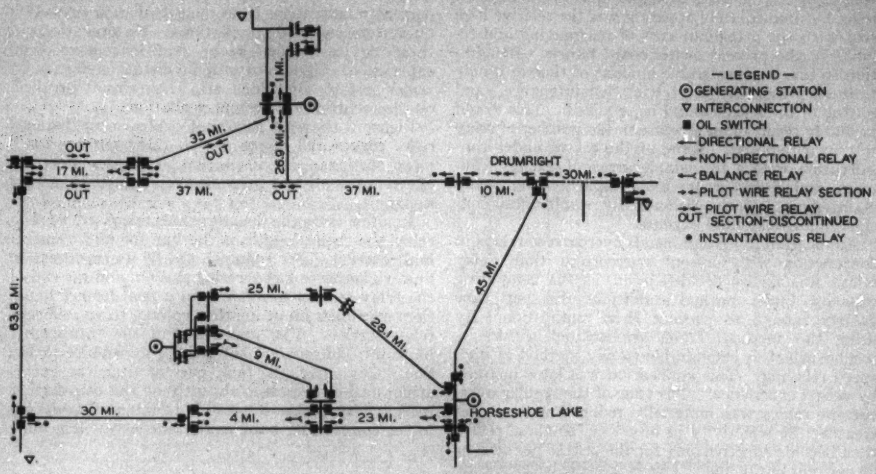

Fig. 1. A typical section of the system of the Oklahoma Gas and Electric Company

Transmission System Studied

Considerable study has been given the Oklahoma Gas and Electric Company's transmission system, particularly to relay sections where high overcurrent relay settings were threatening system stability. The time of relaying some faults has been as high as 2 seconds due to the necessity of backing up other relays on long transmission line loops and generating station tie lines having a large number of sectionalizing stations. Figure 1 is a sketch showing a portion of the 66 kv transmission system and indicating the type of relay equipment used. (This sketch also shows the application of instantaneous overcurrent relays as finally decided upon.) Long sections of line only were involved in this study, as all short lines are protected either by balanced relays or pilot wire relays.

The important problem of relaying lines at the generating plants received first attention as the relay settings at these points must necessarily be high. Comprehensive fault studies, which included 3-phase, line-to-line, and line-to-ground faults were made of each line with the different combinations of generating capacity, and the data plotted as "fault current per mile of line" curves. It was practical to make the great number of calculations necessary for this study by the use of a fixed resistor d-c symmetrical component calculating board,[1] on which the entire system is set up as a permanent unit arranged for readily obtaining fault current values for any condition of system operation. Figure 2 shows fault current values per mile of line from Horseshoe Lake generating station to the Drumright substation, a distance of 45 miles. These curves are plotted for the 3 combinations of generating capacity which obtain at this station.

Relay Schemes Considered

To obtain the objective of faster relaying it was necessary to consider high speed relays. A study of the fault current curves in figure 2 shows considerable variation in fault current values. For this condition a relay such as the ordinary type of distance relay that should clear a definite section of the line regardless of the value of fault current, would be desirable. Instantaneous overcurrent relays (relays without any time delay purposely introduced) alone could only relay a certain distance of the line if the generating capacity did not change appreciably. For any definite setting of these relays a certain section of the line could be relayed instantaneously, but if the generating capacity increased or decreased considerably, then they would either relay too much of the line with the possibility of overreaching into the adjacent relay section, or in the

1. For all numbered references, see list at end of paper.

latter case, relay a smaller portion of the line than desired.

Consideration of the various makes of distance relays indicated that while relays of the distance type would give instantaneous operation for a certain distance of the line only, the balance of the line must still be relayed by the time delay method to obtain back-up protection for the adjacent relay section. Relays of the distance type had desirable characteristics but immediately apparent was the relative high cost with the attendant cost of rearranging and rebuilding the present switchboard panels. In addition to this, a considerable amount of time of highly trained personnel for testing, maintenance, and setting of the relays would be required. This would probably result in an increase in the number of relay test men required. Some of the relays under consideration were a formidable array of springs, contacts, and levers, much too complicated for ready maintenance, which, undoubtedly, would entail considerable trouble and expense.

Application of instantaneous overcurrent relays in conjunction with present overcurrent time delay relays was finally decided upon, as the generating capacity under normal conditions did not vary greatly enough to prevent their application. By using this method, faults are isolated within $^1/_5$ second, which is comparable to any method of high speed relaying. This application was later justified by actual experience. The time of the regular overcurrent relays was materially reduced without decreasing the selectivity in any way, as these relays then become effective only for the last 15 per cent or 20 per cent of the line. This is possible because time delay selectivity is not necessary for faults near the sectionalizing circuit breakers and within the protective zone of the instantaneous relays.

Installation of the Device

In order to make the installation of the instantaneous relays as economical as possible, a unit was selected that could be mounted inside the case of the regular directional and non-directional overcurrent time delay relays. When used with directional relays the device is connected with its trip circuit in series with the directional contacts to insure correct operation in the right direction. Operation indicators were provided for each phase relay and the relay elements connected in such a manner that the operator would know immediately whether the time delay or instantaneous element had operated. By these means accurate records of relay operations are obtainable. A constant check of instantaneous operations is of particular importance as it is necessary to know whether the settings are correct for actual operating conditions.

Operating Results

From July 1933 to December 1934, the Horseshoe Lake-Drumright line tripped 22 times. The instantaneous relays operated 18 times, or 81.8 per cent of the relay operations. Selecting other lines at random, one line had a total of 19 operations, all of which were correct and tripped by instantaneous relays, and another line had a total of 54 operations, of which 57.4 per cent were by instantaneous relays. To date 43 circuit breakers have been equipped with these relays and no incorrect operations due to overreaching into the adjacent relay section have occurred.

On account of the necessarily high current settings which are required on these instantaneous overcurrent relays, there is no danger of their operation on system surges or oscillations. No operations of these devices under such conditions have been experienced. The conventional distance relays may, under certain conditions, trip their circuit breakers on the occurrence of system oscillations.[3]

Figure 3 shows a family of typical time-distance relay curves and instantaneous relay settings for 3 relay sections. By inspection of these curves the effectiveness of the instantaneous relays is readily apparent.

In a few cases the instantaneous relays are used to relay the entire length of the line for any value of fault current. For example, one 66 kv transmission line originates at a generating station, and the end of the relay section terminates in a transformer bank, then continues on at another voltage to an adjacent relay section. The impedance of the transformer bank introduces a relatively high impedance in the line. Obviously, the fault current from the generating station decreases abruptly at the transformer bank, which makes it possible to relay all faults up to the transformer bank instantaneously. The time

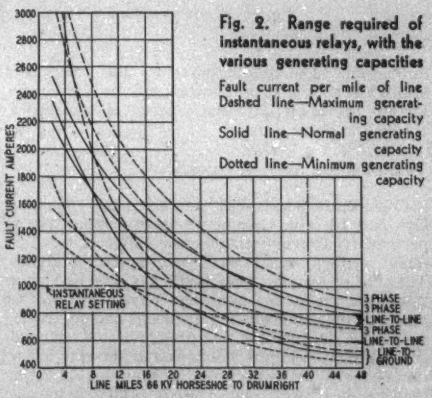

Fig. 2. Range required of instantaneous relays, with the various generating capacities

Fault current per mile of line
Dashed line—Maximum generating capacity
Solid line—Normal generating capacity
Dotted line—Minimum generating capacity

of the regular overcurrent relays can then be decreased materially and used only as back-up protection for the next relay section.

Use on Low Voltage Lines

The instantaneous relays have also been successfully adapted to distribution lines as low as 4 kv. Economies are realized from better coördination

between fuses located on the high voltage side of the transformer bank and relays of circuit breakers on the low voltage side. These relays permit quick tripping of the low-voltage circuit breaker with faults close to the transformer, and further provide better coördination between time delay relays, line sectionalizing fuses in the distribution line, and fuses of small transformer banks connected to the line at various points.

In order to establish instantaneous relay settings definitely, curves of fault current per mile of line, fuse and relay time-current characteristics are plotted upon the same coördinates to give a composite picture of the entire coördination problem. The time and trouble to prepare these data were repaid through fewer incorrect fuse operations.

Figure 4 will illustrate the point more clearly. In this case, without the use of instantaneous overcurrent relays, the time delay relay settings had to be raised sufficiently to allow a line sectionalizing fuse to clear. This then would allow the high voltage fuse to blow first on faults within a certain distance from the low-voltage circuit breaker, obviously an in-

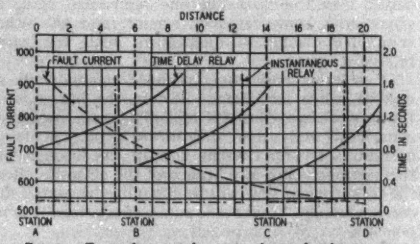

Fig. 3. Typical curves showing relationship between fault current and location of fault, and time-distance curves of instantaneous and time-delay overcurrent relays which are arranged to trip for power flow to a fault in the direction from station A to D

correct operation, with the loss of a costly high voltage fuse, and a prolonged outage due to the fuse blowing. There were only 2 alternatives available to remedy such a condition; either the size of the high voltage fuse had to be increased, or some means had to be provided to trip the circuit breaker more quickly. Since the high voltage fuse was of the correct size to protect the transformer properly, the instantaneous relays were installed and set to trip the breaker immediately with faults far enough out on the line to a point where the high voltage fuse could be coördinated properly with the time delay relays. It is apparent from the foregoing that such coördination will save fuses and also decrease circuit outages since the greater percentage of faults are of transient nature which will permit reclosing the circuit breaker immediately.

Instantaneous relays are also used in connection with bus fault relays. The instantaneous relays trip immediately when bus faults occur and the regular time delay relays act as back-up protection for the low-voltage circuit breakers. This not only shortens the duration of a system disturbance, but lessens the damage to equipment.

Summary

The use of instantaneous overcurrent relays on the Oklahoma Gas and Electric Company system has grown rapidly and problems of relay coördination,

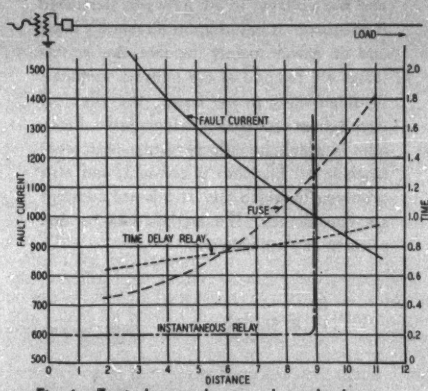

Fig. 4. Typical curves showing relationship between fault current and location of fault, and time-distance curves of instantaneous and time-delay overcurrent relays and fuses

although numerous, have been greatly simplified. These relays are now applied throughout the transmission and distribution system in connection with the present time delay relays and fuses. However, it would not have been practical to adapt these relays to the system unless a short-circuit calculating board was at all times available, as their proper operation depends upon an accurate knowledge of short-circuit current values under all conditions.

In conclusion, instantaneous relays have materially improved system stability, prevented long low-voltage dips, the loss of large blocks of load during fault conditions, and have improved utility service to the customer. The relatively small investment in these relays has been justified. They have also made possible the discontinuance of several pilot wire relay systems[3] operating over leased wire telephone lines at a saving of approximately $3,400 per year for the 193.5 miles of leased wire circuits which were used.

References

1. Symmetrical Component D-C Calculating Bench for Analyzing Line Faults, C. H. Frier. *Elec. South*, v. 11, Aug. 1931, p. 29, Sept. 1931, p. 25.

2. Distance Relay Action During Oscillations, E. H. Bancker and E. M. Hunter. Elec. Engg. (A.I.E.E. Trans.), v. 53, July 1934, p. 1073–80.

3. Relaying With 2 Pilot Wires, C. H. Frier. Elec. Engg., v. 50, 1931, p. 834–6.

Calculation of Power Flow and Bus Voltages

The method for calculation of power flow and bus voltages in a-c networks described in this paper is based upon Kirchhoff's laws, and is novel mainly in that the power losses are lumped at the network terminals in determining power flow. The effect of circuit shunt capacitance is included. Problems in which the ratio of resistance to reactance in all branches is constant, and also problems in which this ratio is not constant are considered. The method can be applied to any a-c network.

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IN developing the lumped loss method described herein for the calculation of power flow and bus voltages in a-c networks, the aim was to set up some definite plan of procedure by which one might solve analytically any a-c network (transmission, distribution, etc.) for power flow and bus voltages. It was desired that the accuracy of results obtainable be comparable with that obtainable on an a-c calculating board, and that the cost of making the analytical solution be less than the cost of obtaining a solution on the a-c calculating board. In the former case, the cost would be entirely labor cost, while in the latter it would also include either rental charges or carrying charges on an a-c calculating board.

It should be understood that the method presented herein is not supposed to be a "short hand" method. In a complicated network the labor involved will be considerable. However, it is felt that one might as well face the facts in that the solution of a complicated network by *any* method (including the method using the a-c board) must necessarily involve considerable labor.

The networks to be dealt with may be considered to fall into 2 general classes: Those in which all circuits or branches involved have, or may be assumed to have, the same ratio of resistance to inductive reactance; and those in which the circuits or branches have different ratios of resistance to inductive reactance. Accordingly, the method of solution described in the following will be divided into:

Case I. Branches have the same ratio of resistance to inductive reactance.

Case II. Branches have different ratios of resistance to inductive reactance.

Charging current of the circuits involved will be taken into account.

In order to apply this method of solution to a particular network the following information must be at hand:

Inputs and outputs of the network.
Nominal voltage.
Circuit data, etc.
Operating voltage for some one bus point.

General Method of Procedure

Suppose the current values of all the inputs and outputs in a network are known. It can be shown that the correct flow of current in the different branches may be obtained by applying the principle of superposition[1,2] as follows:

Let each of the current inputs and outputs be resolved into 2 components, one component being in phase with some reference vector, and the other component being in quadrature with the same reference vector.

Considering only the "in-phase" components of current, solve for current flow in the branches of the network by means of Kirchhoff's laws. Similarly, considering only the "quadrature" components of current, solve for current flow in the branches of the network. For any branch of the network, then, the total current flow will be given by the sum of the corresponding "in-phase" and "quadrature" components.

In the case where all branches of the network have the same ratio of resistance to inductive reactance, it is not necessary to use the complex value of the impedances of the branches in calculating the current flow. Instead, simply resistance, reactance, or impedance magnitude may be used. Besides reducing the labor necessary in an analytical solution, this simplification permits the determination of current flow by means of a d-c calculating board, when one is available.

Thus having determined total current flow in the branches of the network, and knowing the voltage at any one bus point, the voltages at all other bus points can be calculated.

If, however, the inputs and outputs for the network are given in real power units and reactive power units,* such as kilowatts (kw) and reactive kilovoltamperes (rkva), and the voltage is known at only one bus point, then some voltage must be assumed for all other bus points before current values for the network inputs and outputs can be determined. Voltage assumptions must be governed by the fact that total current input must always equal total current output. Generally, in the original data,

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1. For all numbered references see list at end of paper.

* Throughout the rest of this paper the following nomenclature and units will be used:
"Real power" or simply "power"—kilowatts
"Reactive power"—reactive kilovoltamperes
"Total power"—kilovoltamperes

total kilowatt and reactive kilovoltampere input is given equal to total kilowatt and reactive kilovoltampere output, and directions are given for the allocation of the supply of losses. Before the supply of losses can be allocated, however, the value of the losses themselves must be determined. The following will show how the losses may be determined (approximately) and their effect included:

In the first place, the total loss in a circuit is made up of the following components:

Real Power Loss	
Due to series resistance	(P_L)
Due to shunt resistance	(Leakage)
Reactive Power Loss	
Inductive reactive power loss, due to series inductance	(Q_L)
Capacitive reactive power loss, due to shunt capacitance	(Q_s)

Series Resistance Power Loss. This component is determined simply by multiplying the series resistance R of the circuit by the square of the total current flowing through the circuit. It may be called "circuit power loss," P_L.

Shunt Resistance Power Loss (leakage). This component is negligible in practically all problems.

Series Inductance Reactive Power Loss. Determined by multiplying the series inductive reactance X_L of the circuit by the square of the total current flowing through the circuit. This may be called "circuit inductive reactive power loss," Q_L.

Shunt Capacitance Reactive Power Loss. Determined by multiplying the shunt capacitive susceptance by the square of the voltage across the circuit. This may be called "circuit capacitive reactive power loss," Q_s, or simply "charging reactive kilovoltamperes."

The kilowatt input to the circuit will differ from the kilowatt output by the amount P_L.

Q_L, of course, is "lagging" reactive power, while Q_s is "leading" reactive power. If leading reactive power is represented by "+rkva" and lagging reactive power by "−rkva," then the reactive kilovoltampere input to the circuit will differ from the reactive kilovoltampere output by an amount equal to the algebraic sum of Q_s and Q_L. Then, P_L, Q_L, and Q_s, are real and reactive loads which are distributed over the length of the circuit. In calculating the real and reactive power flow in a network, the effect of P_L, Q_L, and Q_s for any branch is approximated if $^1/_2\, P_L$, $^1/_2\, Q_L$, and $^1/_2\, Q_s$ is lumped at each end of the branch. (See Appendix A.)

In order to determine P_L, Q_L, and Q_s for any circuit, the current through the circuit and the voltage across the circuit must be known. As previously stated, the voltage is given for only one bus point, and voltages must be assumed for all other bus points. Having done this, charging reactive kilovoltamperes Q_s can be calculated and lumped at the bus points. The lumped charging rkva can then be combined with the actual inputs or outputs at the respective bus points. Original reactive kilovoltampere inputs and outputs must now be revised in order to allow for the supply of this charging reactive kilovoltamperes. Using the resulting net inputs and outputs in kilowatts and reactive kilovoltamperes, and the assumed bus voltages, current inputs and outputs can be determined and the network solved for current flow. From this current flow solution, a first approximation for P_L and Q_L can be calculated for each branch in the network. For each branch, then, $^1/_2\, P_L$ and $^1/_2\, Q_L$ is lumped at the 2 terminal bus points. After this is done throughout the network, the original local load (including charging reactive kilovoltamperes) or generation at each bus point may be combined with the total "circuit power loss" P_L and "circuit reactive power loss" Q_L which has been lumped at that bus point. This means that the total output of the network (useful load plus losses) is increased. In order to make total input and output for the network again equal, we must either increase the input figures or decrease the figures for *useful* output. This may be done all at one bus point or at several different points, according to directions in original data for supply of losses. New current flow in the network may now be determined (using assumed bus voltages as before). This process is repeated until the loss figures obtained in the last step do not differ too much from those in the preceding step.

From the final current flow in the network and the one specified bus voltage, all other bus voltages are now calculated. Using these calculated bus voltages, new values for current input and output may be obtained and the solution repeated. Each repetition of the solution should give more accurate results. In many cases the results from the first solution are accurate enough.

Detailed Method of Procedure for Case I

Given:

Inputs and outputs of the network in kilowatts (kw) and reactive kilovoltamperes (rkva), nominal voltage, circuit data, etc. Total inputs and outputs given equal.

Voltage specified for some one bus point.

Names of bus points at which losses are to be supplied.

Assumptions:

All circuits in the network have the same ratio of resistance to inductive reactance.

Preliminary Procedure

Determine the impedance for each branch of the network.

It should be kept in mind that, given the above mentioned information, accurate results must necessarily result from a series of solutions involving certain approximations. These approximations become more accurate in the successive solutions. The number of solutions required depends upon the accuracy desired in the results.

First Power Flow Solution

In order to approximate current values at the various input and output points of the network, assume for the moment that the nominal voltage exists at each bus point and all bus voltages are in

phase. This assumption permits power or reactive power values to be treated as current values. Using these kilowatt "current" values, solve for power flow by means of Kirchhoff's laws.

Charging Reactive Kilovoltamperes

Charging reactive kilovoltamperes Q_c for any circuit depends upon size of conductors, spacing of conductors, and operating voltage. (For this solution the voltage is assumed the same over the entire length of a circuit.) Charging reactive kilovoltamperes per mile of circuit may be calculated or may be read directly from tables.[4]

Assuming nominal voltage, determine charging reactive kilovoltamperes Q_c for each branch in the network. For each branch, lump $^1/_2$ Q_c at each terminal bus point. Combine the total charging reactive kilovoltamperes lumped at each bus with the actual reactive kilovoltampere input or output. Revise the input or output figures at the bus points at which losses are to be supplied, so that total reactive power input again equals total reactive power output.

Table I—First Loss Table

Network Branch	No. of Circ.	Length in Miles	Total Resistance and Reactance in Ohms R	X	En Kv	For 3 Phases (All Circuits) Branch Load P Kw	Q Rkva	Branch Losses P_L Kw	Q_L Rkva
A-B	3	33	3.06	9.0	110	58,000	4,000	850	−2,500

First Reactive Power Flow Solution

As before, assume all bus voltages to be in phase and equal to nominal voltage. Treating the reactive power values as "current" values, solve for reactive power flow by means of Kirchhoff's laws.

P_L and Q_L for First Power and Reactive Power Flow Solutions

For each branch of the network calculate the power loss P_L and inductive reactive power loss Q_L due to the flow of power P and reactive power Q through the branch. Assume nominal line to line voltage E_n in these calculations. For 3-phase circuits the following equations apply:

$$P_L = (P^2 + Q^2)\frac{R}{1{,}000E^2_n} \text{ kilowatts (3-phase)} \quad (1)$$

$$Q_L = (P^2 + Q^2)\frac{1{,}000E^2_n}{X_L} \text{ inductive reactive kilovoltampere (3-phase)} \quad (2)$$

In eqs 1 and 2, R and X_L are in ohms to neutral, E_n is in kilovolts from line to line, and P and Q are in 3-phase kilowatts and reactive kilovoltamperes, respectively.

Since there may be any number of branches in the network, it will be convenient to tabulate all the different quantities used in determining P_L and Q_L as in Table I.

For each branch, lump $^1/_2$ P_L and $^1/_2$ Q_L at each terminal bus point. Revise all the original input and output figures to include the additional bus loads due to P_L and Q_L. Revise the input or output figures at the bus points at which losses are to be supplied, so that, after P_L and Q_L have been included, total input again equals total output.

Second Power and Reactive Power Flow Solutions

Using the new input and output figures for the network, solve again for power flow and reactive power flow. Nominal voltage assumed for all bus points as before.

P_L and Q_L for Second Power and Reactive Power Flow Solutions

Draw up the "second loss table" using the figures from the second power and reactive power flow solutions. Nominal voltage assumed for all the bus points as before.

π-Line Total Power Flow Diagram

In calculating voltage drops in the different branches of the network, charging reactive kilovoltamperes may be left lumped at the bus points, but circuit power and reactive power loss must be distributed over the length of each branch—nominal π-line voltage calculations. Therefore, if additional power and reactive power flow solutions appear unnecessary, the next step is to take the power and reactive power loss quantities off of the different busses and redistribute them over each branch. The resulting total power flow figures may be considered to represent "π-line total power flow." This π-line total power flow is obtained by means of the *first* "loss table" and the *second* power and reactive power flow diagrams. In each branch of the network the sending end and receiving end kilovoltamperes should differ by an amount equal to P_L and Q_L. Following is an illustration:

Consider a branch A-B (A and B being the designation for the 2 terminal busses). Refer to Table I. Assume the second power flow solution gave a flow of 57,500 kw from A to B. Then B is the receiving end for branch A-B. Assume the second reactive power flow solution gave a flow of 4,800 leading rkva ($+j4{,}800$) from B to A. This is the same as 4,800 lagging rkva ($-j4{,}800$) from A to B. From Table I, $P_L = 850$ kw and $Q_L = -2{,}500$ rkva.

Then

$$\text{sending end real power} = 57{,}500 + \frac{850}{2} = 57{,}925 \text{ kw}$$

$$\text{sending end reactive power} = -4{,}800 + \frac{-2{,}500}{2} = -6{,}050 \text{ rkva}$$

$$\text{receiving end real power} = 57{,}500 - \frac{850}{2} = 57{,}075 \text{ kw}$$

$$\text{receiving end reactive power} = -4{,}800 - \frac{-2{,}500}{2} = -3{,}550 \text{ rkva}$$

In case more than 2 power and reactive power flow solutions are made, the total power flow diagram should be obtained from the last power and reactive power flow diagrams and the "loss table" corresponding to the next to last power and reactive power flow diagrams.

First Voltage Calculation

In order to calculate bus voltages, there must be a starting point or "reference point." This starting point will be the bus for which the voltage was specified, and the phase angle of the voltage at this point will be zero (reference voltage). Using this reference voltage, and the values of sending or receiving end kilovoltamperes in the branches terminating at this bus point, the magnitudes and phase angles of the voltages at adjacent bus points can be determined. Similarly, using these newly determined voltages, the voltages at other bus points can be calculated.

In calculating the voltages on the busses in any loop of a network, calculations should be made all around the loop and back to the starting point. If this last voltage determined is not the same, both in magnitude and angle, as the voltage started with, the loop does not "close." Of course, for most purposes, the loop does not have to close exactly. Judgment must be used in deciding how great a differential voltage can be tolerated. Failure of a loop to "close" may be due to errors in calculations, or the fact that the ratio of circuit resistance to circuit inductive reactance is not the same throughout the network. If the difference is too great, and there is no error in any of the calculations, power flow or reactive flow or both should be shifted in such a way as to remedy the situation. The necessary shift in power or reactive power flow may be approximated as being the kilovoltamperes corresponding to the current obtained by dividing the differential voltage by the total impedance of the path around the loop. (This principle of superimposing circulating currents has also been used in references 5 and 6.) Of course, both the differential voltage and the impedance must be used in their complex form.

Successive Solutions

After the bus voltages have been obtained in the above manner, the *input* and *output* figures (kilowatts and reactive kilovoltamperes) in the π-line total power flow diagram may be converted into current values (magnitude and angle). The phase angles of these currents, of course, will all be referred to the voltage reference vector. All the current inputs and outputs must now be resolved into 2 components, one component in phase with the reference vector (in-phase current), and one component in quadrature with the reference vector (quadrature current). The total "in-phase" current inputs must equal the total "in-phase" current outputs. Likewise the total "quadrature" current inputs must equal the total "quadrature" current outputs. If these conditions do not already exist, they must be obtained by adjusting the currents *at the busses which are supplying the losses*. This last is done based upon the assumption that power and reactive power input (or output) is directly proportional to in-phase and quadrature current input (or output) respectively. This, of course, is not strictly correct, but is near enough so for this purpose.

Having made total current input equal total current output, separate solutions of the network are then made for in-phase current flow and for quadrature current flow. These solutions are made in the same manner the power flow and reactive power flow solutions were made. Using the resulting in-phase and quadrature current flow diagrams and the one specified bus voltage, all other bus voltages are again calculated. (Second voltage calculation.)

At each bus point, convert current input or output into power and reactive power input or output, using the bus voltage obtained from the second voltage calculation. These power and reactive power input or output figures should agree with those given in the original data for each bus point, except the ones at which losses were to be supplied. Total input and total output should differ by an amount equal to the total losses in the network.

If the above conditions do not exist, again convert the input and output figures in the π-line total power flow diagram into current values (use the voltages obtained in the *second* voltage calculation). As before, the total current input must be made equal to total current output. Solve again for current flow and calculate new bus voltages (third voltage calculation). Convert current inputs and outputs into power and reactive power input or output, and compare with the input and output figures in the original data as before.

The number of successive solutions necessary depends upon the accuracy required. In many cases, the results represented by the π-line total power flow diagram and the first voltage calculation will be sufficiently accurate.

Detailed Method of Procedure for Case II

In the case where the network is made up of branches not having the same ratio of resistance to inductive reactance, current division will be inversely proportional, *not* to the magnitude of the impedance, but to the complex value of the impedance. It follows, then, that the d-c calculating board cannot be used as in Case I. Also, since complex values of impedance must be used, little or nothing would be gained in making separate solutions for "in-phase" and "quadrature" currents as was done in Case I. Current division in the network must be obtained either analytically (using Kirchhoff's laws) or by means of the a-c calculating board.

Following is the method of procedure for Case II. The reader will find some repetition of statements made under Case I. This was done to avoid the possibility of misunderstanding, and to make the procedure for each case complete in itself.

Given:

Inputs and outputs of the network in kilowatts and reactive kilo-

voltamperes, nominal voltage, circuit data, etc. Total inputs and outputs given equal.

Voltage specified for some one bus point.

Names of bus points at which losses are to be supplied.

Preliminary Procedure

Determine the impedances of each branch.

Charging Reactive Kilovoltamperes

Assuming nominal voltage, determine charging reactive kilovoltamperes Q_c for each branch, as was done in Case I. For each branch, lump $^1/_2\, Q_c$ at each terminal bus point. Combine the total charging reactive kilovoltamperes lumped at each bus with the actual reactive power input or output. Revise the input or output figures at the bus points at which losses are to be supplied, so that total reactive power input again equals total reactive power output.

First Total Power Flow Solution

Assume nominal voltage exists at each bus point and all bus voltages are in phase. This assumption permits total power input or output values to be treated as current values. Using these kilovolt-ampere "current" values, solve for total power flow analytically, using Kirchhoff's laws. Total power and impedance values must be used in their complex form. This means the solution of simultaneous equations involving complex numbers. The solution of these equations may be obtained in the conventional manner; however, it is felt that determinants can be used to advantage in this instance.

P_L and Q_L for First Total Power Flow Solution

Calculate power loss as was done in Case I, using eqs 1 and 2, and draw up the "first loss table."

For each branch, lump $^1/_2\, P_L$ and $^1/_2\, Q_L$ at each terminal bus point. Revise all the original input and output figures to include the additional bus loads due to P_L and Q_L. Revise the input or output figures at the bus points at which losses are to be supplied, so that, after P_L and Q_L have been included, total input again equals total output.

Second Total Power Flow Solution

Using the new input and output figures for the network, solve again for total power flow. Nominal voltage is assumed for all bus points as before.

P_L and Q_L for Second Total Power Flow Solution

Draw up the "second loss table," using the figures from the second total power flow solution.

π-Line Total Power Flow Diagram

Total power flow solutions and loss calculations are repeated until the loss figures obtained in the last step do not differ too much from those in the preceding step. When additional total power flow solutions appear unnecessary, the next step is to take the power and reactive power loss quantities off of the different busses and redistribute them over each branch. The resulting total power flow figures may be considered to represent "π-line total power flow." This π-line total power flow is obtained by means of the last total power flow diagram and the line losses corresponding to the next to last total power flow diagram. In each branch of the network the sending end and receiving end kilovoltamperes should differ by an amount equal to P_L and Q_L for that branch. See the illustration given in Case I.

First Voltage Calculation

As in Case I, the voltage calculations will be started from the bus for which the voltage was specified, and the phase angle of the voltage at this point will be zero (reference voltage). See "first voltage calculation" in Case I.

Successive Solutions

Having obtained all bus voltages, the *input* and *output* figures (in kilovoltamperes) in the π-line total power flow diagram should be converted into current values (magnitude and angle). The phase angles of these currents will all be referred to the voltage reference vector. Next, convert the current inputs and outputs from polar to complex form ("in-phase" and "quadrature" components). Total "in-phase" current inputs should equal total "in-phase" current outputs. Likewise, total "quadrature" current inputs and outputs should be equal. If these conditions do not already exist, they must be obtained by adjusting the currents *at the busses which are supplying the losses.*

Having made total current input equal to total current output, a new solution for current flow in the network is made. Using the values of current flow thus determined and the one specified bus voltage, all other bus voltages are again calculated (second voltage calculation).

At each bus point, convert current input or output into power and reactive power input or output, using the bus voltage obtained from the second voltage calculation. These power and reactive power input or output figures should agree with those given in the original data for each bus point, except the ones at which losses were to be supplied. Total input and total output should differ by an amount equal to the losses in the network.

As in Case I, the number of successive solutions necessary depends upon the accuracy required. In many cases, the results represented by the π-line total power flow diagram and the first voltage calculation will be sufficiently accurate.

General Notes

If enough is known about the network involved that an estimate can be made of the average value of the operating voltages of all bus points, this value

should be substituted for nominal voltage wherever the latter is used in the foregoing.

Whenever possible, problems should be solved by the method under Case I, since the amount of work involved will usually be less, and the chances of making errors will be smaller. No hard and fast rules can be set down as to how great a variation in the ratio of resistance to reactance can be tolerated under Case I. This will depend upon the network involved and the accuracy required in the results. In general, it might be stated that if the highest value of $\frac{R}{X}$ is not more than 10 per cent greater than the lowest value of $\frac{R}{X}$, and if fair accuracy is desired in results, Case I may be used. If only rough accuracy in results is desired, the difference between maximum and minimum values of $\frac{R}{X}$ may be 20 per cent. The above figures are given only as a rough guide; after having had some experience in solving problems, one should be able to set down his own tolerances, based on his own ideas of what would be called "accurate," "fairly accurate," or "rough" results.

This method has been applied to existing transmission networks. Results obtained are considered to be at least as accurate as those obtainable on an a-c calculating board.

Whether or not this method will be cheaper than the a-c board method, will depend upon the network considered and the number of different conditions to be studied, besides such factors as cost of using the a-c board, traveling expenses, wages, etc. In general, it appears that the a-c board method will be cheaper only when several different conditions are to be studied in a complicated network.

In Appendix *B* is shown a sample problem to which this method has been applied.

Appendix A

The following is given in case there is some question as to the validity of the method of lumping losses in determining power flow.

Perhaps the easiest way to justify this procedure, without going into too much detail, is to point out the similarity between the flow of current through the distributed shunt capacitance along a circuit, and the consumption of power (real and reactive) in the distributed series resistance and inductive reactance along the circuit:

Neglecting leakage, the receiving end current of any circuit will be less than the sending end current by an amount equal to the "charging" current (current flowing through the distributed shunt capacitance). This charging current can then be considered as lost current—"*current loss*." Similarly the receiving end total power will be less than the sending end total power by an amount equal to the *power losses* in the circuit (I^2R and I^2X).

Assuming uniform voltage along the full length of the circuit, a plot of the current at any point in the circuit will be a straight line. Similarly, assuming uniform current along the full length of the circuit, a plot of the power (real and reactive) at any point will be a straight line.

Therefore, just as current loss (charging current) may be lumped one-half at each end of the circuits in a network in determining current flow, similarly, power losses may be lumped one-half at each end of the circuits in a network in determining power flow.

Assuming a case where actual operating data is available for loads and generation and for power losses in each branch of a network, and where charging current is lumped at the bus points, the process of lumping losses in determining power flow would be exact. However, in the problems which are intended to be handled by the method given in this paper, actual operating data would not be given. Instead, load and generation figures would be the result of estimates, and loss figures would not be given at all. As previously stated, the total of the load figures is usually given equal to the total of the generation figures. Hence, since the losses themselves have to be approximated, the power flow solutions which are determined from the results of these approximations must also be approximations. The errors decrease as the solution is repeated. In the calculation of power losses from power flow, the average of sending end and receiving end power is used (and nominal voltage is assumed). This procedure is accurate enough for the purpose.

Appendix B

In the following, a sample problem is solved to illustrate the method. For convenience "mega-" units are used. "Mega-" units equal "kilo-" units divided by 1,000.

GIVEN: Power transmission line network shown in Fig. 1. (Sixty cycles, 3 phase.)

Generation

Bus Point	Megawatts	Reactive Megavoltamperes
S	86.9	5.7 leading
R	222.7	76.5 leading
T	12.1	3.5 lagging
G	1.1	0.9 leading

Loads

M	3.6	2.1 lagging
B	0.9	5.5 leading
H	4.4	3.5 leading
P	313.9	0.0

Synchronous Condensers

Bus Point	Capacity	Input to Condensers in Reactive Megavoltamperes
R	2—15.0 mva	0.0
M	2—15.0 mva	0.0
P	3—30.0 mva	72.7 leading

Voltage Specifications

Bus *R*	112 kv
Busses *S* and *T*	112–120 kv
Busses *M*, *G*, *B*, and *H*	111–114 kv
Bus *P*	109–113 kv

Assume nominal voltage to be 112 kv.

Supply of Losses

Circuit real power losses (megawatts) to be supplied from bus *P* (deducted from the load).

Circuit reactive power losses (reactive megavoltamperes) to be supplied from synchronous condensers at busses *R*, *M*, and *P*.

FIND

Real and reactive power flow in all branches.

Voltages at all bus points. (Both magnitude and phase angle.)

Necessary synchronous condenser settings.

The problem comes under Case II.

PROCEDURE

From the diagram of circuit data, Fig. 1, the values of branch impedances and charging reactive megavoltamperes are compiled; see Table II.

The first total power set-up, Fig. 2, may then be drawn, and the solution of current values i_1, i_2, and i_3 obtained. This is done by

writing the equation for the impedance drops around the 3 loops, and simplifying:

$$(13.98 + j\,46.48)i_1 - (3.65 + j10.58)i_2 - (3.65 + j10.58)i_3 - 407.6 + j539.2 = 0.0 \quad (3)$$

$$(3.65 + j\,10.58)i_1 - (17.77 + j66.33)i_2 - (8.49 + j\,33.49)i_3 + 270.0 + j10{,}160.0 = 0.0 \quad (4)$$

$$(9.28 + j\,32.85)i_1 - (3.2 + j19.55)i_2 + 274.1 - j\,97.5 = 0.0 \quad (5)$$

Solving eqs 3, 4, and 5 by determinants:

$i_1 = 43.0 - j\,4.2$
$i_2 = 80.4 + j24.8$
$i_3 = 140.1 + j14.7$

These values may then be inserted in the first total power flow diagram, Fig. 3, and the first loss table, Table III, may be compiled. New input and output figures for the network can then be determined as shown in Table IV, and the second total power flow set-up, Fig. 4, can be drawn. Solutions for new values of i_1, i_2, and i_3, can then be obtained from Fig. 4, by writing the equations for the impedance drops around the 3 loops, and simplifying, as follows:

$$(13.98 + 46.48)i_1 - (3.65 + j10.58)i_2 - (3.65 + j10.58)i_3 - 232.26 + j\,447.77 = 0.0 \quad (6)$$

$$(3.65 + j10.58)i_1 - (17.77 + j\,66.33)i_2 - (8.49 + j\,33.49)i_3 + 605.0 + j\,9{,}904.0 = 0.0 \quad (7)$$

$$(9.28 + j\,32.85)i_1 - (3.2 + j19.55)i_2 + 43.7 - j104.6 = 0.0 \quad (8)$$

Solving eqs 6, 7, and 8 by determinants:

$i_1 = 42.2 - j\,0.6$
$i_2 = 80.2 + j19.7$
$i_3 = 136.2 + j15.0$

From these new values of current, the second total power flow diagram, Fig. 5, can be drawn, and the second loss table, Table V, compiled. Comparing Tables III and V, the loss figures are near enough the same that no further power flow solutions will be made. The next step is to draw up the first voltage and total power flow diagram, Fig. 6. The voltage calculations for Fig. 6 are shown in Table VI. The input in amperes, Table VII, can then be determined.

In terms of power and reactive power, the inequality between total input and total output, as shown in column 3, Table VII, is small enough that no further calculations will be made.

The final results, then, are represented on Fig. 6.

Table II—Branch Impedances and Charging Reactive Megavoltamperes

Network Branch	R Ohms	X_L Ohms	Z Ohms	Charging Rmva at 112 Kv
R-S	4.5	13.2	14.1 /69.5°	4.35
S-T	4.64	17.05	17.66/74.8°	6.15
T-G	1.19	5.65	5.78/78.1°	2.15
R-M	2.65	7.7	8.15/71.0°	2.54
M-G	1.0	2.88	3.05/70.9°	0.98
R-B	2.45	7.15	7.55/71.1°	2.36
B-P	6.83	25.7	26.6 /75.5°	9.25
G-H	1.91	9.05	9.26/78.1°	3.45
H-P	2.93	13.85	14.15/78.1°	5.27
R-P	3.2	19.55	19.8 /80.7°	17.9
Total				54.4

Let total charging reactive megavoltamperes be supplied from bus *P*.

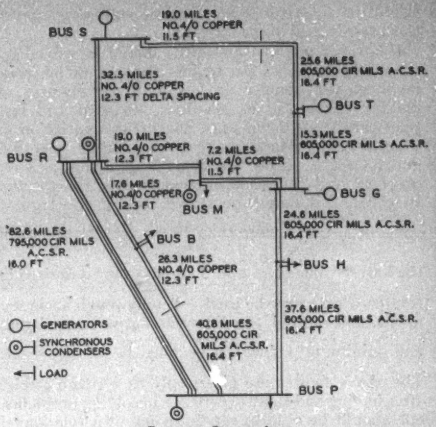

Fig. 1. Circuit data

Circuit data given is length, conductor size, and conductor equivalent delta spacing

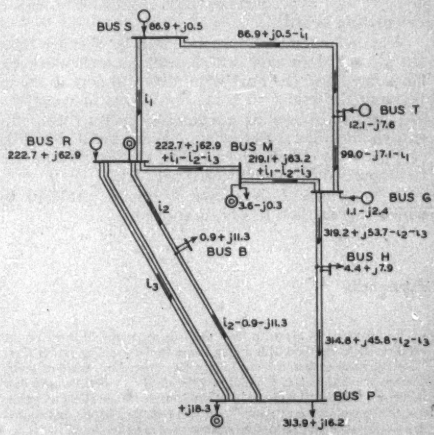

Fig. 2. First total power set-up

Power flow figures are in megawatts and reactive megavoltamperes
+j indicates "leading" reactive megavoltamperes

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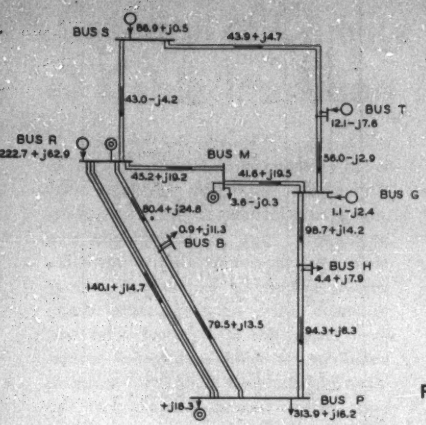

Table III—First Loss Table

Network Branch	Total Power Flow Mva	Voltage Assumed Kv	P_L Mw	Q_L Rmva
R-S	43.2	112.0	0.67	1.06
S-T	44.2	112.0	0.72	2.65
T-G	56.0	112.0	0.3	1.41
R-M	49.1	112.0	0.51	1.48
M-G	46.0	112.0	0.17	0.49
R-B	84.2	112.0	1.40	4.05
B-P	80.7	112.0	3.56	13.35
G-H	99.7	112.0	1.52	7.13
H-P	94.5	112.0	2.09	9.88
R-P	140.9	112.0	5.06	30.9
Total			16.0	73.3 lagging

Losses to be supplied as follows:
From bus *P*, deduct from load 16.0 mw
From bus *P*, synchronous condenser 38.3 rmva lagging
From bus *R*, synchronous condenser 30.0 rmva lagging
From bus *M*, synchronous condenser 5.0 rmva lagging

Fig. 3 (left). First total power flow diagram

Table IV—Determination of New Input and Output Figures for Network

Figures in Megawatts and Reactive Megavoltamperes

Bus Point	(1) Initial Output*	(2) Initial Input*	(3) Lumped Losses (excl. charging rmva)	(4) Supply of Circuit Losses	(5) Resultant Outputs	(6) Resultant Inputs
S	0.0 + *j* 0.0	86.9 + *j* 0.5	0.7 − *j* 2.3	0.0 + *j* 0.0		86.2 + *j* 2.8
R	0.0 + *j* 0.0	222.7 + *j*62.9	3.81 − *j*19.19	0.0 − *j*30.0		218.89 + *j*52.09
T	0.0 + *j* 0.0	12.1 − *j* 7.6	0.51 − *j* 2.03	0.0 + *j* 0.0		11.59 − *j* 5.57
G	0.0 + *j* 0.0	1.1 − *j* 2.4	0.99 − *j* 4.52	0.0 + *j* 0.0		0.11 + *j* 2.12
M	3.6 − *j* 0.3	0.0 + *j* 0.0	0.35 − *j* 0.98	0.0 − *j* 5.0	3.95 + *j* 3.72	
B	0.9 + *j*11.3	0.0 + *j* 0.0	2.48 − *j* 8.7	0.0 + *j* 0.0	3.38 + *j* 2.6	
H	4.4 + *j* 7.9	0.0 + *j* 0.0	1.8 − *j* 8.51	0.0 + *j* 0.0	6.2 − *j* 0.61	
P	313.9 + *j*34.5	0.0 + *j* 0.0	5.36 − *j*27.07	16.0 − *j*38.3	303.26 + *j*45.73	
	322.8 + *j*53.4	322.8 + *j*53.4	16.0 − *j*73.3	16.0 − *j*73.3	316.79 + *j*51.44	316.79 + *j*51.44

+*j* indicates "leading" reactive power.
−*j* indicates "lagging" reactive power.
* Columns 1 and 2 are obtained directly from Fig. 2, and, therefore, include the lumped charging reactive megavoltamperes.

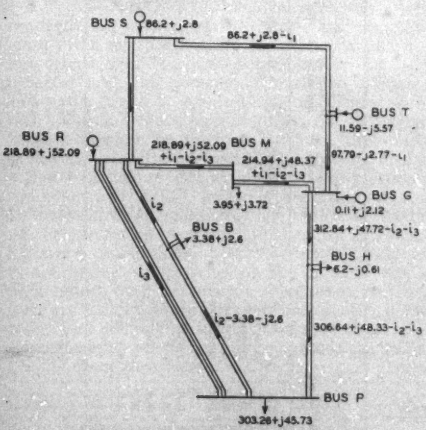

Fig. 4. Second total power flow set-up

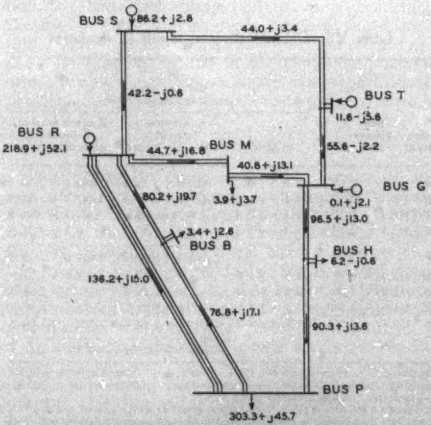

Fig. 5. Second total power flow diagram

Table V—Second Loss Table

Network Branch	Total Power Flow Mva	Voltage Assumed Kv	P_L Mw	Q_L Rmva
R-S	42.2	112.0	0.65	1.88
S-T	44.1	112.0	0.72	2.64
T-G	55.6	112.0	0.29	1.39
R-M	47.8	112.0	0.48	1.40
M-G	42.9	112.0	0.15	0.42
R-B	82.6	112.0	1.33	3.80
B-P	78.7	112.0	3.37	12.67
G-H	97.3	112.0	1.44	6.82
H-P	91.2	112.0	1.94	9.17
R-P	137.0	112.0	4.78	29.20

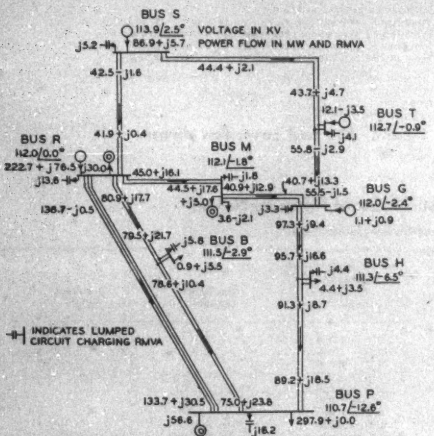

Fig. 6. First voltage and total power flow diagram (π-lines)

Bus voltage in kilovolts. Reference voltage is at bus R

Table VII—Determination of Inputs in Amperes

Bus Point	(1) Bus Voltage Kv	(2) in Mva	(3) Net Bus Inputs (including charging rmva) in Amperes Referred to Reference Vector	(4) Revised Amperes Referred to Reference Vector
S	113.9/ 2.5°	86.9 + j 0.5	440.0 + j 21.5	440.0 + j 21.5
R	112.0/ 0.0°	222.7 + j32.9	1,147.0 + j169.5	1,147.0 + j181.4
T	112.7/− 0.9°	12.1 − j 7.6	61.4 − j39.9	61.4 − j 39.9
G	112.0/− 2.4°	1.1 − j 2.4	5.1 − j 12.6	5.1 − j 12.6
			1,653.5 + j138.5	1,653.5 + j150.4
M	112.1/− 1.8°	−3.6 − j 4.7	−19.3 − j 23.6	−19.3 − j 23.6
B	111.5/− 2.9°	−0.9 − j11.3	−7.6 − j 58.0	−7.6 − j 58.0
H	111.3/− 6.5°	−4.4 − j 7.9	−27.3 − j 38.1	−27.3 − j 38.1
P	110.7/−12.6°	−297.9 − j72.8	−1,600.0 − j 30.7	−1,599.3 − j 30.7
			−1,654.2 − j150.0	−1,653.5 − j150.4

As stated in title, the above is a table of bus *inputs*. Accordingly, a positive quantity represents an actual input, and a negative quantity an actual output. +j indicates "leading" reactive power.

In column 3 the sum of positive quantities should equal the sum of the negative quantities (input equal to output). As seen above this condition does not exist. Current input figures are revised at busses P and R, as shown in column 4, to bring about equality.

Table VI—First Voltage Calculations

Point	Branch	Z in Ohms	E_s in Kv	IZ in % of E_r Ref. to E_r	E_s in % of E_r Ref. to E_r	E_s in Kv Ref. to /0°	Mva.	E_r in Kv	IZ in % of E_s Ref. to E_s	E_r in % of E_s Ref. to E_s	E_r in Kv Ref. to /0°	Average Voltage for Point in Kv
	R-S	14.1 /69.5°	41.9/0.5°	112/0.0°	4.71/70.0°	101.75/2.5°	113.9/2.5°					
	S-T	17.06/74.8°					44.5/ 2.7°	113.9/ 2.5°	6.06/77.5°	98.9 /− 3.4°	112.7/− 0.9°	
	T-G	5.78/78.1°					55.9/− 3.0°	112.7/−0.9°	2.54/75.1°	99.35/− 1.4°	111.9/− 2.3°	
	R-M	8.15/71.0°					47.8/ 19.7°	112.0/ 0.0°	3.11/80.7°	100.1 /− 1.8°	112.1/− 1.8°	
	M-G	3.05/70.0°					42.9/ 17.8°	112.1/−2.3°	1.04/88.4°	99.9 /− 0.6°	112.0/− 2.4°	
G												112.0/− 2.4°
	R-B	7.55/71.1°					82.8/ 12.3°	112.0/ 0.0°	4.99/83.4°	99.5 /− 2.9°	111.5/− 2.9°	
	B-P	26.6 /75.5°					79.3/ 7.5°	111.5/−2.9°	16.98/83.0°	99.4 /− 9.5°	110.8/−12.7°	
	G-H	9.26/78.1°					97.7/ 5.5°	112.0/−2.4°	7.21/83.5°	99.4 /− 4.1°	111.3/− 6.5°	
	H-P	14.15/78.1°					91.7/ 5.4°	111.3/−6.5°	10.46/83.3°	99.35/− 6.1°	110.6/−12.6°	
	R-P	19.8 /80.7°					138.7/− 0.2°	112.0/ 0.0°	21.9 /80.5°	98.8 /−12.6°	110.7/−12.6°	
P												110.7/−12.6°

A Criterion of Quality of Cable Insulation

Radial uniformity of oil impregnated paper cable insulation, that is, uniformity in a radial direction from conductor to sheath, is a characteristic of well manufactured cable that is fully as important or more so than longitudinal uniformity. Radial power factor curves for several brands of new cable included in this paper show marked irregularities which are attributed to poorly controlled manufacturing methods. On the basis of such studies, some manufacturers have made efforts to improve the radial uniformity of their insulation with resulting great improvement in quality. This characteristic of cable insulation thus provides a criterion of insulation quality that should be useful to both manufacturer and user.

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OF ALL the characteristics of oil-impregnated paper-insulated cable that make for quality the one upon which the electrical industry has placed most emphasis is uniformity. On each batch of cable the variation of insulation resistance and power factor is watched carefully from reel to reel. This is a check on uniformity, but in a longitudinal direction only. Until recently, uniformity of new cable insulation never had been determined in a radial direction, that is, along a radius between conductor and sheath, probably because apparatus for precise measurements was not available. Methods for measuring electrical and chemical characteristics in a radial direction were developed, however, in the course of researches on the deterioration of high voltage cable insulation.[1] When these methods were applied to cables of all types and all ages, it was found that not only was the insulation of used cables nonuniform in a radial direction, but also the insulation of most new cables was radially nonuniform. Only cable manufactured under the most careful conditions approached radial uniformity. Radial uniformity of new cable insulation is thus a valuable criterion of the quality of new cable, just as lack of radial uniformity of used cable is a criterion of the degree of deterioration. Recognition of this important cable characteristic should prove a boon to the cable manufacturer anxious to improve his product. It also should serve as a valuable guide to the purchaser of cable in judging the care that has been taken in the selection of materials and in methods of manufacture.

A paper recommended for publication by the A.I.E.E. committee on power transmission and distribution, and scheduled for discussion at the A.I.E.E. summer convention, Ithaca, N. Y., Apr. 24–28, 1935. Manuscript submitted Feb. 19, 1935; released for publication March 1, 1935.

1. For all numbered references see list at end of paper.

Radial Method of Examination

The usefulness of the radial method of examining cable insulation was first demonstrated in tracing the source and nature of deterioration in the insulation of high voltage cables from service. It consists in measuring the power factor and the degree of oxidation of the individual paper tapes taken one by one between the conductor and the sheath of a cable. For measuring the power factor of the single paper tapes, a cell that can be used in a routine manner and that gives reliable results has been devised. The degree of oxidation of the oil removed[2] from the individual tapes is determined on an Adam balance using the hydrophil or water spread method based upon the pioneer work of Langmuir.[3] With the use of these 2 instruments radial power factor and oxidation curves can be obtained which, in the absence of moisture, are roughly U-shaped.

The similarity between the power factor and hydrophil curves indicates the likelihood that the high power factor near the conductor and sheath is caused by some form of oxidation. Occasionally abnormal radial curves are obtained, and from their shape and the degree of correspondence between the power factor and oxidation curves much may be learned as to the nature and source of deterioration. Not least among the results of the radial method of examination has been the elimination of many academic theories of deterioration from practical consideration. (This remark applies only to cable for use up to 66 kv that has insulation of the standard thickness. Without question, at higher stresses additional mechanisms of deterioration become of importance.)

Application of Radial Method to New Cable

On applying the radial method of examination to new cables, curves frequently were obtained that were similar in shape to those for used cables, the upturns near the conductor and sheath, however, being far less pronounced. Typical curves showing the variation in radial power factor for new and used cable are given in figure 1. The lowest curve represents the most uniform radial characteristics observed so far in any cable yet tested.

In comparing the radial power factor curves in figure 1, attention should be directed to the following items: The triangular areas *abc* and *def* under the upturns at either end of the curve represent a deterioration of the insulation, and it is important to note the distance that they penetrate into the insula-

tion. The heights *ab* and *ef* of the 2 triangles are of interest since these appear to represent the locations of maximum concentrations of the substance causing high loss. The middle portion of the curve, *cd*, probably represents the best insulation that can be obtained with the component materials under the given conditions of manufacture. Some importance may be attached to the degree of regularity of the

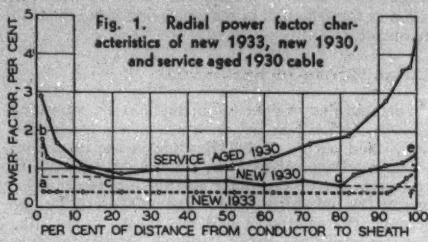

Fig. 1. Radial power factor characteristics of new 1933, new 1930, and service aged 1930 cable

cd portion of the curve as information often may be gained from it as to conditions of manufacture.

The foregoing findings resulted in the decision to investigate the radial characteristics of several brands of new cable. Six manufacturers were approached on the subject of submitting samples of cable that would represent their best 1933 practice, and were fully instructed to take all necessary precautions in protecting the samples from contamination caused by certain forms of end sealing and exposure to air. These samples were duly received and all necessary precautions were taken in the laboratory to prevent undue exposure to air or contamination. Therefore any results obtained in the diagnostic studies should represent the true characteristics of the cable as manufactured.

Results of the study of these 6 brands of new 24-kv 3-conductor cable are represented graphically in figure 2. The curve for only one conductor of each cable is shown, the curves for all 3 usually being similar in character. All the curves exhibit an upturn at both conductor and sheath. The curve having the lowest power factor and the greatest uniformity is that of brand *A* cable. Brand *B* follows closely upon *A* with regard to radial uniformity, and its excellence follows likewise from careful factory control. Both *A* and *B* are impregnated with mineral oil alone. This fact probably accounts for the special precautions taken in manufacture, since the use of rosin considerably increases the dielectric loss, thereby masking small variations in manufacture.

The 4 remaining brands of cable contained rosin, which accounts for the higher average power factor when compared with that of the 2 mineral oil cables. The curve for brand *C* is irregular in its middle portion; this cable, however, shows a reasonably small upturn of the curve at either end. Brand *D*, despite its having the highest average value of power factor of any, exhibits remarkably good radial uniformity except in close proximity to the conductor and sheath; its high loss may be attributed to the amount or grade of rosin used in the impregnating oil. A different characteristic is found in brand *E*, where the high loss or "deterioration triangles" penetrate unusually deeply into the insulation. Several undesirable features are indicated in the curve for brand *F*. It exhibits high power factor next to the sheath, high average value of power factor, a "deterioration triangle" that penetrates deeply into the insulation at the copper, and an irregular power factor in the intermediate portion of the curve. Lack of uniformity may be characteristic of this brand of cable since similar curves recently have been obtained by another investigator[5] on cables made in the same factory at different times during the last 8 years.

Causes of Radial Nonuniformity

The cause of the upturn in some of the radial power factor curves possibly may be explained by the radial oxidation curves. The general correspondence between the radial power factor and radial oxidation or hydrophil curves of figure 3 for a mineral oil cable suggest that the upturn in power factor at the sheath results from oxidation of the oil. The explanation appears to be reasonable since as the cable passes through the lead press some oil from the insulation touching the hot lead in the presence of air undoubtedly becomes oxidized as it flows backward over the incoming new insulation. Oxidation products in the oil, formed either at the lead press or in the oil prior to leading, are probably chiefly responsible for the increases in power factor.

Another cause of increased power factor of the paper layers next to the lead sheath may be the absorption of moisture if there is a prolonged exposure of the impregnated cable to factory atmosphere previous to leading. In some cables contamination by dirt may be a factor. The interval between various factory operations occasionally may be long enough to permit dust or metallic particles to accumulate on the surface of the insulation. In some

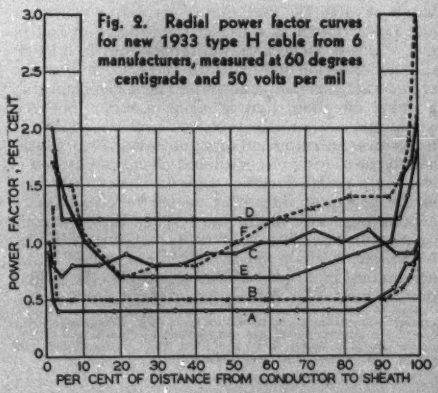

Fig. 2. Radial power factor curves for new 1933 type H cable from 6 manufacturers, measured at 60 degrees centigrade and 50 volts per mil

factories the cable is submerged just before leading in an oil bath in the floor, and it is possible for foreign material from the floor to become mixed with the oil, thus contaminating the outer layers of insulation.

The cause of the irregularity in the middle portions of the radial power factor curves usually may be traced to the manner in which the cable is dried, degassed, and impregnated, and in a lesser degree to the type of saturant and paper used. For example, in figure 2 the radial characteristics of the several brands of cable may be interpreted in terms of materials or manufacturing methods then in use. One manufacturer uses an inert gas at one stage of manufacture to displace residual air in the insulation in order to reduce oxidation and to improve the thoroughness of impregnation. Another manufacturer uses different types of paper to effect a so-called "graded" insulation. Another manufacturer expends considerable effort toward thoroughly degassing both oil and paper. Special apparatus has been installed for frequently filtering and purifying the oil. Still another manufacturer utilizes a process in which, after the paper insulated core has been dried and evacuated, the vacuum is broken and air again allowed to rush in. After a short period, said not to exceed 10 minutes, the cable is plunged into the impregnating tank. This procedure probably results in small amounts of air being trapped in the insulation and the resulting oxidation of the oil might account for the variations shown by the radial power factor curve. One of the cables is made by the "pan-saturation method." In this method each reel of cable is placed in a separate pan for impregnation. Upon removal from the impregnating tank the pan accompanies the cable so that the cable remains immersed in the oil in which it was impregnated right up to the moment it enters the lead press. In this way the absorption by the insulation of air and moisture from the factory atmosphere during unavoidable delays is minimized. It will be evident from the foregoing that a variety of methods of degassing and impregnation are prevalent in the cable industry.

Significance of Radial Nonuniformity

The significance of the radial curves lies in the information they give regarding the care used in manufacturing. Poor materials, outmoded methods of manufacture, or undue exposure to the factory atmosphere as well as the use of good materials and good practice will be indicated in the radial characteristics.

At present the irregularities in the radial curves that some conditions of manufacture produce cannot be evaluated directly in terms of operating life; but where 2 brands of cable are under consideration, one exhibiting highly erratic radial characteristics, indicating poorly controlled conditions of manufacture, and the other having uniform radial curves of low value, indicating careful and studied manufacturing methods, the likelihood of long life in service is much greater for the radially uniform cable. This conclusion is supported by another investigator's[5] observation that initial peaks in radial power factor curves of new cable become much more pronounced after a period of service. In those cables in which errors in manufacturing methods can be detected by the radial power factor test, it is probable that other errors, which cannot be detected by present available means, also are present. Radial uniformity of cable insulation, therefore, may be considered as an indication of quality.

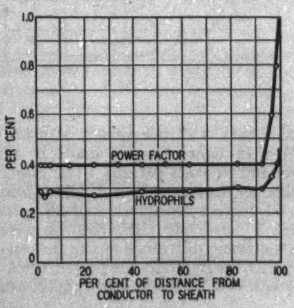

Fig. 3. General correspondence of radial hydrophil and power factor values

Power factor measured at 60 degrees centigrade and 50 volts per mil

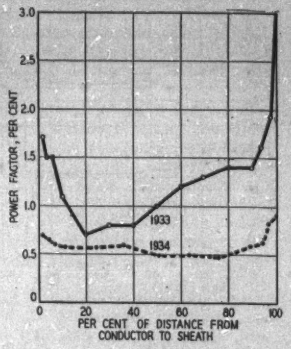

Fig. 4. Effect of modified manufacturing methods on the radial characteristics of brand F cable

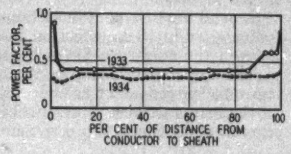

Fig. 5. Effect of modified manufacturing methods on the radial characteristics of brand A cable

Practical Results of the Radial Method

Measurement of the radial characteristics of cable insulation has proved useful to the enterprising cable manufacturer in improving quality. During the past year, the manufacturer of brand *F*, figure 2, which

had the least desirable radial characteristics of the 6 brands tested, has greatly improved his methods and technique. The radial power factor curve of his most recent product is shown in figure 4, in order to permit more ready comparison the curve F (1933 product) of figure 2 has been replotted in this figure.

Even the best product may be improved when a means is available for detecting flaws. The manufacturer represented by brand A in figure 2 desired to eliminate the upturns of the radial power factor curve. The results of his efforts may be judged by comparing the radial power factor curve for 1934 cable with that of 1933 cable of the same brand (figure 5). It may be seen that a distinct improvement has been effected by the known improvements in the process.

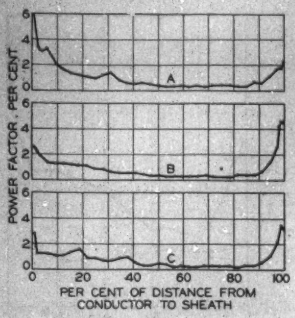

Fig. 6. Radial power factor of 3 sections from a 64 foot length of single conductor extra-high-voltage cable, measured at 60 degrees centigrade and 50 volts per mil

General improvement in all brands of cable should follow a study of the effect on the radial characteristics of the finished cable of the more rigid control of each step in manufacture. Apparatus for measuring radial power factor has been built by practically all the manufacturers represented in figure 2 and by several power companies active in cable research.

Reliability of Measurement of Power Factor of Individual Paper Tapes

The question frequently has been raised as to whether the power factors of the individual layers of the cable give a reliable indication of the power factor of the cable measured as a whole.[4] An opportunity to answer this question presented itself when a 64 foot length of used single-conductor high-voltage cable, the over-all power factor of which carefully had been measured in a hot box, was submitted for radial examination. Six sections, each 18 inches long were removed from the 64 foot length, one from each of the ends and the remaining 4 at equal intervals. One section was removed at a time; radial power factor measurements were made immediately following removal and preparation of samples. Extra precautions were taken in the preparation to prevent contamination from exposure of the ends of the cable to the atmosphere.

The radial power factors of 3 representative sections are shown in figure 6. In calculating the power factor of the cable it would not be correct to average the areas under the 6 radial power factor curves since a high loss tape at the conductor obviously would not affect the total power factor as much as a high loss tape at the sheath, because of volume considerations.

Taking due account of the volume considerations, the power factor of the cable may be calculated with close approximation from the formula

$$P_t = \frac{\int_a^b \frac{P_n dr}{r}}{\log \frac{b}{a}}$$

where

P_t = power factor of the cable
P_n = power factor of individual tape n at radius r
r = radius at which tape n is located
a = radius of the conductor of the cable
b = radius of the outer layer of the insulation

In a cable the stress throughout the insulation varies whereas in the tape power factor cell the stress is maintained constant for each layer. This would have considerable bearing on the correctness of this method were it not true that the power factor of impregnated paper insulation that is not badly deteriorated does not vary greatly with stress below the ionization point.

The values P_n/r in the formula were plotted against r for each of the 6 sections; r varied between 620 and 1,340 mils. Representative curves for 2 of the sections are shown in figure 7. The power factor of each section was determined by graphical integration and division by log (b/a) and the 6 power factors averaged. The average of these 6 values was considered as the power factor P_t of the cable.

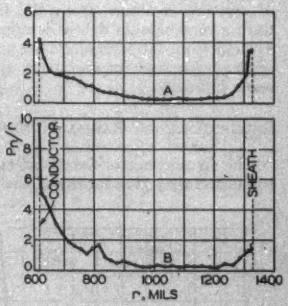

Fig. 7. Plots for 2 sections of cable of P_n/r versus r used for graphical integration in obtaining the total power factor from power factors of individual paper tapes

This average value was 0.82 per cent. Measurements as indicated in figure 6 were made at 60 degrees centigrade and 50 volts per mil. The power factor of the cable as measured in a hot box was 0.75 per cent at 60 degrees centigrade and 28 volts per mil. In the 2 tests the temperatures were equal, but there was some difference in the measuring stress. Because of the fact that the power factor-voltage characteristics of impregnated paper are

slightly rising, the agreement would have been even closer had the measuring stress been the same.

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Adequate Lighting Is a Sound Investment

A number of examples in which an increased intensity of illumination in industrial establishments resulted in an actual increase in production are cited in this paper. Other results also attributed to adequate lighting are that better work can be done, accidents are reduced, and waste space may be made available for production.

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BECAUSE better illumination does cut costs, increase efficiency, reduce accidents, and establish better working conditions, lighting in industrial plants everywhere will probably be revolutionized in the next few years. At present industrial lighting averages less than 5 foot candles, one survey of 2,000 industrial plants even averaging below 3, as compared with the safe minimum of 10 foot candles. Industry is awakening to advantages of better lighting as a result of recent developments in lighting and of many industrial lighting surveys. The following are only a few examples of many instances where proper illumination definitely increased production.

ADEQUATE LIGHTING INCREASES PRODUCTION

One of the most conclusive proofs that good lighting pays its cost is furnished by a national piston company. This plant was inadequately lighted and the local power company induced them to make a lighting test. The president reports that at the beginning of the test the plant was running at about 70 per cent capacity with a lighting intensity of 1.2 foot candles. In one department the lighting was stepped up to 6.5 foot candles and production increased 13 per cent. Then it was further increased to 9 foot candles and an additional 4.9 per cent increase was obtained. Finally the lighting was increased to 14 foot candles and production jumped another 6.9 per cent. In all, the lighting of 14 foot candle intensity increased production 25.8 per cent over the old installation.

In the inspection department of a large roller bearing manufacturer a thorough test of the effectiveness of light in increased production was made. The original system of lighting provided 5 foot candles at the inspection table. The number of pieces inspected per hour per operator was 408. When the new lighting installation providing 20 foot candles was in operation, production jumped to 458 pieces per hour per operator—an increase of 12.5 per cent. This intensity was maintained for 2 weeks, then decreased to 13 foot candles, and immediately production dropped to 440 pieces per hour per operator. When it was later set back to 20 foot candles production increased to its peak.

In a hosiery plant proper illumination was installed and immediately production of knitting machines jumped 10.8 per cent and of looping machines 6.1 per cent. The cost of the installation was only 0.4 per cent and the operating cost 0.1 per cent of the yearly pay roll.

In the composing room of a large register company the lighting was old-fashioned, inadequate, and spotty. Men at work setting type were slow and errors were frequent. The management consulted a lighting specialist and he recommended an entirely new system with modern equipment and mazda lamps of proper size. After the new installation was made a careful check was kept; production increased 6 per cent and only 20 cents per day was added to the light bill.

In a plant operating a battery of wire drawing machines a haphazard system of drop cord lighting was replaced with a scientifically planned overhead system. Immediately the output of the machines was increased 21 per cent.

A manufacturer of automobile parts reports that after installing a new lighting system which increased lighting intensity 133 per cent, labor turnover dropped from 6.37 per cent per month to 2.78 per cent per month. In addition, work was speeded up enough to pay for the complete installation in 18 months.

ADEQUATE LIGHTING AIDED BY MANY FACTORS

The development of the light meter, which is a portable compact means of measuring lighting intensities, makes it possible to check easily and

Full text of a paper recommended for publication by the A.I.E.E. committee on production and application of light. Manuscript submitted Aug. 15, 1934; released for publication Aug. 22, 1934.

accurately the intensity of light provided by artificial illumination in industrial plants everywhere. Illumination research laboratories have discovered by actual test that wherever eyes are used for work that 10 foot candles is an absolute minimum. Further tests have also revealed that working under intensities less than 10 foot candles causes not only severe eye strain but results in fatigue, sleepiness, nervousness, headaches, indigestion, etc. Glare from light sources in the line of vision, reflections from glossy surfaces, and uneven distribution of light are also features which contribute to this condition.

As a general premise to a new lighting approach to industry, 3 definite recommendations are being made: (1) Increase intensities; (2) abolish glare; and (3) provide uniform distribution.

Adequate lighting is a working tool in any plant. The importance is best summed up in an adaptation of a well-known adage "As a man sees, so does he work."

Industry has spent tens of thousands of dollars in developing machines of greater efficiency, but the most delicate machine is not half as sensitive as the operator. And when conditions are such that it is difficult to see, when surroundings are dark and gloomy, operators cannot be expected to get the most out of machines. Production suffers. Costs increase. Accidents increase.

Other important considerations are the new industrial codes under which industry is working. Shorter work days and shorter work weeks have necessitated the addition of more shifts and the employment of more men. Better illumination enables employers to get a greater volume of work and greater securacy from each employee under the shorter hours and perhaps increased pay.

Better Work and Reduction in Accidents Result

But not only does better lighting mean increased production, it also means better work. Employees can see better, but equally important they have a more inviting, improved working condition and plant atmosphere. A dark, gloomy plant is depressing to workers and they cannot be expected to do their best in surroundings of this character. Better light will increase the morale of the entire staff to a pitch which assures good work and high efficiency. Also, workers are more dependable in well-lighted plants, and more satisfied to stay on the job—therefore, labor turnover is substantially reduced.

Improved lighting also means decreased accidents. Workmen who can see danger rather than merely sense it are less likely to be involved in accidents. And accidents in addition to their regrettable nature cost industries large sums of money year after year.

One of the most interesting descriptions of the relationship between lighting and accidents is found in the code of lighting prepared under the direction of the Illuminating Engineering Society. This report points out that the National Safety Council estimates that the number of fatalities in the United States arising out of or in the course of gainful employment was 24,000 for the year 1928, and that during the same period the lost time nonfatal accidents reached the staggering total of 3,125,000. The report also points out that a prominent insurance company shows justification for assuming that defective vision and deficient or unsatisfactory lighting installations are contributing factors of 18 per cent of these accidents. This means that from these causes industries are being deprived of the equivalent of the services of 35,000 men throughout each entire year due to lost time nonfatal accidents. This is indeed a high price to pay for neglect of light and vision.

Quoting further from this report it is discovered how from a dollars and cents standpoint accidents cause industry thousands of dollars a year.

"Compensation insurance premiums for a plant are based on the amount of the pay roll, and the rate is determined by the accident experience of a given industry, modified by the experience of a particular plant under consideration. With a rate of 1.5 per cent the annual premium in the case of 1,000 employees at an average wage of $40 per week would be $31,200.

"An insurance carrier might, at an average, pay the claims resulting from 4 accidents per month in this plant, and meet its own overhead cost, and still have slight margin of profit. An experience of 5 accidents per month, $^1/_5$ of them due to improper lighting (a not unlikely event) would probably leave the insurance carrier no option but to increase the rate by 25 per cent. This premium would then be $39,000, an increase of $7,800. If poor lighting costs only $3 per employee or $3,000 per year total, the owner's annual expense for poor illumination actually amounts to $10,800, of which $7,800 is required by the insurance company to meet additional accident claims. An expenditure of $6 to $8 per year per employee for more adequate illumination might save a large portion, if not all, of the latter amount. The important point here is the fact that the cost of accidents, due to poor illumination, greatly exceeds the cost of providing adequate illumination."

Waste Space Made Available for Production

Another important advantage of modern lighting in industry is that it makes all space available for active production. With spotty and inadequate illumination there is a large percentage of modern plant floor area which is dark and useless for actual production. The machinery and production line must be grouped close to existing lighting units, leaving large areas which are useful only for storage purposes, et cetera. These areas can be transformed immediately through installation of modern lighting to useful productive activity. Machinery can be arranged for efficient production, and in many cases more machinery and men can be employed in a given plant area. Also, in a plant where dark corners and out-of-the-way spots exist, there exists the opportunity for workmen to seek these spots for idle, unproductive moments.

From the foregoing facts it is readily evident why industry is taking a definite step toward revolutionizing industrial lighting standards.

The lighting industry for years has had the equipment to make possible illumination as now recommended. But it has only been recently that any one has fully appreciated the intimate relationship between light and sight and human efficiency. Now that the facts are known, and that electrical manufacturers are taking steps toward disseminating this knowledge, it will be interesting to observe how quick industry will be in establishing the new standards as recommended.

Probability in Engineering

The value of probability theory in the field of engineering is forcefully brought out in this paper, which explains the fundamentals of the theory, not by the use of mathematics, but by the solution of sample problems of types frequently encountered.

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THE purpose of this paper is to emphasize the practical value of probability theory in engineering. Since engineering problems are of a quantitative character the paper relates to the mathematical aspect of the theory. But the reader will not be burdened with a lot of mathematics; for the purpose of this paper a few comments on the theory itself, followed by the presentation of the solution of some problems, will suffice.

What is probability? The greatest authority on the subject, Laplace, wrote that "the theory of probability is, fundamentally, nothing but good sense reduced to calculation."

Note carefully the qualification "reduced to calculation." Good, or common, sense so reduced does not subscribe, for example, to the placing of odds in favor of tail in the ninth throw if the first 8 throws of a penny gave head every time.

Essentially full text of a paper presented at a meeting of the Sharon (Pa.) Section of the A.I.E.E., April 9, 1934, and at a joint meeting of the Pittsburgh (Pa.) Section of the A.I.E.E. and the electrical section of the Engineer's Society of Western Pennsylvania, April 10, 1934; and recommended for publication by the A.I.E.E. committee on communication. Manuscript submitted April 20, 1934; released for publication August 1, 1934.

EDITOR'S NOTE: Those interested in the subject of probability from the point of view of engineering application may wish to read Albert A. Bennett's article ("Theory of Probability," ELEC. ENGG., v. 52, 1933, p. 752–7) which was the first article of the special "Science Series for Engineers" sponsored by the A.I.E.E. committee on education.

The "reduction to calculation" was inaugurated in 1654 when a notorious gambler, the Chevalier de Méré, submitted to the mathematician Pascal a problem of chances involving dice. Pascal and his friend Fermat then started a voluminous correspondence in which they embodied the elementary principles of the theory. During the following $2^1/_2$ centuries such famous mathematicians as James Bernoulli, DeMoivre, Laplace, Poisson, Gauss, DeMorgan, Boole, Bertrand and Poincaré contributed their share to the "reduction" with the result that today the mathematical theory of probability constitutes a body of principles which transforms into an exact science the rule of thumb methods previously used in the handling of certain broad classes of problems. The chief characteristic of these problems is that they involve mass phenomena where law and order reign in the aggregate in spite of apparent chaos in the individual.

From both the theoretical and practical points of view the domain of probability splits into 2 main divisions known as the *a priori* and the *a posteriori*. Two simple problems, one *a priori*, the other *a posteriori*, quoted from the "theory of sampling" will serve as definitions of these terms.

a priori: A box contains 1,000 relays. It is known that 50 of them are defective. If 100 of them are selected at random what is the probability that, say, 10 of the 100 selected will be defective?

a posteriori: A box contained 1,000 relays of which some unknown number were defective. Of 100 relays selected at random from the box, 10 were defective. What is the probability that, say, 50 of the 1,000 relays were defective?

In the first case a universe with *known* characteristics is given and a probability question is asked regarding a sample which is to be taken from the universe. In the second case the characteristics are given of a sample which has been taken and a probability question is asked regarding the *unknown* sampled universe.

So much for the theory of probability as such and its 2 logical divisions. Let some applications be considered.

Three problems will be presented from the domain of engineering with which the writer is most familiar, telephony. However, their probability aspects are shared by other fields of engineering and moreover details and qualifications, which are of interest only to the telephone engineer, will be omitted.

The first and second problems belong in the *a priori* division of probability theory, but it is not essential to bear this in mind. At the end of the discussion of the third problem, some comments will be made on an aspect of *a posteriori* problems which, if overlooked, may lead one to quite erroneous conclusions as to the significance of a sample from an unknown universe.

I—Application to a "Trunking" Problem

The engineer responsible for the amounts of equipment which should be installed for the giving of adequate service at a fair price is confronted with the following question: Knowing the average demands which will be made for a certain service,

what are the probabilities for or against various fluctuations in excess of the anticipated average demands?

As an example consider, in a general way, what is technically known as a "trunking" problem.

Imagine a telephone exchange serving 2,000 subscribers; call this exchange A. To simplify the

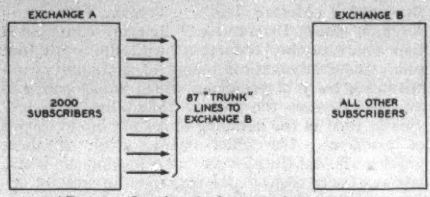

Fig. 1. Simple telephone exchange system

discussion assume that all outgoing calls from A are made for subscribers in a nearby exchange which will be referred to as exchange B. (See Fig. 1.)

Shall 2,000 interoffice trunk lines be installed so that the entire 2,000 subscribers of A may talk simultaneously with their friends of exchange B? Of course not; in the first place, not once in a century would all the subscribers wish to talk simultaneously unless an earthquake or some such catastrophe were to occur; in the second place, the cost would be intolerable. A more rational and practical point of departure would be to assume that, under normal conditions, only one out of every 100 calls shall fail to find immediately an idle trunk line at its disposal.

Suppose that during the busy hour of the day each of the 2,000 subscribers of exchange A makes a call for B and, moreover, that when a connection is established between the 2 exchanges the conversation lasts for exactly 2 min. Since 2 min. is $^1/_{30}$ of the hour, it is anticipated that *on the average* $^1/_{30}$ of 2,000 = 66.7, say 67, simultaneous conversations must be provided for. But what about deviations from the average; more particularly, what are the probabilities that the average number will be exceeded to various extents? To answer this question examine Table I. This table is based on the Poisson probability or "frequency" law which gives

$$a^x e^{-a}/x!$$

as the probability that an event will happen *exactly* x times if on the average it happens a times. The corresponding probability that the event will happen *at least*, say c times, is

$$\sum_{x=c}^{x=\infty} a^x e^{-a}/x!$$

In these formulas e represents the number 2.7182 . . . which is the base of natural or hyperbolic logarithms.

Although the number of conceivable laws relating average results to deviations therefrom is legion, the Poisson law is one which has a great range of applications in physics, biology, engineering, and elsewhere. Its application to the telephone problem under consideration is justified both on theoretical grounds and by the results of numerous observations.

To determine the number of trunk lines which should be installed to meet the 1 in 100 condition, read down column III of the table until a probability of 0.01, or the nearest value thereto, is encountered. Then reading across to the corresponding entry in column I the number 87 is found. Thus, finally, 87 interoffice trunk lines must be installed when the average number of conversations expected is 67.

In order to emphasize the utility and significance of tables such as Table I and Table II, also based upon the Poisson law, the trunking problem will be carried a step further.

Manual or automatic means are required in order that any one of the 2,000 subscribers shall have access to all of the 87 outgoing trunks. The mechanics of this part of the problem would be simpler and perhaps cheaper if the subscribers were divided into 2 groups of 1,000 each and then 2 separate groups of trunks running from exchange A to exchange B were installed. To what extent will this arrangement, if put into effect, increase or decrease the total number of trunks? Consider the following analysis.

On the assumptions made above each group of 1,000 subscribers will contribute on the average 66.7/2 = 33.4 simultaneous conversations. When the average is 33.4, Table II tells us that 48 trunks are required to give a 1 in 100 grade of service. Therefore, it will be necessary to install 48 trunks *per group* of 1,000 subscribers or a total of 2 × 48 = 96 trunks. This is an excess of 96 − 87 = 9 trunks over the number required when it is feasible to serve the subscribers as a single group of 2,000.

The reader will appreciate without further analysis that the theory of probability, together with a knowledge of unit cost figures and other factors which the telephone engineer must take under consideration, enables him to determine the optimum division of subscribers into subgroups.

A problem of the type which has been under discussion here and is of special interest to the power engineer forms the subject matter of the paper entitled "Spare Capacity Fixed by Probabilities of

Table I—Probability Table

Possible Number of Simultaneous Conversations	Probability That Number of Simultaneous Conversations Will Be: Exactly That Specified in Column I	Probability That Number of Simultaneous Conversations Will Be: At Least That Specified in Column I
I	II	III
65 = 67 − 2	0.047952	0.612877
66 = 67 − 1	0.048678	0.564925
67 = average	0.048678	0.516246
68 = 67 + 1	0.047962	0.467567
69 = 67 + 2	0.046572	0.419606
80 = 67 + 13	0.013600	0.066446
85 = 67 + 18	0.004665	0.019069
86 = 67 + 19	0.003634	0.014404
87 = 67 + 20	0.002799	0.010770
88 = 67 + 21	0.002131	0.007971
106 = 67 + 39	0.000003	0.000006

Outage" by S. A. Smith, Jr. (*Elec. World*, v. 103, 1934, p. 222–5). In the opening paragraph the author says:

"In the engineering of power systems one of the most important objects is the attainment of a high degree of continuity of service. In attempting to achieve this many millions of dollars are spent for reserve equipment and protective devices. Seldom, however, is the proper degree of service reliability known or defined in quantitative terms, and rarely does the designer employ a truly rational method to attain it. Some way of defining the goal must be found and some scientific means of reaching it sought."

Mr. Smith then proceeds to outline how probability theory supplies a "scientific means" of arriving at results.

II—Application to a Problem in Recurrent Structures

An extensive class of probability problems arises from the recurrent or periodic structure of certain kinds of equipment. In long telephone circuits, for example, such a structure results from "transpositions" in the pair of wires of a talking circuit in order to eliminate crosstalk between adjacent pairs. Another example is circuits wherein "repeaters" for amplifying the voice currents are inserted at several points along the line. (See Fig. 2.)

Now in any recurrent structure one is confronted with irregularities; no 2 transposed sections are exactly alike in length or in the distance between adjacent pairs, no 2 repeaters are exactly alike in their electrical characteristics or there may be slight variations in the voltages of the local batteries which supply them with current.

The central question in this class of problems is: What is the probability that the *cumulative* effect, or sum, of several relatively small independent irregularities will lie within a specified range? It is to be understood that each individual irregularity is likely to have any one of a finite number, or of an infinite number, of possible values.

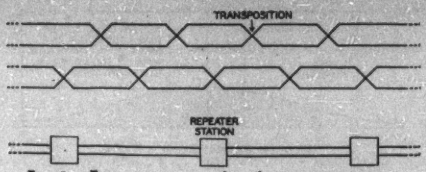

Fig. 2. Engineering examples of recurrent structures

One may venture to state that every field of engineering is saturated with problems of the type now under consideration. Of course, the saturation point may be much lower in some fields than in others.

Consider the line equipped with repeaters, limiting the discussion to the irregularities resulting from slight variations in the voltage of the local batteries installed at each repeater station. Assume that each repeater gives a nominal gain, or amplification, of say 30 db (decibels). For the purpose of this paper the precise meaning of the term decibel is not essential; it suffices to bear in mind that it is a convenient unit for measuring power gains or losses in transmission.

An irregularity or departure on the part of an individual repeater from the nominal value of the gain expected from it will, of course, react on the total transmission gain to be expected from the several repeaters collectively. The problem confronting the telephone engineer is, then, to find the probability

Table II—Averages Corresponding to Average Plus Deviation to Be Expected With Different Probabilities

Average plus Deviation	Probabilities										Average plus Deviation
	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.010	
ϵ	Average α										c
1	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.010	1
2	0.045	0.065	0.080	0.092	0.104	0.114	0.124	0.133	0.141	0.149	2
3	0.191	0.243	0.281	0.312	0.338	0.361	0.382	0.402	0.419	0.436	3
4	0.429	0.518	0.581	0.630	0.672	0.709	0.741	0.771	0.798	0.823	4
5	0.739	0.872	0.954	1.02	1.08	1.13	1.17	1.21	1.25	1.28	5
6	1.11	1.27	1.38	1.47	1.54	1.60	1.65	1.70	1.74	1.79	6
7	1.52	1.72	1.85	1.95	2.04	2.11	2.17	2.23	2.28	2.33	7
8	1.97	2.20	2.36	2.47	2.57	2.65	2.73	2.79	2.85	2.91	8
9	2.45	2.72	2.80	3.02	3.13	3:22	3.31	3.38	3.45	3.51	9
10	2.96	3.26	3.45	3.60	3.72	3.82	3.91	3.99	4.06	4.13	10
12	4.04	4.40	4.63	4.80	4.94	5.06	5.17	5.26	5.35	5.43	12
14	5.20	5.61	5.87	6.07	6.23	6.37	6.49	6.60	6.69	6.78	14
16	6.41	6.87	7.16	7.39	7.57	7.72	7.86	7.97	8.08	8.18	16
18	7.66	8.17	8.50	8.75	8.94	9.11	9.26	9.39	9.51	9.62	18
20	8.96	9.52	9.87	10.14	10.35	10.54	10.70	10.84	10.97	11.08	20
22	10.29	10.89	11.27	11.56	11.79	11.99	12.16	12.31	12.45	12.57	22
24	11.65	12.29	12.70	13.01	13.26	13.47	13.65	13.81	13.96	14.09	24
26	13.03	13.72	14.15	14.48	14.74	14.96	15.16	15.33	15.48	15.62	26
28	14.44	15.17	15.63	15.97	16.24	16.48	16.68	16.86	17.03	17.18	28
30	15.87	16.64	17.12	17.48	17.77	18.01	18.23	18.42	18.59	18.74	30
32	17.32	18.12	18.62	19.00	19.31	19.56	19.79	19.98	20.16	20.32	32
34	18.78	19.62	20.15	20.54	20.86	21.13	21.36	21.57	21.75	21.92	34
36	20.26	21.13	21.68	22.09	22.42	22.70	22.94	23.16	23.35	23.53	36
38	21.76	22.66	23.23	23.66	24.00	24.29	24.54	24.76	24.96	25.14	38
40	23.25	24.20	24.79	25.23	25.59	25.89	26.14	26.38	26.58	26.77	40
42	24.78	25.75	26.36	26.82	27.19	27.49	27.76	28.00	28.21	28.41	42
44	26.30	27.31	27.95	28.41	28.79	29.11	29.39	29.63	29.85	30.05	44
46	27.85	28.89	29.54	30.02	30.41	30.74	31.02	31.27	31.50	31.71	46
48	29.40	30.47	31.14	31.63	32.03	32.37	32.66	32.92	33.18	33.37	48
50	30.96	32.06	32.74	33.25	33.67	34.01	34.31	34.58	34.82	35.03	50

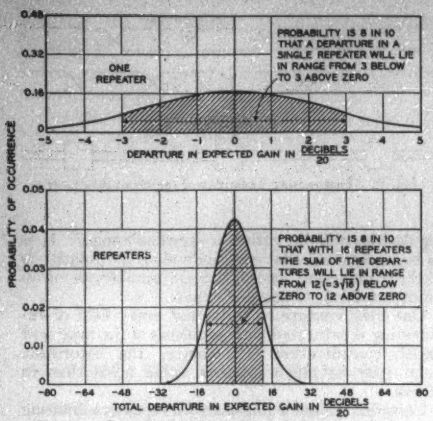

Fig. 3. Gain fluctuation in line equipped with repeaters

or chance that the total gain of a number of repeaters will depart from the total nominal gain (for that number of repeaters) by an amount equal to or less than a specified amount.

In the solution of the problem the first question to be answered is: What are the possible values for the departure at an individual repeater and what is the probability in favor of each value, or infinitesimal range of values? This question is usually answered by an appeal to existing records of the past behavior of individual repeaters.

Let us assume, then, that the information embodied in the upper curve of Fig. 3 is given.

The abscissa x of a point on the curve represents a possible value for the departure, the unit departure being 0.05 db, for example; the ordinate y represents the relative probability in favor of the occurrence of the departure of magnitude x. Moreover, assume that the equation to this curve is

$$y = \frac{1}{\sigma_1\sqrt{2\pi}} e^{-X^2/2\sigma_1^2}$$

with, for example

$$\sigma_1 = 2.34$$

This is another outstanding law relating average, or mean, values to departures therefrom. In Fig. 3 the mean value is represented by the origin 0 of abscissas. The constant σ_1 conventionally known as the "standard deviation" determines the slope of the curve and is a measure of the extent to which the departures tend to cluster around the most probable value. Many readers of this paper will recognize the law, although it has changed its name several times; Normal, DeMoivre, Gaussian, Laplace-Gaussian are among those under which it travels.

Now, when the individual departure obeys a Normal law, the mathematical theory of probability shows that the sum of n departures likewise obeys a Normal law, but with a standard deviation, $\sigma_n = \sigma_1\sqrt{n}$. (This relation between standard deviations holds even when the individual and cumulative departures do not obey normal laws.) Write

$$X = x_1 + x_2 + x_3 + \ldots x_n$$

for the sum of the n individual departures. There then results

$$\frac{1}{(\sigma_1\sqrt{n})\sqrt{2\pi}} e^{-X^2/2(n\sigma_1^2)}\, dX$$

for the probability in favor of the occurrence of a sum whose value lies in the infinitesimal range $X \pm \frac{dX}{2}$, and

$$\frac{2}{(\sigma_1\sqrt{n})\sqrt{2\pi}} \int_0^{X'} e^{-X^2/2(n\sigma_1^2)}\, dX$$

for the probability that the total gain given by n repeaters will lie within the range X' on either side of n times 30 db.

There can now be stated in general terms a conclusion of great practical importance which results from the theory of probability: As consideration is transferred from a line equipped with a number, say n, of repeaters to a line equipped with a larger number, say N, *the range of values for which there is a specified probability that the sum of the departures from normal gain will lie therein*, instead of increasing in the ratio of N to n, increases only as the square root of this ratio.

In the lower half of Fig. 3 the outcome is observed for a line equipped with 16 repeaters, the "standard deviation," for each individual irregularity being $\sigma_1 = 2.34$, as assumed above.

III—Application to a Problem of the *A Posteriori* Type

The 2 telephone problems which have been considered belong to the *a priori* domain of probability theory. The *a posteriori* domain will now be en-

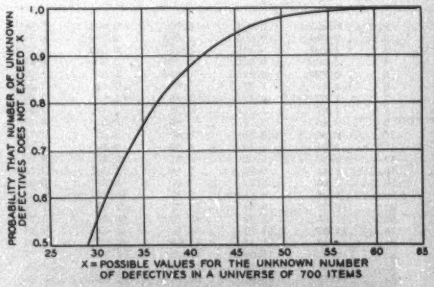

Fig. 4. Curve showing probability that the unknown per cent of defectives in a universe of 700 items does not exceed a specified value, it being known that a sample of 200 out of the 700 contained 4 per cent defectives

tered. The importance in engineering of this aspect of the mathematical theory of probability will be emphasized by a brief analysis of a "sampling" problem.

It is necessary to distinguish between the sampling of "attributes" and the sampling of "variables" since they involve different techniques. The sampling of "attributes" relates to problems where each individual of the universe sampled has or has not a specified characteristic; the case of "variables" arises when it is asked *to what extent* each item of the universe possesses a certain character.

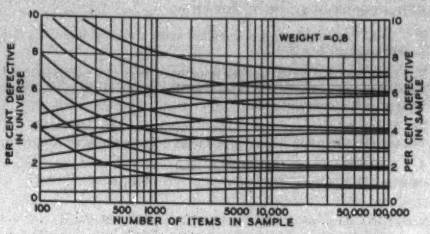

Fig. 5. Curves showing, for an infinite universe and with a weight or surety of 8 in 10, the range within which lies the per cent of defectives in the universe for various sizes of sample and various per cent defectives in the sample

The figures at the right are the designations (in whole numbers) of each pair of curves which tend to converge at the right. The ordinate scale is on the left

A typical sampling of "attributes" problem is the following: Suppose a shop has received a shipment of 700 triode tubes. Assume that a test of 200 of these tubes, selected at random, disclosed that 4 per cent of them had broken filaments. What inference does this disclosure justify as to the per cent of triodes with broken filaments in the entire lot of 700? For example, what is the probability that it is not greater than 5 per cent; that it is not greater than 6 per cent?

These and equivalent questions can be readily answered by reference to the curve in Fig. 4. The abscissas indicate possible values for the number of triodes with broken filaments in the universe of 700; the ordinates give the probabilities that the unknown number of defectives does not exceed the values indicated by the abscissas.

To answer these questions proceed as follows: 5 per cent of 700 is 35; the point on the curve whose abscissa is 35 has 0.75 for its ordinate. Therefore, it is inferred that the probability is 75 in 100 that not more than 5 per cent of the 700 triodes are defective. Likewise, since 6 per cent of 700 is 42, a probability is inferred of 91 in 100 that the defectives do not exceed 6 per cent of the total number of tubes.

If the number of individuals in the universe is very large compared with the number sampled, the inferences which can be drawn from the characteristics of the items sampled are, approximately, independent of the size of the universe. Therefore, the next step is to go the limit and assume that the sample of 200 triodes containing 4 per cent defectives was obtained by selections at random from an *infinite* universe. In this situation pairs of curves, such as those in Fig. 5, are very useful. Each pair of curves corresponds to a specified per cent of defectives in the sample; this per cent is indicated at the extreme right end where a pair converges together. The sample sizes are indicated by the abscissas plotted on a logarithmic scale. The ordinate scale on the left relates to the unknown per cent defectives in the infinite universe from which the sample was taken.

Next, find the abscissa corresponding to the sample of 200 triodes. Then follow the vertical line above this abscissa to where it crosses the pair of curves converging toward the value 4 at the right. The ordinate of the crossing with the lower curve reads 2.7 on the scale to the left, with the upper curve its value is 6.5. Now the caption to all the curves reads "Weight 0.8." Therefore, it is inferred that:

a. The probability is 8 in 10 that the true unknown per cent defectives, in the infinite universe of triodes, lies in the range 2.7 to 6.5.

b. The probability is 1 in 10 that it *exceeds* 6.5; likewise, the probability is 1 in 10 that it is *below* 2.7.

In drawing inferences as to the number of defectives in the shipment of 700 triodes, no consideration has yet been given to any available information on the character of the shipment other than that obtained from the sample of 200 tubes. For example the fact has been ignored that the shipment came from, say, one or the other of 2 manufactories, one having a well established reputation for reliability in its product, the other being a relatively new concern. The probabilities assignable from this information to the various possible values for the unknown per cent of defectives in the shipment must be taken into account in conjunction with the probabilities based upon the outcome of the sample. The former probabilities are called in the literature *a priori existence probabilities* because they relate to information existing before the sample is drawn although it need not be taken into account until later.

The curves shown in Fig. 4 and 5 are based upon the assumption that the *a priori existence probabilities* are all equal or, in nontechnical words, that all the possible values for the number of defectives in the universe were equally likely before the sample was taken. Such an assumption can be made without serious consequences when the number of items sampled is large, because the implications of a large sample will outweigh to a great extent any prior information about the character of the universe.

In closing this discussion of sampling theory the writer would express an opinion which is certainly justified on theoretical grounds though not, as yet, on sad experience: It is that when circumstances are such that inferences must be drawn from a *small* sample, one should consult an expert in probability theory and, in doing so, make sure that there is no misunderstanding with him as to just what inferences are under consideration.

Lubrication Increases Life of Meter Bearings

Recent research reported in this paper shows that lubrication of pivot bearings of electric watthour meters is essential for maximum bearing life. The performance of these bearings represents the most important mechanical factor in sustained meter accuracy. The comparatively high rate of wear in a new bearing is found to decrease rapidly with use, finally becoming extremely small. With a well lubricated bearing, the effect of the increased friction resulting from wear on the calibration of the meter is shown to be negligible. A jewel screw of new design, having a large oil reservoir to provide for proper lubrication over a long period of time, also is described.

By
T. A. ABBOTT
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ATTAINMENT of sustained accuracy always has been the most important problem in the manufacture and use of electric watthour meters. With the modern tendency toward longer intervals between periodic tests, a review of the factors affecting this problem is pertinent.

Electrically, the accuracy of the meter is dependent upon the permanence of the damping magnets and the permanence of the mechanical positioning of the parts of the electric and magnetic circuits. The use of properly treated and processed high strength magnets has reduced the first factor to one that is unaffected by time. Careful design and manufacture made possible by years of experience have practically eliminated the changes resulting from mechanical shifting of the parts of the meter.

The parts that now need to be carefully considered, are those subject to mechanical change resulting from wear. Most of the parts of the meter operate at such slow speeds and low pressures that the slight wear is not of sufficient magnitude to affect the accuracy of the meter even over extremely long periods of time. The lower bearing, however, operates at a very high pressure and, although the linear speed is low, serious wear may take place if the conditions are not controlled properly. The lower bearing becomes, therefore, the most important mechanical factor in sustained meter accuracy and is the subject of the research reported in this paper.

From the results of the work done, the following conclusions have been drawn:

1. A well lubricated pivot bearing has many times the useful life of a poorly lubricated or dry one.
2. Under normal conditions the amount of wear of a well lubricated bearing, as indicated by the worn area on the end of the pivot, tends to approach a constant value.
3. The amount of wear of the well lubricated bearings tested was not sufficient to result in any appreciable decrease in meter accuracy.
4. A special type of jewel screw is necessary to provide good lubrication, and hence sustained accuracy, over long periods of time.

Obtaining Data on Bearing Performance

Three methods of obtaining data on bearing performance are:

1. Field tests made under actual service conditions.
2. Normal speed tests made in the laboratory under controlled conditions.
3. Accelerated tests made in the laboratory and devised to give results within a short time that would require years of operation in normal service.

A considerable amount of information on the long time performance of bearings under certain specific conditions was available from both field and laboratory tests made over several years. Certain things were indicated by these data that it was important to test out within a reasonably short time. The following accelerated life test was set up for this purpose.

A 5-ampere 115-volt standard-type watthour meter operating at 100 per cent load rotates at the rate of 15.97 rpm. The damping magnets were removed so that the speed increased to about 30 times normal. If the bearing be considered as a power consuming device in which work is done in overcoming friction and wear be assumed to be proportional to the work done, then as much energy must be dissipated per revolution at the accelerated speed as at normal operating speed if the same wear is to be obtained under both conditions. However, as the coefficient of friction is known to decrease somewhat with velocity, other conditions remaining the same, less energy is dissipated per revolution at the higher speeds. This decrease in friction coefficient can be compensated by increasing the weight of the disk; accordingly, as it was desirable to make the wear per revolution at the high speed greater than under normal operating conditions, the 13.2 gram standard rotor was replaced by a special rotor weighing 75 grams. A tremendous increase in the bearing pressure was thus obtained, which added materially to the severity of the test.

To simulate service conditions it was desirable to run the test meters on an intermittent load cycle. A time switch therefore was connected in series with the load and set to give an operating cycle of $3^1/_2$

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minutes *on* and $^1/_2$ minute *off*. The potential circuit was connected at all times, and the potential flux was sufficient to damp the rotating element practically to rest during this $^1/_2$ minute *off* period.

Consideration was given to the effect of the higher speeds on the lubricating problem, but calculations showed the speed of a point on the contact circle to be so low that even at the speed of approximately 500 rpm the linear velocity of a point on the outer edge of the circle of contact for a new bearing was only 0.730 inch per minute. With so low a speed it is evident that the lubrication conditions cannot be affected materially by the inertia forces resulting from the increase in speed.

Bearing Wear as a Function of Lubrication

Accelerated tests were made to determine the relationship between the rate of wear and the lubrication of the bearing. Three fundamentally different conditions of lubrication were tested. The first involved chemically clean surfaces from which even the slightest trace of lubricant had been removed. The second provided a very thin film of lubricant duplicating the conditions when the amount of lubricant is inadequate. The third provided an appreciable amount of lubricant so that the bearing surfaces were covered and the oil extended well up on the pivot.

The well lubricated bearings were run for 120 million revolutions without failure or sufficient wear in either the pivot or the jewel to affect the accuracy of the meter appreciably. The dry bearings were in very bad condition at the end of 10 million revolutions; the pivots and jewels were badly worn and

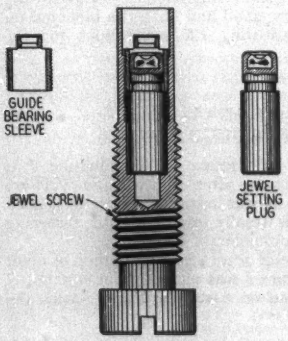

Fig. 1. A jewel screw for pivot bearings of watt-hour meters, with large oil retaining cup

rust was present in considerable quantities. The film lubricated bearings operated satisfactorily for a short period of time, but apparently the very thin film was not adequate so that wear comparable to that in the dry bearings soon resulted. The fact that the film provided sufficient lubrication for a short time and then failed indicated that the film actually deteriorated because of wear or for other reasons to a point where the lubrication was inadequate.

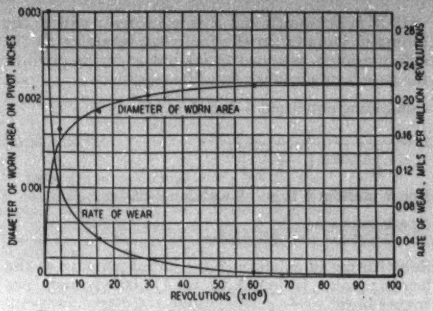

Fig. 2. Average diameter of worn area and rate of wear of 4 well lubricated pivot bearings on accelerated life tests

Confirmation of Accelerated Test Results

While these accelerated tests were being made an extensive examination was made of all the life test data on meters that had been running in the laboratory for several years. The results indicated in the accelerated tests were confirmed. The number of dry bearings or insufficiently lubricated bearings reported from laboratory normal-speed life tests was small, and even in these the accuracy was not affected appreciably; but the dry bearings and the inadequately lubricated bearings were undoubtedly in a worse condition than the well lubricated ones.

Further confirmation was found from the examination of a large number of bearings taken from meters used under actual service conditions. These findings are confirmed also by data in an article recently published by Mr. G. F. Shotter.[5]

An examination of pivots from well oiled bearings that had been operating in meters under normal service conditions for a long time revealed that the worn area on the end of the pivot was usually quite small and apparently independent of the revolutions of the meter. As a result of this observation the worn area on several accelerated life test pivots was measured and plotted against revolutions as shown in figure 2, which is an average for 4 bearings. Evidently the worn area reaches almost its final value after a few million revolutions and from then on increases at a greatly reduced rate. The following computations are interesting in this connection.

The average pressure P over the circular contact area of a sphere of radius R resting on a flat plate and supporting a load W is given by the expression:

$$P = \frac{W}{\pi r^2} \tag{1}$$

where r is the radius of the circle of contact and was calculated by Dr. Föppl[1] to be

$$r = \left[0.75WR\left(\frac{1-\rho^2}{E}\right)\right]^{1/3} \tag{2}$$

in which

ρ = Poissens ratio for the pivot steel (0.25)

E = modulus of elasticity for the pivot steel (30×10^6)

5. For all numbered references see list at end of paper.

If W is in pounds and R is in inches, r will be the radius in inches. In the foregoing formulas all the deformation is assumed to take place in the pivot as the steel is much softer than the sapphire.

Combining equations 1 and 2

$$P = \frac{W}{\pi \left[0.75WR\left(\frac{1-\rho^2}{E}\right)\right]^{2/3}} \tag{3}$$

For a standard type of watthour meter:

W = 0.0291 pound
R = 0.0185 inch pivot point radius

Substituting in equation 3 the initial pressure at the bearing point is found to be 172,000 pounds per square inch.

It has been seen that a new pivot bearing is in contact over a very small area initially and that this area is governed by the elastic constants of the material. For a properly designed pivot bearing there is no permanent deformation of the point. Possibly the reason for this is that the center section of the spherical surface in contact tends to be driven up into the main body of the pivot and is resisted by the material adjacent to it which is in tension. The combined stresses are such as to offset one another and result in a working stress well within the strength of the material. After a relatively small number of revolutions the contact area wears to the jewel contour and the pressure decreases until the area is large enough to reduce the bearing pressure to the point where the oil film is able to support the moving system. The variation of pressure with contact area as shown by the curve in figure 3 indicates the rapidity with which the pressure decreases as the area increases. The high pressure accounts for the rapid initial wear and consequently for the rapid rise of the curve shown in figure 2.

An examination of the wear of the jewels of the accelerated life test bearings showed that the jewel wear was smooth and even less than that of the pivots.

Computation of Effect of Bearing Friction on Meter Accuracy

The effect on the accuracy of the meter of the increase in bearing contact area shown in figure 2 may be determined by considering the increased friction torque resulting and its relation to the meter driving torque. For a new pivot and jewel, the contact area being a function of the elastic constants of the materials, the friction torque of the pivot bearing may be expressed by:[2]

$$T_f = \frac{3}{16}\pi\mu W\left[0.75WR\left(\frac{1-\rho^2}{E}\right)\right]^{1/3} \tag{4}$$

where μ represents the coefficient of friction and the other symbols have the same meanings as in the previous formulas.

Solving equation 4 for the initial friction torque for the specific meter, T_f = 0.000892 gram-millimeter.

After the pivot has run for 10,000,000 revolutions or more as shown by figure 2, the worn area is large enough to support the load with little or no elastic deformation and the expression for the pivot friction torque changes from equation 4 to:[2]

$$T_f' = {}^2/_3\mu W r' \tag{5}$$

where r' is measured, or, as in this example, is determined from figure 2 for any desired number of revolutions. Choosing the diameter of worn area from the curve in figure 2 for 60 million revolutions and solving equation 5, T_f' = 0.00469 gram-millimeter.

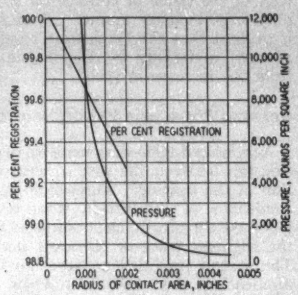

Fig. 3. Effect of pivot wear on meter calibration at 5 per cent load, and variation of bearing pressure with wear

The percentage error in registration of a meter at any load resulting from a change in lower bearing friction may be expressed as:

$$\text{Per cent error} = 100 \times \frac{\text{Friction torque (final)} - \text{Friction torque (initial)}}{\text{\% Load} \times \text{(Meter driving torque at 100\% load)}} \tag{6}$$

Equation 6 neglects the friction compensating torque as it is very small and has little influence on the result. Substituting the expressions for the torque in equation 6:

$$\text{Per cent error} = 100 \times \frac{\frac{2}{3}\mu W r' - \frac{3}{16}\mu W\left[0.75WR\left(\frac{1-\rho^2}{E}\right)\right]^{1/3}}{\text{\% Load (Meter driving torque at 100\% load)}} \tag{7}$$

The coefficient of friction (μ) in equation 7 is assumed to be the same after the jewel and pivot are worn together as it was initially. In a well oiled bearing the wear is usually smooth and the foregoing assumption is approximately correct.

The curve of meter accuracy as a function of pivot wear shown in figure 3 was plotted from equation 7 for 5 per cent load on a standard meter with the following constants:

W = 0.0291 pound
R = 0.0185 inch
Full load torque = 51.60 gram-millimeters
μ = 0.05
ρ = 0.25
E = 30×10^6

It should be observed from this curve that the change in accuracy is small and comparable with the accuracy of ordinary measurements.

The question naturally arises that if the increase in area on the end of the pivot is desirable, why not

produce this shape at the time the pivot is manufactured? Analysis reveals that the amount of material to be removed is minute and represents a decrease in the pivot length of only 28×10^{-6} inch for a pivot having an initial radius of 0.0185 inch. It is apparent that this cannot be accomplished by any reasonable manufacturing procedure.

In order to obtain the advantages of reduced wear of the bearing by providing a quantity of fluid lubricant, a special design is necessary. The usual type of jewel will hold a small drop of oil but when the pivot is inserted, it causes much of the oil to flow out.

Figure 1 shows a sketch of a new jewel mounting that recently was proposed by the authors. Essentially, the assembly consists of 3 parts: a main screw, a small plug which holds the jewel, and a guide sleeve used to clamp the parts together. When oil is placed in the reservoir of the main screw, it cannot leak out while the screw is in an upright position. If all parts are made carefully to close dimensions, when it becomes necessary to renew the jewel the small plug containing the jewel is the only part to be replaced.

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Discussions

Of A.I.E.E. Papers—as Recommended for Publication by Technical Committees

On this and the following 18 pages appear discussions submitted for publication and approved by the technical committees on papers presented at the sessions on cables, noise, overhead line problems, and electric welding at the 1935 A.I.E.E. winter convention, New York, N. Y., January 22–25. Other discussions of winter convention papers, and authors' closures, will be published in later issues. The first discussions of winter convention papers appear in Electrical Engineering for March 1935, pages 322–35.

Members anywhere are encouraged to submit written discussion of any paper published in Electrical Engineering, which discussion will be reviewed by the proper technical committee and considered for possible publication in a subsequent issue. Discussions on papers scheduled for presentation at an A.I.E.E. meeting or convention will be closed 2 weeks after presentation. Discussions should be: (1) concise; (2) restricted to the subject of the paper or papers under consideration; and (3) typewritten and submitted in triplicate to C. S. Rich, secretary, technical program committee, A.I.E.E. headquarters, 33 West 39th Street, New York, N. Y.

Dielectric Properties of Cellulose Paper

Discussion of a paper by J. B. Whitehead and E. W. Greenfield published in the October 1934 issue, pages 1389–96, and in the November 1934 issue, pages 1498–1503, and presented for oral discussion at the cables session of the winter convention, New York, N. Y., January 24, 1935. Other discussions of this paper were published in the March 1935 issue, pages 322–4.

R. W. Atkinson (General Cable Corp., Perth Amboy, N. J.): The general effect of moisture on paper insulation is one which is very fully recognized. However, quantitative information concerning the relation between moisture and other properties is sadly lacking. This paper contributes valuable test data on this subject and presents an ingenious method of analysis. I am glad to see the correction which makes it entirely clear that the values of moisture content as calculated and given in the paper are minimum rather than expected values. I am also glad that the authors have supplemented their paper by a calculation of maximum values of moisture content. Comparison of these limits with values actually measured in our laboratory will be of interest. These are presented by A. M. Myers in his discussion.

All of the departure of the paper insulation from the properties of a perfect or zero loss dielectric is attributed by the authors to residual moisture. I am inclined to challenge this assumption. It may be granted that addition of water to the paper increases the departure from the behavior of a perfect dielectric and that extraction of moisture reduces such departure, but that is not evidence that some of the departure is not due to an inherent property of the cellulose or other ingredient of the paper. In other words, it cannot be concluded from the data given that if all of the moisture were removed, the moisture free dielectric would be entirely free of "anomalous" characteristics. Though the conclusions based on this assumption cannot be considered to be proved, they are the less important conclusions of the paper. The facts attributable to moisture added above the driest state obtained are not affected by the assumption. Incidentally, the last traces of water seem to be attached to the paper fibers with a bond as strong as the chemical bond of the material and hence "perfectly dry" fiber is only a hypothetical condition. Any conclusion as to the characteristics of such a material can be drawn only by indirect means and can have no more than an indirect practical significance.

The authors conclude that if due account is taken of changes in electrode dimensions, the dielectric constant of their specimens remains substantially constant over the range of temperature from 25 to 100 degrees

centigrade. We have had occasion to investigate the change in capacitance with temperature on unimpregnated cables with 750,000 circular mil (0.998 inch diameter) conductor and about 400 mils of insulation. It was found that there was a linear increase in capacitance of 4.1 per cent for the temperature range of from 57 to 123 degrees centigrade. The maximum increase in capacitance which can be accounted for by thermal expansion of electrodes (i. e., inner electrode expanded and outer electrode remaining unchanged) is less than $^1/_2$ of 1 per cent, so that an increase of over $3^1/_2$ per cent in capacitance over this range of temperature appears to be an inherent property of the paper-air combination of this cable.

On account of the large dimensions of the cable and because the wall thickness of the dielectric is so large compared with the conductor diameter there is little difficulty in determining within rather narrow limits the possible major physical dimensional changes resulting from temperature change. It appears therefore that the conclusion of the authors that there is substantially no change of capacitance of dry paper with temperature does not apply generally to paper insulation in cables.

Our measurements were made at 60 cycles only. Figures 24 and 25 of the paper indicate, however, that there is practically no difference in the temperature coefficient of capacitance from 60 to 20,000 cycles.

Detailed consideration of the data presented by the authors relating to change of dielectric constant with temperature has developed new matters affecting the analysis presented. These are discussed by Louis Meyerhoff.

Although we have questioned some of the conclusions of the authors, we believe that their data and method of analysis have made a very important contribution toward changing the purely empirical data on the subject to a rational explanation of the behavior of the complex dielectric, paper-water-air, in terms of the basic properties of the components.

A. M. Myers (General Cable Corp., Perth Amboy, N. J.): Several years ago we attempted to measure the rate of drying of wood pulp paper and the change in its dielectric characteristics with per cent of moisture content. Our plan was actually to measure the amount of moisture as removed from the paper. The paper sample was made up of $1^1/_2$ inches wide 5 mil wood pulp paper wound in the form of a flat roll such as is used in ordinary paper taping machines, except that 4 tapes were wound in parallel with two 1 inch lead foil tapes inserted so as to be separated by 2 layers of paper. This sample was placed in a small vacuum oven heated electrically and arranged with automatic temperature control.

Two methods were used for measuring the amount of moisture removed from the paper. For determination of the larger amounts a method of weighing the oven with contained sample was used. This method had a sensitivity of $^1/_4$ gram, the accuracy being of the order of probably $\pm^1/_2$ gram, or less than 0.1 per cent of the weight of the paper. For determination of amounts of moisture too small to be measured by the difference in weight method, a flow meter was constructed and connected between the kettle and the vacuum pump. This flow meter consisted of a smooth copper tube 18 inches long with a U gauge connected so as to show the drop in pressure between the 2 ends. This drop in pressure is proportional to volumetric rate of flow through the tube. In order to transfer this to gravimetric units a McLeod gauge was arranged adjacent to one end of the tube, and the weight of water was calculated on the basis of the *average* pressure in the flow meter tube. The calibration of the flow meter was checked for both air and water vapor and was found to agree closely with the theoretical values.

The periods of drying at each vacuum step were approximately the same as those used by the authors, but our drying was done at 110 degrees centigrade instead of 100 degrees centigrade, and all measurements were made without releasing the vacuum.

For the purposes of our investigation, we arbitrarily assumed that zero moisture was represented by the driest condition we were able to attain at 110 degrees centigrade. For each step of absolute pressure used in the drying process the corresponding moisture content was taken to be the total moisture removed after the drying at that step had been completed. Since a very small amount of moisture is present even in our final "dry" condition our figures for moisture content should be in every case somewhat lower than the true values.

Since this test gives experimental data concerning the relation between measured moisture content of the paper and its dielectric properties, a comparison of our results with the calculated values should be extremely interesting. After drying at 100 degrees centigrade and 765 millimeters pressure the authors obtained a power factor of 3 per cent, whereas in our tests, even after 90 hours at 110 degrees centigrade and atmospheric pressure the power factor was 20.5 per cent. Similarly, after drying at a pressure of 400 millimeters our power factor was 8 per cent as compared with their 1 per cent. Furthermore (even making allowance for the effect of the different temperatures at which the electrical measurements were made) we were not able to reach a power factor corresponding to the 3 per cent they got at atmospheric pressure until the pressure had been reduced to about 325 millimeters.

Consideration of these large differences between our data and those given in this paper leads us to examine closely if there was anything inherently different in the methods of drying. We notice that, when making measurements, the authors brought the pressure to atmospheric by the admission of dry air to the vacuum oven. This introduces an element of indefiniteness which was also present in some degree in the first readings of our tests, but which we failed to recognize until we came to make this comparison of results. A large number of measurements were made by Whitehead and Greenfield and this repeated admission of dry air followed by reëvacuation approaches what might have been obtained by continuous circulation of dry air. The effectiveness of drying at atmospheric pressure by continuous replacement of the water vapor in the drying chamber by dry air has been pointed out by Whitehead in a previous paper (A.I.E.E. Transactions, volume 47, July 1928, page 835). The difference between the power factors obtained at identical pressures under the different conditions of drying may be explained on this basis, since in our tests the vacuum was never broken and the pressure in the drying chamber was largely that of water vapor, while in the authors' experiment the pressure after the introduction of dry air would be largely that of the residual air left in the tank on the subsequent evacuation, the partial pressure of the water vapor being very materially lower than the total pressure. The drying under these conditions will not be at the same rate nor will the final dryness be the same as it would be if the oven were filled with water vapor, since the final degree of drying is more nearly a function of the partial pressure of the water vapor in the oven than of the total pressure as read on the vacuum gauge.

Although, for the above reasons, we cannot expect to find the relations between the moisture content or dielectric properties on the one hand, and the drying pressures on the other to be the same for our conditions as for those of the authors, it is practical to make comparison between the measured amount of water and the calculated minimum values corresponding to different power factors. This comparison is given in table I of this discussion.

Table I—Moisture Content Versus Power Factor

Power Factor, Per Cent	Per Cent Moisture Content: Calculated (Minimum) 100° C	Estimated From Measurements 110° C	Measured 100° C
3	0.26	1.5	1.7
2	0.23	1.4	1.6
1	0.18	0.95	1.2
0.5	0.13	0.45	0.6

The first column shows power factors, the second column the corresponding per cent moisture taken from the curves given in the paper, and the third shows per cent moisture obtained by our measurements. The figures in the fourth column were obtained from our power factor-moisture content curves by calculation on the basis of the temperature coefficient of power factor of dry paper.

It will be seen that the measured quantities of moisture are several times the minimum values determined by calculation, and comparison with the additional data given in Whitehead's presentation indicates that they are of the same order as the calculated maximum values. Our measurements were not so precise as we would have liked, and we have now under way measurements on a commercial length of cable which will give more accurate information.

Louis Meyerhoff (General Cable Corp., Perth Amboy, N. J.): In table V the authors have tabulated the measured expansion of the component parts of their samples as a result of temperature change. From these data it may be calculated readily that the average coefficient of expansion of the inner brass electrode over the range of from 16.2 to 100.3 degrees centigrade is

31×10^{-6} per degree. In the range from 16.2 to 41.8 degrees centigrade the coefficient is 50×10^{-6}, dropping to 18×10^{-6} in the range from 73.5 to 100.3 degrees centigrade.

The average value of 31×10^{-6} found by the authors for the coefficient of expansion of their brass electrode does not agree with values given for brass in standard physical tables, which give for nearly all types of brass a coefficient in the neighborhood of 19×10^{-6} over the range from 0 to 100 degrees centigrade. The drop in coefficient from 50×10^{-6} to 18×10^{-6} as temperature increases is also contrary to what would be expected from generally accepted ideas as to the behavior of metals under going thermal changes. We have given the matter some thought, but have not been able to think of a reasonable explanation. Perhaps the authors can explain this.

Additional analysis clarifies the discussion of dielectric constant with temperature. In figure 20 of the paper it is shown that the geometric capacitance has increased about 5.1 per cent as a result of a temperature increase from 22 to 100 degrees centigrade. In the same range of temperature the insulation thickness of 60 mils has been reduced by about 2.8 mils or 4.7 per cent, the external diameter remaining constant, this decrease in thickness resulting from an increase of the inner electrode diameter of only about 0.22 per cent. By taking into account change in dimensions, the authors find according to figure 25 that the dielectric constant remains substantially the same at all temperatures within the given range. As the specimen is heated from 22 to 100 degrees centigrade, the given mass of paper is compressed in thickness from 60 mils to 57.2 mils, the total volume occupied by the paper being reduced by about 4.6 per cent. In other words, the expansion of the inner electrode, the outer electrode remaining unchanged, not only increases the "electrode system capacitance" as taken into account by the authors, but also increases the specific gravity of the insulation. Data obtained in our laboratory several years ago show that, for an increase in specific gravity of dry paper insulation in the ratio of 1.046 to 1, there is an increase of about $6^1/_2$ per cent in the dielectric constant. The data given in the paper show that the dielectric constant of the specimen has remained substantially constant in spite of this increase in specific gravity. From this it follows that had the insulation retained its original dimensions, the authors' results would have shown a *decrease* of $6^1/_2$ per cent in dielectric constant with *increase* in temperature from 22 to 100 degrees centigrade. This would indicate a *negative* coefficient of capacitance change with temperature as large as the apparent *positive* coefficient.

If the expansion of the inner electrode were only as great as would correspond to the generally accepted coefficient of expansion, it would much more nearly account for the data obtained on capacitance change with temperature.

In calculating moisture content on the basis of observed data the authors use a value of 48 for the dielectric constant of water at 100 degrees centigrade. This agrees with a formula given in the International Critical Tables, volume VI, page 78, which is $\epsilon = 80 - 0.4(t - 20°)$, where ϵ is the dielectric constant of water and t is the temperature in degrees centigrade. According to this formula the dielectric constant is widely different for different temperatures, being, in particular, 80 at 20 degrees centigrade and 48 at 100 degrees centigrade. This furnishes a basis for suggesting that 2 sets of measurements, one at 100 degrees centigrade and one at 20 degrees centigrade, the drying being done at one temperature of course, would produce an additional equation or set of equations with regard to the effect of moisture content on the electrical properties. On the basis of the analysis used by the authors, the value of $C_\infty - C_0$ should be much greater at 20 degrees centigrade than at 100 due to the much higher value of dielectric constant of water. The curves of figures 17 show that there is a greater difference between 60 cycle and geometric capacitance at low than at high temperature, which indicates that it is quite likely that $C_\infty - C_0$ is also greater at low than at high temperature, and this is in line with the above mentioned expectation on the basis of the dielectric constant of water. On the contrary, all effects which we have noted as results of moisture content have been in the direction of increasing effect with increasing temperature. However, our data have been only at 60 cycles and perhaps are not pertinent in this connection. At any rate, systematic measurement at more than one temperature may form the basis of an additional check on the authors' very interesting explanation of the effect of water on the basis of the simple constant of the materials.

If the authors have in contemplation any further work along this line, it will be desirable to give consideration to an arrangement for weighing or otherwise measuring the extracted moisture. By having actual measurements of moisture content, as well as the mathematical maximum and minimum values as determined from electrical measurements at two temperatures, it should be possible to add much to the clearness of the picture as to the probable distribution of moisture in paper.

Herman Halperin (Commonwealth Edison Co., Chicago, Ill.): I found the article by the authors quite interesting, but I was disturbed when I came to the end where the authors state that it appears highly probable "that the increases of capacitance with temperature frequently noted in both cables and laboratory samples are caused by corresponding temperature changes in the dimensions of the electrode systems."

As indicated in the following, this is not corroborated by observations of changes of the capacitance of cable with temperature obtained on 9 samples of 750,000-circular mil, single-conductor 69-kv solid type cables during 54 cycles of accelerated aging tests conducted by the Commonwealth Edison Company.

The increases in capacitance observed on 8 cables during a heating cycle from 25 to 70 degrees centigrade, copper temperature, varied from 0.01 to 0.21 per cent per degree centigrade, i. e., total increases in capacitance as large as $9^1/_2$ per cent. The calculated increase in geometric capacitance of the cables was only about 0.004 per cent per degree centigrade. This latter value was calculated on the assumptions that the diameter of the sheath remained constant after the initial expansion and that only the conductor expanded both radially and longitudinally. The measured changes in capacitance were, therefore, much larger than could be accounted for by geometrical changes.

Since all cables had the same dimensions, it would be expected that temperature changes would cause about the same percentage changes in capacitance for the various cables if geometrical changes were the main cause of the change in capacitance. Actually, the changes in capacitance varied for the cables from 0.01 to 0.21 per cent per degree centigrade.

Instead of the minimum values of capacitance occurring at the minimum temperature, as would be expected from the authors' hypothesis, the minimum values were in all but one case found to occur between 30 and 50 degrees centigrade during heating.

For one cable, the maximum capacitances in 14 heating cycles occurred after cooling down to room temperature, instead of occurring at maximum temperature in line with the authors' ideas; in 7 additional cycles there were 2 maxima in each cycle, one at elevated temperature and one at 30 degrees centigrade while cooling.

There are 3 important differences between the samples discussed by the authors and ordinary cable. First, the diameters of the sheaths of the laboratory samples were practically fixed by binding them with linen thread and by providing longitudinal slots which closed on heating, while cable sheath is cylindrical and is, therefore, subject to the normal thermal expansion of a cylinder. Second, the insulation of the laboratory samples was dry paper, while that of cable contained oil or compound which had a relatively high coefficient of expansion. These differences would lower the theoretical change in capacitance to less than 0.004 per cent per degree centigrade, thus widening the gap between the theoretical and measured changes.

Further, the ratio b/a, that is, ratio of the diameter over the insulation to diameter over the conductor, is about 1.04 for the samples discussed by the authors, while this ratio was about 2.5 for the 66 kv cables on which capacitance measurements were made. From figure 22 of the paper showing capacitance versus the ratio b/a it appears that a value of b/a of 1.04 falls in a portion of the curve where little change in b/a causes a comparatively large change in capacitance, while for a value of 2.5 as for the cables a small change in b/a causes a very small change in capacitance.

Based on these considerations, it appears that the changes in the capacitance of impregnated-paper insulated cable with changes in temperature are due only in small part to thermal changes in the dimensions. Changes in the characteristics of the dielectric itself with temperature are apparently most important.

R. J. Wiseman (Okonite Co., Passaic, N. J.): As a cable manufacturer I always read with great interest papers written by Dr. Whitehead in order to be certain that we have not missed anything in our manfacturing processes. I think the present paper is a very valuable one to cable manufacturers; in fact, it is a sort of a pat on

the back to the latter as it confirms their drying processes. Figures 1, 2, and 3 give curves of change in power factor and capacitance with time and pressure of drying at 100 degrees centigrade. Note that the power factor and capacitance at 1 millimeter pressure are not much different than at 10 millimeters pressure. All manufacturers get about 4 to 5 millimeters pressure when drying cables in large tanks, whereas the authors' samples were dried and tested in a laboratory. These curves show us that it would not be worth while to go to the expense of obtaining 1 millimeter pressure. Also, they help us to assure the cable purchaser that we do thoroughly dry our cables before we impregnate them with oil. When we come to oil filled cables, we can work to much lower pressures—about 50 microns because of the nature of the cable design and the way it is handled, namely, in a lead sheath. Here again we are able to dry our cables thoroughly. I am quite interested in the values of residual moisture as a function of drying pressures as shown in figure 10. The authors computed the moisture content from their test data. I think this is unique. I wish they had also determined it by the well-known physical methods and compared results. According to actual measurements of moisture content of the paper after impregnation and then removal of the oil, we get lower values than are possible according to the curve in figure 10. This may be due to a slightly higher drying temperature that we use. If we assume lower moisture contents than shown in figure 10, then according to figure 11 we should get lower power factors, and we actually do—on dry cables about 0.2 to 0.3 per cent power factor, 0.002 to 0.003 on the scale shown in figure 11.

W. A. Del Mar (Habirshaw Cable and Wire Corp., Yonkers, N. Y.): The formula for the calculation of minimum moisture content is exceedingly interesting and may have applications to other forms of insulation than dry paper. For instance, it might be of great value in the estimation of moisture content of rubber compounds. It would add greatly to the value of the paper if the authors would give either the derivation of the formula or the assumptions upon which the formula is based.

It is obvious that the distribution of moisture in the insulation is unknown. Two extreme conditions may therefore be assumed, one where the moisture is in series with the remainder of the insulation and the other where it is in parallel. Formulas based on these 2 assumptions would seem to give the extremes between which the true moisture content must lie.

A very similar formula to that given in the paper may be derived by considering the moisture to occupy the entire space, but to be attenuated in specific inductive capacity proportionately to its expanded volume. We might refer to this as a ghost condenser. The other condenser would consist of the dry cellulose fibers and might be called a skeleton condenser. If we imagine the ghost and the skeleton to be superimposed, we have the 2 condensers in parallel and their joint capacity is related to the moisture content as in the authors' formula for M except that -1 does not appear after K_w. This would have very little effect on the numerical value of M as K_w is of the order of 48.

I am able to add a few words in substantiation of the discussion by Roper (Electrical Engineering, March 1935, pages 323–4). Some cable which has been on test on the Commonwealth Edison Company's system for 9 years at about 60 per cent over its rated voltage has been removed and power factor tests made, both of the entire cable and of the individual tapes. It was found that the increase in power factor suffered by the entire cable was many times as great as that suffered by the individual tapes. This can only be interpreted as showing that the deterioration of a cable in service takes place principally in the oil between tapes.

G. M. L. Sommerman (American Steel and Wire Co., Worcester, Mass.): This paper is another in a series of contributions by Doctor Whitehead and his associates in which, by careful control of experimental conditions and accurate measuring technique, they have been able to deduce a number of correlations in the basic properties of a product too often thought to be incapable of rational explanation.

It appears that the relationships between the various electrical properties and moisture, while very striking, can be stated only qualitatively as yet. The amounts of moisture calculated are admittedly probable minimum values. It has been assumed apparently that the moisture is distributed in sheets parallel to the electric field, since this distribution will give the formula for M used. This formula can be put in the form

$$M_p = 100 \frac{K_0}{K_w - 1} \frac{C_\infty - C_0}{C_0} \tag{1}$$

which, for the values used in the paper, reduces to

$$M_p = 5.0 \frac{C_\infty - C_0}{C_0} \tag{2}$$

If the moisture is assumed to be in series distribution, i. e., in thin sheets bounded by equipotential surfaces, a corresponding formula, true for any electrode system, can be derived, thus

$$M_s = 100 \frac{K_w}{K_w - 1} \cdot \frac{1}{K_\infty} \cdot \frac{C_\infty - C_0}{C_0} \tag{3}$$

which, for the same values, gives

$$M_s \sim 42 \frac{C_0}{C_\infty - C_0} \tag{4}$$

Since the moisture is actually distributed along the walls of capillaries largely perpendicular to the field, the actual effect will be somewhere between those for series and parallel distributions, of the order of

$$M_a \sim 20 \frac{C_\infty - C_0}{C_0} \tag{5}$$

It would be interesting to check this figure, since the range of possible variation is rather large, by actual tests for moisture content, such as the standard xylol test. A rough idea of its correctness can be obtained by calculating the moisture content at the beginning of the drying run at 110 degrees centigrade, figure 1 of the paper, at which time $C_\infty = 973$ micromicrofarads. The results are $M_p = 1.2$, $M_s = 10$, and $M_a = 5$ per cent. The last figure is about right since some of the original probable 10 per cent of moisture is removed in heating the specimen up to 110 degrees centigrade.

It also appears that K_w, the dielectric constant of water, may vary considerably with the degree of dryness. Leaving out of consideration chemically combined water, the water present at the condition of greatest dryness is a monomolecular film of adsorbed moisture. These water molecules are probably so tightly bound that they cannot orient appreciably with an applied electric field, so that the dielectric constant is probably little higher than that of electronic polarization only, or about 2. For subsequent adsorbed layers, the forces of attraction are reduced more and more, and the increased freedom of motion gives rise to higher values of dielectric constant, and finally, for the most loosely held water, the full value of 80 is approached asymptotically. Such a variation of the dielectric constant of water with its concentration naturally leads to departures from the linear relation between moisture content and capacity change exemplified in equations 2, 4, and 5. It is interesting to note that the departure is much less for the series distribution (equation 3) than for the parallel distribution (equation 1). The actual behavior can, of course, be checked by the direct tests for moisture content.

Cable System Neutral Grounding Impedance

Discussion of a paper by J. E. Clem published in the January 1935 issue, pages 30–40, and presented for oral discussion at the cables session of the winter convention, New York, N. Y., January 24, 1935. Other discussions of this paper were published in the March 1935 issue, page 324.

F. O. Wollaston (Commonwealth Edison Co., Chicago, Ill.): The author's theory applied to the 12 kv system of the Commonwealth Edison Company indicates that with the present 3 ohm neutral resistances, the arcing ground overvoltages would not exceed about 2.3 times normal. This result is not in accord with operating experience. At least 30 per cent of the 12 kv line failures cause overvoltages in excess of 3.2 times normal. This indicates that the proposed criterion for effectively grounded systems is based on the wrong assumptions.

The overvoltages on the 12 kv system were measured by needle gaps connected to some substation busses distributed through the system. The gaps have timing devices which record the time of occurrence of each surge, so that they can be correlated with other occurrences on the system. In the 5 year period ending December 1932, 87 surges were recorded which exceeded 3.2 times normal, and 72 of these were definitely correlated as occurring at the time of line or apparatus failures. The records of line failures show that only about 2 out of the 50 or so 12 kv line failures per year cause a simultaneous or secondary failure in another 12 kv line. These secondary failures invariably occur in cable or joints having insulation of poor quality and so it appears that the surges are relatively harm-

less with the present neutral resistance of 3 ohms. Insulation of fair to excellent quality has never failed from transient voltages on our system.

The data justify the suspicion that there is an element of risk in adopting the proposed criterion, which suspicion is not dispelled by careful reading of the paper. If the resistance per neutral were to be increased from 3 ohms to the theoretical maximum safe value of 21 ohms, calculated from the author's formula, then the overvoltages might become definitely hazardous both to cables and to terminal apparatus. The author states that switching surges would not be increased if our neutral resistance were increased. This statement, if reliable, would dispose of the element of risk if all the surges measured by our spark gaps were switching surges. However, so little is definitely known about system transients that there is no justification for assuming that we are getting nothing but switching surges under fault conditions. We are going to make a more detailed analysis of our data to determine, if possible, the conditions under which the higher transient voltages occur.

In one test on an artificial transmission line (see figure 113, "Electric Transients," Magnusson, Kalin, and Tolmie, first edition) recurrent overvoltages of about $2^1/_4$ times normal occurred through some action of the circuit which was distinctly different from the theory of this paper. The results were equivalent to obtaining $2^1/_2$ times normal voltage on the faulted phase of a 3 phase line with solidly grounded neutral. In cables under fault conditions the electrical circuit has distributed resistance, inductance, and capacitance, and an arc in shunt which represents a highly variable conductance. With the conductance of the arc varying erratically between zero and infinity, an infinite variety of both traveling waves and oscillations may occur, which may reach dangerously high values under some conditions. There is still a good deal of theoretical work and field experimentation to be done before the subject of transients on cable conductors and permissible maximum neutral impedances is satisfactorily settled.

It is news to us to find the author's statement (page 33, column 1) that the operating engineers have tentatively accepted the proposal of the Insulated Power Cable Engineers Association to consider that the limiting safe value of calculated arcing ground overvoltages is 3 times normal. This limit for overvoltages lasting perhaps a few seconds seems unnecessarily conservative in view of our operating experience and the fact that each reel of high voltage cable at the factory withstands a test of about 4 times normal for 15 minutes, and representative samples withstand tests of about 4 times normal for 6 hours.

There are some errors in table V, which deals with the system of the Commonwealth Edison Company. The values in item 1*a* are microfarads, not millifarads. These figures, which are obscurely referred to as values of LK, are values of C_a as defined in the paper. Thus x_a and the resistances in item 4 can be readily calculated from the proposed formula $R = 1.15X_a$, and it will be found that the figures given in item 4 are erroneous. The correct values, reading from left to right, are 34, 21, 537, 654, and 495 ohms. An item of information which should have been given is that the frequency is 25 cycles for the 9 kv system, and 60 cycles for the others. The 9 kv and 12 kv systems are each normally operated in 2 independent parts with only one neutral on each part, the total LK and kilovoltampere shown in items 1*a* and 1*b* being divided between the 2 parts.

R. D. Evans (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The author has presented a formula for giving the relation between system constants to limit the voltage to ground to 3 times normal. The formula is based on the theory of arcing grounds, that is, the phenomenon in which overvoltages are produced by cumulative action of alternate initiation and suppression of an arc to ground. It is evident that the value of the paper depends largely on the prevalence of cumulative arcing grounds. As indicated in the paper, the theory of cumulative arcing grounds is subject to an increasing amount of skepticism. In 1931 Eaton, Peck, and Dunham reported the results of certain tests whose object was to obtain data on cumulative arcing phenomena on aerial lines, but it was found that the voltages with unstable arcs were no higher than with stable arcs.

In supporting his theory Clem cites the early operating experiences with ungrounded neutral systems. While there is no doubt that overvoltages were encountered in the operation of extensive ungrounded neutral systems with aerial lines, we fail to see that it is permissible to draw the conclusion that these voltages were necessarily the result of the mechanism which he has assumed. Overvoltages from grounds and switching operations have been recorded which are comparable in magnitude to the values of cumulative arcing ground voltages calculated according to the theory which assumes that the arc characteristic changes are governed by the fundamental frequency wave. Overvoltages of about this magnitude have been obtained by artificially made grounds in staged tests.

P. A. Jeanne (Bell Telephone Laboratories, Inc., New York, N. Y.): The term c_m in formula 1 of the paper is defined as the average mutual capacitance between pairs of conductors, and later the statement is made that in a 3 phase circuit using shielded cables or single conductor lead sheathed cables c_m becomes infinite. By going back to Clem's previous paper on "Arcing Grounds" (A.I.E.E. TRANSACTIONS, volume 49, July 1930, page 986) it will be found that the mathematical definition of the term C_m shows it as the reciprocal of the coefficient relating the charge on one wire to the potential resulting from it on a second wire in the equations which express potential in terms of charges for a multiconductor system. While under this definition C_m becomes infinite for a shielded cable, it is not mutual capacitance in accordance with the usual understanding of the term. It is true that there has not been unanimity of usage of the term "mutual capacity" but I believe it is more commonly understood to mean the capacitance existing between 2 wires either alone or, if in the presence of other conductors, under certain specified conditions regarding the latter. For instance, the definition of mutual capacitance in the proposed American Standard Definitions reads: "Mutual capacitance between 2 conductors is the capacitance between them when the other $(n - 2)$ conductors, including ground, are connected together and then regarded as an ignored conductor." In this sense the mutual capacitance between pairs in a shielded cable would be equal to half the capacitance from conductor to sheath. Thus, while Clem handles the term c_m properly in the formulas, the definition which he gives to it appears to be in error and is likely to be confusing to those who use his paper.

J. M. Dunham (Bell Telephone Laboratories, Inc., New York, N. Y.): In figure 3, page 34, the author has shown the diagram of the discharge circuit which he used in determining the discharge leakage factor $(1 - a)$. My understanding is that this circuit represents the conditions immediately following arc extinction, and for this condition the capacitance to ground of the previously faulted conductor is a part of the discharge circuit. I should like to ask if the effect of the capacitance to ground of the previously faulted conductor should not be included in the determination of the discharge leakage factor.

At the top of page 35, first column, in the definition of C, it is stated that "C is the capacitance to ground and third conductor, when the third conductor is assumed as grounded, of each of 2 conductors in multiple." Since the third conductor is not grounded during discharge I should like to know why this conductor was assumed grounded.

In equations 77, 78, and 79 on page 39 the last term under the radical should not be squared. This, I believe, is a typographical error. In equation 80 which is obtained by dividing equation 79 by equation 78, not equation 73 by equation 72, as stated, it appears to me that a term $\frac{\sqrt{X_m}}{\sqrt{X_s}}$ has been omitted, since the equation as given can only be obtained if $X_s = X_m$. According to definition, these 2 values are not equivalent. I wonder if this is a typographical error and if not whether table V will be changed when the correct ratio $\frac{R_s}{R_m}$ is used.

J. R. Eaton (Consumers Power Co., Jackson, Mich.): This paper refers primarily to overvoltages which may occur on cable systems; however, a previous paper by the same author applies this theory of overvoltages to overhead transmission systems. The author has referred quite briefly to certain staged tests which were made on the Consumers Power Company system and which possibly warrant further discussion at this time.

The major part of this transmission system, consisting of approximately 2,000 miles of overhead lines ranging in voltage from 11 to 140 kv, is operated with the neutral ungrounded; and since the theory points out that such a system should be frequently

subjected to extreme overvoltages, it is only natural that an extensive study of this phenomenon should be undertaken by the company. The field study of this subject was begun in 1930 and is continuing up to the present time.

In all cases, the tests have consisted of measuring the line to ground voltages at the time of line to ground faults on the transmission system. The measurement of voltage has been made by conventional magnetic oscillographs supplemented in practically all cases by surge voltage recorders installed to record any overvoltage of a frequency too great to be recorded by the magnetic oscillographs. The study has included the measurement of voltage during staged tests and during transient fault conditions occurring on the actual operating system. The staged tests have been conducted on lines varying in length from 1.5 to 226 miles, and at line to line voltages ranging from 57 to 140 kv. Various tests have been made to determine the effect of fault locations with reference to other system apparatus, arcs have been established by almost every conceivable method, and check tests have been made with solid ground faults so that no arcing condition existed.

Details of the staged tests have been reported previously ("Field Studies of Arcing Faults on Power Lines," J. R. Eaton, J. K. Peck, and J. M. Dunham, ELECTRICAL ENGINEERING, November 1931, pages 857–60, and "Petersen Coil Tests on 140 Kv System," J. R. North and J. R. Eaton, ELECTRICAL ENGINEERING, January 1934, pages 63–74). A description of the records made during transient conditions on the actual operating system of the company is included in the paper by C. L. Gilkeson and P. A. Jeanne ("Overvoltages on Transmission Lines," ELECTRICAL ENGINEERING, September 1934, pages 1301–9).

In the 74 individual staged tests and the 350 transients occurring on the operating system, there has not been a single case definitely showing the piling up of voltage with the restriking of the arc as required by either the normal frequency or oscillatory frequency arc extinction theories.

Overvoltages of the order of 3.5 times normal have been recorded on the 140 kv operating system, but are accounted for by an entirely different phenomenon. Moreover, the oscillograms of all these faults showed no behavior peculiar to the arcing ground fault as compared with the solid ground fault. The oscillograms of ground fault currents, that is, the current through the arc made during the staged test, very rarely show any tendency of the arc to extinguish and restrike as is required by the arcing ground theory. In a few cases where restriking was noted, the arc had stretched out to the point that it was unstable and was introducing so much resistance into the circuit that voltage to ground on the sound conductors was lower than during a condition of uninterrupted arc current. Arc current was substantially a power frequency sine wave, having superimposed some third and fifth harmonics.

While it is realized that the existence of any condition cannot be disproved by any amount of negative information, we do feel that, if arcing ground overvoltages occur on overhead lines from a trapping of charge on the line as described in the paper, they evidently require some special condition and very rarely exist on the isolated neutral system of this company. We stand ready to make a thorough study of arcing ground overvoltages whenever somebody can show us a method of producing them on a practical operating system. In writing definite standards, it seems very desirable to give serious consideration to field studies of arcing ground voltages rather than relying entirely on a theoretical analysis.

C. A. Powel (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper again draws attention to the unsatisfactory situation in regard to a definition of what constitutes an effectively grounded system. This was recognized by the subject committee on grounding of which I was chairman in its second report submitted in March 1931. (A.I.E.E. TRANSACTIONS, volume 50, Sept. 1931, page 892.) The report included certain definitions to make possible a comparison with the first report, but the committee was not satisfied with them and arranged for a companion paper by R. D. Evans and S. H. Wright ("Some Effects of Unbalanced Faults," ELECTRICAL ENGINEERING, June 1931, pages 415–20) in which it was shown that a system with the neutral of some transformers or generators connected directly to ground might be less effectively grounded than a neighboring system grounded through resistance or reactance. It was suggested that such terms as "solidly grounded" and "reactance grounded" be dropped and that the "degree of grounding" be expressed as the "ratio of the zero sequence impedance to the positive sequence reactance of the system." It is interesting to note that Clem makes use of this ratio in a term in which he evaluates neutral shift in terms of system constants. It would seem, however, that the zero sequence impedance ratio itself presents a more fundamental relationship than neutral shift.

Transient Voltages on Bonded Cable Sheaths

Discussion of a paper by Herman Halperin, J. E. Clem, and K. W. Miller published in the January 1935 issue, pages 73–82, and presented for oral discussion at the cables session of the winter convention, New York, N. Y., January 24, 1935.

E. R. Thomas (The New York Edison Company, New York, N. Y.): In the New York area insulating sheath joints are installed on 100 miles of single conductor cable. The sheath sections are cross-bonded by the Kirke-Searing method. This installation is used on cables operating at 45, 27, and 11 kv. Some of the cable has been in operation since 1928 but to date we have not noticed any effect of a transient voltage of sufficient magnitude to have left any indication of its presence.

This high voltage cable which is operated with cross-bonding connections of the sheath is different in one respect from that discussed by the authors of the paper. The switching operations on the cable are generally confined to other voltages than those at which the cross-bonded cable is operated and, therefore, transformers appear in the electrical circuit as shunt impedances to that part of the circuit which contains the cross-bonded sheaths.

I believe the authors of the paper are to be congratulated in presenting a composite résumé of a subject which is extremely complex in all its phases and I would like to suggest that they might well continue their investigation, particularly to determine what the relative magnitudes of direct current transients may be when cables which have their sheaths cross-bonded are subject to transient voltages incidental with the energizing and discharging of the cables during high voltage tests with rectified current.

Resistance and Reactance of 3-Conductor Cables

Discussion of a paper by E. H. Salter, G. B. Shanklin, and R. J. Wiseman published in the December 1934 issue, pages 1581–9, and presented for oral discussion at the cables session of the winter convention, New York, N. Y., January 24, 1935. Other discussions of this paper were published in the March 1935 issue, pages 324–6.

D. W. Roper (Commonwealth Edison Co., Chicago, Ill.): This paper gives for the first time some interesting technical information regarding the reactance of 3 conductor cable with the belted type of insulation and also of shielded conductor cable of 2 different types of construction. The paper calls attention in a gentle way to the precautions which must be observed in ordering cable of different types to be operated in parallel, but the example given by the authors in the first column on page 1585 of the paper is not well chosen. The example would have been more typical if they had discussed the problem of installing a shielded-type 3-conductor cable in parallel with the 350,000 circular-mil 15-kv cable with belted insulation already in service. This is the type of a problem that is ordinarily met by the utility engineers, as by far the larger portion of 3 conductor cable now installed is of the belted type. Reference to figure 5 of the paper shows that no size of shielded conductor cable will operate in parallel with such a line and properly divide the load without an external reactor in series with the belted type of cable already installed. A reference to this figure will also show that the same comments apply to any of the commercial sizes of cable above 4/0 American wire gauge, or 211,600 circular mils.

One of the alleged advantages of the shielded conductor type of 3 conductor 15 kv cable is that it has a larger carrying capacity, because of the better radiating characteristics and the higher permissible operating temperature; but this type of cable also commands a correspondingly higher price. If the additional carrying capacity of the shielded conductor cable is desired, it can be obtained by using a somewhat larger size conductor in 3 conductor belted cable at practically the same cost

per foot, so that in comparing the total cost of the completed installation of 2 lines using these 2 types of cables, the purchaser is faced with the additional cost of the external reactance to be installed in series with the belted cable already in place, in order to make it divide the load properly with the proposed line of shielded conductor cable without any compensating advantages.

W. H. Cole (The Edison Electric Illuminating Co. of Boston, Mass.): Unfortunately the magnitude of the effects of certain well-known fundamentals are not always known or appreciated at the outset when unusual sizes or types of apparatus, equipment, or transmission lines are under consideration or construction. Such a situation appears to have existed some 5 years ago when The Edison Electric Illuminating Company of Boston proposed to install some shielded type transmission cable of unusually large capacity.

As a result the company found itself, early in 1930, in possession of 2 important station tie line cables which did not measure up to their expected value as transmission units within $40,000 of what the company then had a full right to expect, or if the present design value of a-c losses in equivalent conductor size cables are accepted as a basis, the deficiency amounts to approximately $25,000. These deficiencies are of the order of from 5 to 8 per cent. These costs do not include any allowance for station capacity or changes in external reactors required to produce proper division of load between these cables and older cables already in place.

The events leading up to the discovery of the deficiency are substantially as stated by the authors but are not material to this discussion.

The work performed by the joint group of investigators and the authors of this paper should be very useful in future cable practice if properly interpreted. For instance, the data given in figure 5, in my opinion, support the contention that magnetic material has no substantial value in shielded cable construction. I can hardly imagine a case where an engineer would prefer high reactance cable as a means of effecting proper division of load. Cable lines are frequently altered in length or "cut over" and combined with other cables having possibly different destinations. External and more flexible means of controlling load division should, therefore, usually be preferable to the means inherent to intentionally high reactance cable.

The authors find that compact stranding of conductors reduces radial or contact resistance and thus effects a reduction in proximity effect losses. In view of this result, one might expect still lower proximity effect losses with a solid conductor. Granting that solid conductors are not practicable, we should know by actual test the relative magnitude of proximity effect losses in them.

Early in the progress of the work described by the authors I suggested that by test on a full sized cable model proximity effect losses be determined for solid conductors of large cross section. My purpose was to obtain basic information since at that time there seemed reason to doubt the accuracy of published values. I suggest and hope, therefore, that if the authors cannot cause these fundamental determinations to be made, some university or technical institute may undertake the job.

If both isolated strand and solid conductors are prohibitive types of conductors, we should have reliable data for practicable conductor design so that at least we might know toward which construction extreme the trend should be.

Standardization of Noise Meters

R. G. McCurdy, January 1935 issue, pages 14–5.

Noise Measurements for Engineering Purposes

B. G. Churcher, January 1935 issue, pages 55–65.

Measurement of Noise From Power Transformers

A. P. Fugill, December 1934 issue, pages 1603–8.

Measurement of Noise From Small Motors

C. G. Veinott, December 1934 issue, pages 1624–8.

Quieting Substation Equipment

E. J. Abbott, January 1935 issue, pages 20–6.

Discussion of a group of papers presented for oral discussion at the noise session of the winter convention, New York, N. Y., January 23, 1935.

P. L. Alger (General Electric Co., Schenectady, N. Y.): Everybody knows that the public wants quieter living conditions, as manifested by a growing and insistent demand for quieter apparatus. However, very few know how this need is being met, or are conscious that there is any program for making progress in this new field. This symposium demonstrates the progress that has been made in defining and controlling noise and suggests the further progress which we may expect in the future.

At the Institute's convention in Rochester, N. Y., in May 1931, the possibility of the control of noise by design methods was suggested, and our ability to measure it was demonstrated. However, there was no common language for describing noise, and any real understanding of it was confined to a few laboratory experts. Largely stimulated by the discussion there, subsequent discussions led to the formation in January 1932 of the American Standards Association's sectional committee on acoustical measurements and terminology, which brought out in May 1934 the first draft of a proposed standard, establishing an adequate language for describing noise and a fundamental method of determining the loudness of any sound.

Now, we have presented to us the basis of a proposed standard for noise instruments that will enable measurements made by any one anywhere to be truly compared with past and future measurements. When this standard comes into actual use, we shall for the first time have an industrial technique for measuring noise, which may well mark the birth of the real science of noise control.

Papers also have been presented showing how noise instruments may be used to describe and improve noise conditions, forecasting the imminent general use of numerical loudness to describe noise and to specify required noise levels. It is evident that all industries, such as building, air conditioning, domestic appliance, and others concerned with living conditions, will find it of great advantage to take up the use of these new instruments and to so develop their own testing methods that the noise produced by their apparatus may be clearly specified.

Besides this rapid development in the use of noise instruments and noise specifications that may be expected, we may look for the development of accepted levels of quietness for various living conditions. Just as we have comfort levels of temperature, humidity, and light, so may we expect confort levels of quietness for the home, the office, and the street to be determined by the scientists, and established as measures of desirable quality in all forms of apparatus.

E. J. Abbott (nonmember): The general experience at the laboratory of the University of Michigan agrees well with Churcher's observations. We agree with him that no present meter measures loudness as defined, and that if one wishes to determine this quantity it is necessary to use ear comparisons. We also agree that a scale of loudness in which twice as loud numbers correspond to twice as loud sounds is obtained only with a scale approximately like that given in the appendix of his paper. We also agree that ear judgments seem to be a proper basis for such a scale.

Our differences seem to be largely a matter of degree. In making loudness balances we have usually encountered a range of about 20 decibels among the individual observers, while we have never encountered discrepancies of more than 5 decibels between noise meter measurements and the average judgment of a group of observers. We have not encountered the difficulty with harmonic sounds which he reports, although as mentioned in his paper we did make tests on just this type of tone. Measurements show that the loudness of a combination of harmonic notes can be changed by as much as 10 decibels by altering the relative phases of the components, at least at high levels ("The Influence of Phase on Tone Quality and Loudness,"

E. K. Chapin and F. A. Firestone, *Acoustical Society of America Journal*, January 1934, page 173).

From the engineering viewpoint, perhaps the most practical application of sound measurements is to determine the relative importance of various components or sources of noise in order to know what sounds must be reduced in order to obtain quieting and to locate the parts of the mechanism to which attention must be directed. On the basis of these data, experiments are devised after which measurements are made to determine which sounds are changed and how much. Our experience has been that properly weighted and interpreted sound pressure measurements are very satisfactory for this purpose and that such instrumental measurements are far more valuable than audiometric observations for this class of work. As Fugill has pointed out, specifications based on such data appear to be sufficient to insure a given level of quietness, even though the loudness as determined by a jury of observers is not measured.

In connection with Veinott's paper, we have come to place slight confidence in a single sound measurement taken at any position or in any sort of enclosure, even for relative comparisons. For routine inspection of a given type of product, this can sometimes be accomplished after investigation to make sure that proper comparisons are obtained. For use in connection with development, or for comparisons among different models or different types or sizes of unit, conclusions based on single readings are likely to be very misleading.

In the course of the discussion it was pointed out that 2 transformers which are equally loud nearby are not equally loud at a distance if their frequency analyses are different. This is a direct consequence of the variations in frequency response of the ear with level as indicated in figure 2 of my paper. The different types of noise can be differentiated easily by properly weighted instrumental measurements.

Another of the discussers raised the point as to the relative advantages of frequency analyses and total noise readings. We regard these as supplementary rather than alternate measurements and use either or both, depending on the needs of the problem. This symposium was of great interest to me as it appears that we are passing from a consideration of units, instruments, and scales to the application of sound measurements to practical problems, which after all is the essential engineering feature of sound measurement.

L. J. Gorman (The New York Edison Co., New York, N. Y.): The papers of this symposium treat the problem of noise measurement in electrical equipment in a practical manner. There is no doubt of the urgent need for standardization in noise measuring equipment and in the technique for measuring noise in various classes of machinery. It is believed that the symposium will do much to promote the desired standardization.

Our experience during the past 4 years has given us considerable faith in the noise meter as an aid in the practical solution of noise problems as they occur on our system. These problems include noise and vibration from transformers, blowers, and various substation and utilization equipment. Our experience in this work checks very closely with that reported in the papers by Fugill and Abbott. Our procedure for making noise tests is quite similar to that outlined in these papers.

The greatest difficulty in making noise measurements in the field is to obtain locations where the background or street noise is sufficiently low, even during the quiet periods of the early morning, to give satisfactory test conditions. The best that we can expect is about 30 decibels based on the old reference level or 44 decibels based on the tentative reference. When making tests for total noise on transformers in the yard, the surroundings such as building walls, etc., do not seem to have an important influence provided they are distant 50 feet or more from the transformer. Consideration, however, must be given to standing waves and effects of the deflection of sound, particularly in field tests where measurements are made at considerable distances from the source. If the difference between the total noise and the background noise is 10 decibels or more, the background noise will have no material effect on the result. If the difference is less than 10 decibels, a correction must be made.

It is believed that the present noise instrument design can be improved. C. G. Veinott has suggested 2 or 3 desirable modifications from the standpoint of field use. These include a flat frequency response with provision for cutting in a weighting network, and head phones arranged so that the noise can be heard while the reading is taken. The quality index suggested in his paper is often very helpful in measuring total noise where a complete frequency analysis is not warranted. We have found it advantageous to use something quite similar in several of our noise investigations. However, a good analyzer is an essential part of every noise measuring equipment.

The question of a standard of noise and a practical procedure for calibrating and checking noise instruments is of fundamental importance. In so far as we know, there are no authoritative standards by which one manufacturer can make his noise instrument agree with another of different manufacture. There are no practical means by which the purchaser of a noise instrument can be assured that its calibration will agree with one of a different make. As shown by Fugill, instruments of different manufacture may disagree by as much as 8 decibels. Experience has shown that the noise instrument is practical but there is an urgent need for a little standardization in the matter of calibration.

We are now discussing noise measurements in terms of the tentative reference intensity of 10^{-16} watts per square centimeter, corresponding to a pressure reference level of 0.0002 dyne per square centimeter. There are numerous field data on noise based on the reference of 0.001 dyne per square centimeter, and it is believed that there are still in use many noise instruments in which the scale is based on the old reference. When comparisons are made between data based on the old and new reference levels, there is likely to be some confusion unless the difference is kept in mind. The change in reference level has the effect of increasing the noise scale approximately 14 decibels; that is, the scale reading for a given noise based on a reference level of 0.0002 dyne per square centimeter will be 14 decibels higher than the same noise measured with reference to a level of 0.001 dyne per square centimeter.

Our most difficult noise problems have been with comparatively quiet equipment located where the noise is transmitted by vibrations set up in floors and building framework. For this reason, vibration and its measurement and treatment should be very closely correlated with noise studies on electrical and other machinery. It is obvious that machinery noise is the result of some form of mechanical vibration. It seems probable that some relationship can be established and a procedure determined by which noise conditions could be predicted from a knowledge of the vibration. This would be of particular advantage from a manufacturing standpoint, and in locations where noise measurements are not practicable.

H. Fahnoe (nonmember): The papers by Fugill, Abbott, and Churcher cover a large amount of data on the measurement of noise emitted from transformers. They bring out the facts that standardization of noise instruments and auxiliary equipment is very desirable, that under certain specific conditions fairly consistent results can be obtained, and that the results obtained with commercial noise instruments should be carefully analyzed in order to get the proper interpretation.

Fugill, in addition to presenting the experimental data, even at this early stage of the art, suggests that he is ready to include values for permissible noise of transformers in the purchasing specifications for such equipment.

Granted that in the near future it is possible to measure either the total noise of transformers or its components with a fair degree of accuracy under specified conditions, the art has not progressed so far that the designer can predetermine the noise or the distance that a transformer of a new design can be heard. This holds true whether this measure of noise is expressed in decibels, or average vibrational velocity of tank surface, or average amplitude of tank vibration. The manufacturer may therefore be taking some risk if he accepts a hard and fast noise clause in a specification, since it is frequently next to impossible to correct a noisy transformer without a complete redesign.

For the investigation of noise from transformers, the modern noise instrument is a very valuable apparatus for both the manufacturer and the operator. It has enabled the manufacturer to analyze in great detail the source of noise emitted from transformers and thereby suggested remedies for its reduction.

The major fundamental source of transformer noise is the core. In a well built transformer, the tank vibrations caused by the load current are in general only of fundamental frequency (120 cycles in a 60 cycle transformer) and these vibrations are relatively small compared to the vibrations caused by the excitation of the core at the flux densities generally used in power transformers. The core is practically the sole generator of the even and odd harmonic

vibrations present. Depending upon the quality of the steel used in the core, the higher harmonics decrease rapidly with decrease in flux density, leaving the fundamental and second harmonic as the principal vibrations transmitted to the tank surface. Because of the large number of requirements of the tank construction, it is exceedingly difficult to predetermine its vibrational characteristics. A certain amount of experimental data has been obtained which may guide the designer, but the possibility of obtaining partial resonance of a certain wall or cover section is always present.

From the manufacturer's standpoint, the method of specifying transformer noise as decibel "total noise" has many objections from a test standpoint. With the core worked at such a flux density that practically only the first and second harmonics are present, the "total noise" measured with a noise instrument at a relatively large number of locations around the transformer will in general be closely related to the distance at which the transformer can be heard in free space. However, if large extraneous noises are present or interference patterns are produced from surrounding buildings, the "total noise" measurements are of little value. Such measurements should therefore be made in a relatively large open space. Since it would not always be possible to make the test at a definite date, due to unfavorable weather conditions, etc., this method would frequently interfere with the production schedule. Fugill mentions the possibility of making such tests inside the manufacturer's factory buildings at night. In general, the testing department is located close to the generating equipment supplying power to the test. The noise from the rotating machinery will practically completely mask the noise coming from the transformer. We have found that even with the transformer located nearly centrally in a separate large building, such a large number of interference patterns are produced that the "total noise" measured has no relation to the distance the transformer can be heard.

In our investigation we have made great use of measuring the vibrational velocities of the vibrating surfaces by means of a vibration pickup connected to the noise instrument. Where these vibrations have been reduced principally to fundamental and second harmonics, our data seem to indicate that such values when properly weighted will represent some measure of the distance at which the transformer can be heard. These measurements are taken at a large number of regularly spaced points of the tank surface, and where only 2 frequencies are involved, the readings can be taken in a relatively short time. For instance, a 6,000-kva, 3-phase 13,200-volt transformer was analyzed in approximately 4 hours. These measurements of course can be taken in any suitable location except for stray fields. They also might be taken on customers' premises, preferably when it is permissible to disconnect the load. It would have been interesting if Fugill had made such tests on some of the units he investigated, because a considerable amount of experimental data will have to be obtained before definite conclusions can be drawn as to the suitability of such measurements as a measure of the loudness of a transformer.

Measurement of Noise From Power Transformers

Discussion of a paper by A. P. Fugill published in the December 1934 issue, pages 1603–8, and presented for oral discussion at the noise session of the winter convention, New York, N. Y., January 23, 1935.

E. T. Norris (Ferranti Ltd., Hollinwood, England): We have experimented with noise instruments employing frequency weighting networks, but have not found them satisfactory as yet. A number of subjective audiometers, as described in Churcher's paper, are available in this country, and will no doubt find considerable application. The great difficulty, however, is to determine standard conditions of test which will permit direct comparison between transformers working under different operating conditions. In this connection the results of the third group of investigations being carried out by the author will be awaited with interest.

For analysis work and for the most accurate comparison, we have found it necessary to develop an apparatus in which the noise is analyzed by filtering out each component of frequency. In this way the results of every measurement can be expressed in decibels for each component harmonic. Although such an apparatus is much more cumbersome than the subjective audiometer, it is portable, and has the advantage that the effect of extraneous noises is largely eliminated. With this apparatus the distribution of noise emission over the whole surface of transformer cores has been explored and a similar study made on the completed transformer in its tank. The effects of stiffeners and flanges on the natural frequency of tank side vibrations were studied extensively. Sound measurements have also been made on many transformers of different types and sizes on site during normal operating conditions. For this purpose a sound analyzing apparatus was installed in a motor van and sent on tour.

I notice that the author has measured only the noise emitted from the sides of the transformer. This is not usually of prime importance in the case of apparatus installed in the open air. Very often other apparatus or low walls cut off the noise in that direction. Noise is usually most objectionable to local residents, and particularly so at night when the residents are in bed. We found it necessary, therefore, to examine the noise emission from the cover of the transformer, as in many cases this had a more important effect than the sides.

As an alternative to exploring the noise emission over the whole surface of the transformer by means of microphones situated a few inches from the tank walls, we found measurement along a fixed line 25 yards away and 15 feet high a satisfactory method. The horizontal distance of 25 yards is based on the assumed nearest residence and the height of 15 feet represents a bedroom in that residence. For standard comparative measurements the microphone was arranged on a portable tripod of this height.

It appears from our investigations that there is no single and complete solution to the problem. Since much of the noise emission depends upon the natural frequency of vibration of the mechanical parts of the transformer, any change which removes this natural frequency outside the objectionable audible range in either direction will be an improvement. Thus, transformer radiators and plain nonreinforced tank walls (unless circular) do not usually cause much trouble as their natural frequencies are well below 120 cycles. However, increasing the thickness of the tank wall, or adding stiffeners in order to reduce mechanical vibration, may raise the natural frequency and make matters worse by bringing it into the more audible range. Stiffening and clamping, however, become effective if carried far enough to bring the natural frequency above the audible range.

Noise Measurements for Engineering Purposes

Discussion of a paper by B. G. Churcher published in the January 1935 issue, pages 55–65, and presented for oral discussion at the noise session of the winter convention, New York, N. Y., January 23, 1935.

A. P. Fugill (Detroit Edison Co., Detroit, Mich.): Churcher has presented some pertinent conclusions based upon an extensive series of carefully performed experiments. I am particularly interested in the results of his comparisons of noise measurements by the subjective and objective methods, using, respectively, the audiometer with which the noise being measured is balanced against an adjustable standard reference tone until the 2 are judged equal, and the total noise instrument which sums up the sound energy of the component notes in the measured noise, according to a selected weighting curve and converts the results to a readable electrical quantity. In the remainder of this discussion, I shall refer to the former instrument simply as an audiometer and to the latter as a noise instrument.

As I interpret the paper, the experiments showed that while many types of noise gave essentially equal results by both methods of measurement, certain "harmonic" noises which were checked gave values with the audiometer as much as 30 decibels higher than the results obtained with the noise instrument. In view of the thorough manner in which the investigation was carried out, the volume of data obtained, and the lack of conclusive evidence to the contrary, it seems that we should accept Churcher's findings as indicating that such a discrepancy between the 2 methods of measurement actually does exist for certain types of noise. I am particularly concerned with the effect of this conclusion on the use of the noise instrument for the measurement of noise from power transformers. Unfortunately, Churcher did not include this equipment in his experiment, or at least did not mention the fact in his paper. I have a feeling, however, for reasons which will be mentioned shortly, that, for power transformers, this discrepancy dwindles to an insignificant amount.

Let us grant for the moment that this

difference in results is appreciable and see how that affects the use of the noise instrument for specification and acceptance test purposes. If you wish to specify the tolerable noise in a transformer to be purchased, you cannot refer to a table of average values for motor generators, turbines, automobile traffic, and the rustle of leaves, and choose a value which seems to be about what you would like. The best way to determine the

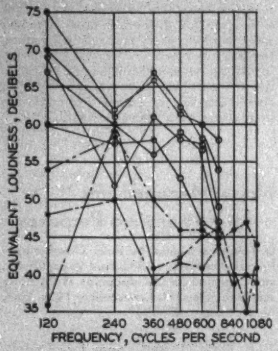

Fig. 1. Analysis of power transformer noise

○ 500-kva single-phase units
● 6,000-kva 3-phase units

value to include in your specifications—I almost am tempted to say the only way at the present time—is to select a transformer installation as similar to the proposed one as possible which, by experience or by a concensus of opinion of competent judges, is deemed acceptable as to noise. Then with a noise instrument as we have done, or with any other method of measurement which by experience has proved itself to be reliable, dependable, and accurate for comparisons of noise from similar equipment, measure the noise from the reference unit to obtain a value to be included in the specifications. When the new unit arrives, measurement of noise from it by the same method will determine whether the specification has been met. Obviously to make such technique valid, the instrument used must give results which are compatible with the impressions obtained by ear, even though the power transformers compared are different in general design. We have used instruments to measure the noise from many different designs of transformers, which by analysis of the component notes we know to have quite different sound patterns, and have always found when any comparison by ear was possible that the transformer noises which gave higher readings on the instrument sounded louder to a person listening to them. Whether 2 noises, one from a power transformer and one from a motor generator or turbine, which gave equal results on the noise instrument, would sound equally loud to a person listening to them is really of no practical importance for this particular purpose although it would make the general situation of noise measurement simpler.

It would be necessary, of course, to specify the type of noise instrument used in setting up the specifications and the manufacturer, if he cared to check the noise, would have to use the same type of instrument, but that will be necessary, regardless of the type of instrument used, until such time as calibration standards are adopted and universally accepted. Looking at the situation from the purely practical viewpoint, the use of the noise instrument for specification and acceptance test purposes assures us that, if the specification is met, we will get a transformer essentially as quiet as we asked for, and that is all that is required of any method for this purpose.

I mentioned at the start that perhaps for power transformers this difference between methods might be negligible. I would like to support this statement by a little data which we have collected. I believe Churcher feels that the audiometer method in which a person listens to a noise with one ear and to a reference tone in an earphone with the other duplicates accurately the impressions received by a person listening to a noise with both ears uncovered in the normal manner. I wonder whether this is always true even with the precautions taken to make it so. Granting that it is, however, his results would indicate that if a person judged a harmonic and a nonharmonic noise to be equal, the noise instrument would give a lower reading for the harmonic noise, and the difference might reach 30 decibels in extreme cases. In addition to the measurements of noise from power transformers, we have used the noise instrument to a limited extent to measure noise from gears, motors, fans, turbines, automobiles, and miscellaneous equipment, and have never found any evidence of this effect. Since most of this equipment was in actual service, there was little opportunity for direct comparisons. However, the concensus of opinion of several of our experimenters who have been engaged in this work is that any of these nonharmonic noises which gave a meter reading of from 15 to 30 decibels higher than the noise from a power transformer sounded much louder to the ear. It is not difficult to discern a difference of this amount even after the lapse of a reasonable time. Since it was impossible, of course, under such inadequate methods of comparison to judge equality between noises as close as 5 or 10 decibels, we decided to carry out a few experiments under conditions more favorable for direct comparison. Although we are primarily interested in power transformers, we included other harmonic noises more nearly in the class of the ones Churcher investigated, to see if we could detect the effect he found.

As has been stated many times, the court of last resort in all noise problems is the human ear. To be sure, it is at times a fickle and unreliable judge, but we must admit that if complaints of noisy equipment are received at all, they are on the basis of how the equipment sounds and not on the basis of readings on any instrument. Therefore, we thought it best for the few comparisons we had time to make to allow the individual to listen directly to the noise with both ears, unhindered by any mechanical device. The technique of comparison was very simple and one might say unscientific; but we believe it gave us the facts we were seeking. We merely allowed the experimenter to listen naturally with both ears uncovered to 2 noises alternately; one a harmonic noise and the other nonharmonic. The loudness at the ear was modified by changing the distance from the source or by controlling the volume of the source. When the individual decided that both noises sounded equally loud to him, measurement of each noise was made with the noise instrument and the readings compared. If the effect which Churcher found in his tests were pronounced, for the equipment being compared, wide discrepancies should be found in the 2 comparative readings. During the series of experiments, 4 experimenters made a total of about 60 comparisons for a number of different pieces of equipment, and the average results for each group of similar comparisons were determined. To produce the harmonic noises, we used a 500-kva single-phase oil-immersed self-cooled transformer, 3 100-kva single-phase O.I.S.C. transformers, a small 0.5 kva filament transformer, a 1.25-kva air-cooled induction regulator, and a magnetic loud speaker excited at 60 cycles. To produce the nonharmonic noises we used 3

Table I—Equal Loudness Comparisons Between Harmonic and Nonharmonic Noise, Natural Listening vs. Measurements

Noise Equipment Compared			Number of Readings	Average Results, Decibels*		
				Harmonic Noise	Difference	
Group	Harmonic	Nonharmonic			Range	Average
A....1	500 kva trans.	Automobile engine	10	54	+3 to −3	−0.2
B....1	500 kva trans.	Automobile engine	6	45	+1 to −2	−0.6
C....1	500 kva trans.	Fan on heater	6	48	+2 to −1	−0.5
D....3	100 kva trans.	¼ hp motor	9	40	+7 to 0	+3.0
E....1	100 kva trans.	¼ hp motor	4	42	−1 to −3	−2.5
F....1	1.25 kva ind. reg.	Gas lighter	4	39	+6 to −4	+0.6
G....1	1.25 kva ind. reg.	Universal motor No. 1	3	38	+0 to −3	−1.3
H....1	0.5 kva trans.	Universal motor No. 1	3	45	+7 to +3	+3.3
1	1.25 kva ind. reg.					
I....1	0.5 kva trans.	Universal motor No. 2	6	44	+6 to 0	+3.5
1	1.25 kva ind. reg.					
J....1	Loud speaker	Universal motor No. 2	3	60	+3 to −1	+0.3
K....1	Loud speaker	Universal motor No. 2	4	47	+5 to 0	+1.5

*Results in decibels above the reference pressure o 10.0002 dynes per square centimeter were obtained by average noise instrument measurements for each group after harmonic and nonharmonic noises had been judged equal by ear. The plus sign indicates that the nonharmonic noise gave a higher instrument reading than the harmonic noise.

automobile engines, a fan on a unit steam radiator used for heating, 2 single-phase fractional horse power induction motors, 2 single-phase fractional horse power commutator type universal motors, and a gas lighter for a domestic furnace.

With this method of comparison, we expected to find that a given individual would be unable to repeat his results consistently on check tests, but we were agreeably surprised to discover that this was not the case. Apparently each person had a definite idea as to the values he considered equally loud, even though the noises being compared were radically different in character so that on check comparisons for the same equipment, but under slightly different conditions, he would repeat within 1 or 2 decibels. As would be expected, there was a greater difference in the results of individuals than of the same person on check tests.

The results of the investigation are given in table I of this discussion. The last column giving the average difference in instrument readings for the 2 classes of noise indicates that only in groups *D*, *H*, and *I* did the effect which Churcher found appear, and then the indication was very slight, 3.5 decibels maximum. In all other cases, and particularly for groups *A*, *B*, and *C* involving the power transformers, when the individual judged the 2 noises to be the same the noise instrument gave equal readings. Obviously, this investigation was not extensive enough to offer as conclusive evidence. Considerably more work would be necessary before the results could be used as definite proof. These facts are offered, however, as an indication that for much of the transformer equipment used by power companies perhaps the noise instrument, after all, does give results compatible with the impressions on the human ear even when compared to nonharmonic noises.

There is one factor I should like to mention which is an additional reason why this might be so. Churcher points out that the fewer the component notes, the less the discrepancy between the 2 methods. Power transformers, and for that matter any distribution transformers we have measured, have 10 or even more measurable components but usually 2 or 3 frequencies predominate. Figure 1 of this discussion shows some analyses of noise from power transformers which are typical for those we have measured. Obviously, the points connected by lines are for one transformer. The magnitude is plotted in terms of equivalent loudness obtained by applying the loudness curves proposed by the American Standards Association, so that each component is shown about as it affects the noise instrument reading. It will be noted that usually 2 or 3 components are about 10 decibels higher than the rest. In all probability, then, power transformer noise compares essentially to the harmonic noises of 2 or 3 components which Churcher measured, and would not show much discrepancy even according to his results.

It is quite clear that much more work, both practical and theoretical, must be done before noise measurement becomes a finished art. The present equipment, however, is an entirely practicable tool and will give satisfactory and correct answers to most noise problems if intelligently used. We personally prefer the noise instrument to any method which depends upon the indefinite character of a pair of human ears, or 2 or 3 pairs, and we believe most power companies will find it more satisfactory. We do not believe that the discoveries Churcher has made invalidate the use of the noise meter for the measurement of the noise of most power equipment, harmonic or nonharmonic. Whether you prefer the audiometer or the noise instrument is of no great importance. The main point is that this equipment is ready for use and unless the power industry and other industries use it in its present form, without waiting until perfection is attained, progress in noise measurement will be unnecessarily retarded.

Control of Transients in Welding Generators

F. B. Hornby, December 1934 issue, pages 1598–1602.

Transient Voltages in Welding Generators

A. R. Miller, September 1934 issue, pages 1296–1301.

Discussion of papers presented for oral discussion at the electric welding session of the winter convention, New York, N. Y., January 23, 1935.

R. E. Hellmund (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The great divergence of opinion on arc welding and entirely opposite points of view was brought home to me very forcibly during a recent trip to Europe when I made inquiries with regard to such questions as a-c versus d-c welding, bare versus covered electrodes, etc. On the continent there is a strong leaning toward welding with direct current and with bare or lightly covered electrodes for everything except high quality work and very special requirements, while in England there is a preference for a-c welding with covered electrodes for all work. However, in view of the many variables entering into this question, it is not at all surprising to find such differences in opinion.

The material to be welded, the material used in the electrodes and more particularly the materials used for the various types of coatings, the size of the electrodes, the character of the structures to be welded, and the uses made thereof, the amount of current used, the characteristics of the current supply, relation of labor to material costs, the skill of the welder, and a great many other variables make the entire problem one that is very confusing indeed. In addition to this, I feel that much of the difference in opinion can be attributed to the fact that a different type of work is expected in each individual case. In many of the discussions carried on by expert engineers, the quality of the weld is stressed as being of greatest importance, which, of course, is the correct point of view in many cases. However, there is a great deal of work in which quality is not as important a factor as the cost of the weld, which in turn is closely tied up with the speed at which the metal can be deposited. It is quite imaginable that for this latter type of work certain characteristics of the power supply would prove very favorable, while for high quality work different characteristics would be preferable.

Although it is generally conceded that for high quality work covered electrodes are to be preferred, there is still considerable difference in opinion as to whether ordinary work can be done more economically with alternating or direct-current, or with bare or covered electrodes. A rather careful analysis carried on in Germany indicates that with the relatively high cost of covered electrodes and relatively low labor rates for the welding operation, decidedly lower costs can be obtained with bare electrodes. In England, it seems to be the opinion that the lowest costs can be obtained with covered electrodes. Recent indications in this country are that for smaller welds, assuming equal sizes of electrodes and the use of direct current, the cost of welding with covered electrodes compares quite favorably with that done with bare electrodes, while for heavy plate welding the cost with bare electrodes seems to be appreciably lower. However, with the somewhat heavier electrode wire which can be used satisfactorily with covered electrodes, it has been found that in some cases welding of $^1/_4$ inch fillets can be done most economically with covered electrodes; in welding $^1/_2$ inch fillets there seems to be little difference; but for larger fillets the cost with covered electrodes still exceeds that with bare electrodes.

With reference to alternating versus direct current, in using very heavy currents alternating seems to compare favorably with direct both in cost and quality, while with smaller currents direct seems to be in general more advantageous, particularly in cost. From these relations it might be concluded that with heavy direct currents the presence of transients would not be objectionable, while with the smaller direct currents they might be disadvantageous. This in turn may be one reason for the differences in opinion.

On the whole, these considerations indicate that investigations and discussions regarding any one of the variables may be of little value unless the other variables in the cases being compared are similar, or at least such that the difference in them can be definitely evaluated. A few interesting articles have recently appeared covering studies of this nature, but I believe that it would be well for the committee on welding to sponsor further papers covering carefully conducted investigations of this nature.

T. M. Linville (General Electric Co., Schenectady, N. Y.): This discussion is presented to show the transient voltages and currents which occur in the split-pole self-excited generator described by Hornby. The analysis is applicable to any welding generator and is similar to that which Miller has presented, although the method is different in many respects. In addition, the writer wishes to compare Hornby's type of generator with the conventional 4 pole generator having a differentially wound series field from a reactance point of view. Moreover, a foremost object of the discussion is to present 2 criteria for comparing, in the case of 2 or more generators,

the relative stability of the arc and the ease with which it can be ignited.

All welding generators consist fundamentally of 2 circuits, the exciting circuit (with constant exciting voltage) and the welding circuit, the latter including the armature and series field of the generator. It is necessary to reduce the magnetic coupling of these 2 circuits in order to produce a good welding machine free from serious transients.

Any discussion of transients ought to be related to their effect upon welding. Hornby concludes his paper by stating that "there is considerable disagreement in regard to the relations between the welding generator characteristics and the production of good welding." However, probably everyone will agree that some surging of current will produce more nearly constant heat at the arc and will result in stronger welds of greater depth. (Ernst Scharz in V.D.I. Zeitschrift, Nov. 15, 1930, volume 74, pages 1565 and 1567, figures 3 and 4, shows photographs of depth of weld showing appreciably deeper welds with a current of 180 amperes when the peaks are 430 amperes than when the peaks are 340 amperes.) However this may be, it is absolutely necessary to limit these surges to the point where the operator may ignite and hold a steady arc without trouble. This latter quality in a welding generator is outstanding. Therefore, analyses such as Miller's applied to actual machines mean a great deal especially when the effect of the transients on the arc stability is known. In this discussion it will be shown how the transients are related to stability.

From these remarks, it is assumed that in designing a welding generator the transients are to be controlled only to the point which will positively insure easy operation for the operator. This does not mean their complete elimination. Such procedure will result in a successful, economical, generator giving the least variation of heat at the weld with a steady, nonsplattering arc, easy to ignite and easy to hold.

Current Transients

Considering the current on sudden changes in arc length or short circuit, the diagrammatic arrangement of windings and connections of the split pole generator have been shown by Hornby in figure 2 of his paper. Let the transient impedance of the field circuit from brush E to brush A be $(r_1 + px_1)$ where p is the operator d/dt, and the total transient impedance of the welding circuit be $(r_2 + px_2)$ exclusive of the arc. Then let x_m be the total mutual inductance between the 2 circuits.

The exciting voltage may be expressed over the working range by

$$e_1 = E + K_2 (i_1 - I_0)$$

where

E = normal open circuit excitation voltage
I_0 = normal open circuit exciting current
i_1 = instantaneous field current
K_2 = volts per ampere of field current
= slope of main pole saturation curve over working range.

Also let

K_3 = slope of main pole saturation curve over working range.
= volts per ampere of armature current.

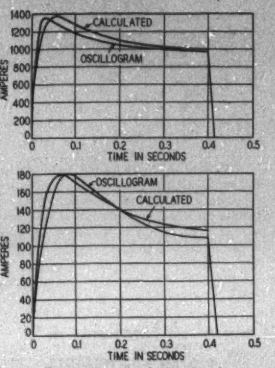

Fig. 1. Comparison of calculated and measured short circuit currents of 400-ampere 40-volt welding generator, 85 volts open circuit

Top: Maximum setting, calculated values from the equation $978 + 837\,\epsilon^{-10.5t} - 1820\,\epsilon^{-56t}$

Bottom: Minimum setting, calculated values from the equation $109 + 164\,\epsilon^{-8.22t} - 273\epsilon^{-56t}$

Finally, the saturation curve of the cross pole is linear where

K_0 = volts per ampere of armature current.
K_1 = volts per ampere of field current.

Then if e_3 is the arc voltage and i_2 the arc current, the voltage equations for the 2 circuits are, for the welding circuit,

$$E + K_2 (i_1 - I_0) + K_1 i_1 + K_3 i_2 - K_0 i_2 = e_2 + (r_2 + px_2)\, i_2 - x_m p i_1 \qquad (1)$$

and for the field circuit

$$E + K_2 (i_1 - I_0) + K_3 i_2 = (r_1 + Px_1)\, i_1 - x_m p i_2 \qquad (2)$$

Short circuit is equivalent to suddenly applying a voltage equal and opposite to e_3 thereby bringing the arc voltage to zero. Therefore, in place of e_3 is written $(e_3 - e_3 1)$ where 1 is the operational unit function. The solution of the equations, resulting directly from application of the expansion theorem, gives for the short circuit current

$$i_2 = \frac{(E - K_3 I_0)\,(r_1 + K_1)}{c} + \frac{(r_1 - K_2 + x_1\alpha_1)\, e_3 \epsilon^{\alpha_1 t}}{\alpha_1\,(2a\alpha_1 + b)} + \frac{(r_1 - K_2 + x_1\alpha_2)\, e_3 \epsilon^{\alpha_2 t}}{\alpha_2\,(2a\alpha_2 + b)} \qquad (3)$$

where
$$a = x_1 x_2 - x_m^2$$
$$b = (r_1 - K_2) x_2 + (r_2 + K_0 - K_3) \times x_1 - (K_2 + K_1 + K_3)\, x_m$$
$$c = (r_2 + K_0 - K_3)\,(r_1 - K_2) - K_2\,(K_2 + K_1)$$
$$\alpha_1 = \sqrt{\frac{-b + (b^2 - 4ac)}{2a}}$$
$$\alpha_2 = \sqrt{\frac{-b - (b^2 - 4ac)}{2a}}$$

The steady state volt-ampere characteristic is given by the first term of equation 3.

Calculations made for a developmental generator are compared in figure 1 of this discussion with the actual current recorded by the oscillograph.

It should be noted that all of the coefficients in the equations can be determined by simple arithmetic from the design data. That is, the inductance of any circuit is proportional to the product of the turns and the slopes of the saturation curves for the 2 poles. It is not strictly necessary to make elaborate calculations for leakage inductances as these can be taken care of by the ordinary factors used for them in routine design.

For the analysis of current surge on sudden change in arc length it is necessary to find an expression for the arc voltage. Seeliger ("Physick der Gasentladunger," page 286) gives for the voltage of an arc between iron electrodes

$$v = 15.5 + 2.5l + \frac{9.4 + 15l}{i} \qquad (4)$$

where l is the length of the arc in millimeters. Ludwig and Silverman ("Arc Stability with D-C Welding Generators," A.I.E.E. Transactions, volume 52, Sept. 1933, pages 987–93) use

$$v = A - Bi$$

for the straight line portion of the characteristic.

The calculation here will be limited to surges along the straight line portion. Therefore, the calculation of current when the arc is drawn out from short circuit is made from equation 1 and 2 substituting $(A1 - e_3)$ for e_3 and $(r_3 - B)$ for r_3. A and B are the coefficients for the Ludwig-Silverman arc characteristic for the length L to which the arc is suddenly drawn.

When the arc is suddenly changed from an initial condition

$$v_0 = A_0 - B i_0$$

the substitutions are

$[(A - A_0)\,1 - e_3 + A_0]$ for e_3

and $(r_3 - B)$ for r_3.

There are 2 impulsive changes, namely, one of e_3 and one of r_3. However, the readjustment of the initial current to the sudden change in r_3 will be neglected. Ordinarily this is satisfactory, for the change in r_3 is small.

Making the above substitution in equations 1 and 2 gives the current for a change in arc length as follows:

$$i_2 = \frac{(-A + E - K_3 I_1)(r_1 - K_2) + (E - K_3 I_0)\,(K_2 + K_1)}{(r_3 - B + K_0 - K_3)\,(r_1 - K_2) - K_2\,(K_2 + K_1)} + \frac{(r_1 - K_2 + x_1\alpha_1)\,(A_0 - A)\epsilon^{\alpha_1 t}}{\alpha_1(2a\alpha_1 + b)} + \frac{(r_1 - K_2 + x_1\alpha_2)\,(A_0 - A)\epsilon^{\alpha_2 t}}{\alpha_2\,(2a\alpha_2 + b)} \qquad (5)$$

where
$$a = x_1 x_2 - x_m^2$$
$$b = (r_1 - K_2)\, x_m + (r_3 - B + K_0 - K) x_m - (k_2 + K_1 + K_2) x_m$$
$$c = (r_1 - B + K_0 - K_3) \times (r_1 - K_2) - K_2\,(K_2 + K_1)$$
$$\alpha_1 = \sqrt{\frac{-b + (b^2 - 4ac)}{2a}}$$
$$\alpha_2 = \sqrt{\frac{-b - (b^2 - 4ac)}{2a}}$$

This equation is useful in predicting the stability of the arc. For example, if values of A_0, A, and B are substituted (representing an arc suddenly drawn out to 10 millimeters from short circuit) and the

resulting current surges negative it is obvious that the arc will go out. If the current surge is entirely along the straight line portion of the arc characteristic, it is equally certain that the arc can be held. Therefore, it is possible to calculate roughly how far the electrodes may be separated and the arc maintained.

Ludwig and Silverman point out that the arc has a transient characteristic as though it was inductive. That is, the transient characteristic is

$$v = A - Bi + L\frac{di}{dt}$$

The inductive term is neglected in deriving equation 5. Its existence makes it doubly certain that a stable arc according to equation 5 will be stable in reality.

Voltage Recovery

When the arc is extinguished, the voltage recovery is calculated assuming the arc to be broken instantaneously. The formulas apply to any initial arc current or for short circuit.

Immediately upon extinguishing the arc there is an instantaneous induced voltage rising to a relatively large value. This kick voltage will help to hold the arc and possibly will restrike it but the important quality of voltage recovery is not a large kick, but a large sustained voltage available instantaneously to hold the arc. When igniting the arc, the machine is short circuited and the terminal voltage is zero. Then the electrode is pulled away from the work drawing out a 25 to 50 volt arc according to how far the electrode is raised from the work and how skillful the operator is. Ordinarily the energy stored in the reactance of the welding circuit is dissipated very quickly and the arc will continue only if the terminal voltage of the generator has recovered to 25 or 50 volts, as the case may be, in the short interval of time. Since the kick voltage is not important and is not harmfully large, it is not concerned in this calculation. It is desired to calculate the generated terminal voltage. When the arc or short circuit is broken this rises at once to 50 per cent or more of full voltage and then builds up exponentially.

The calculation is made by determining the field current at the first instant and its decay, expressing the voltage in terms of this current. Induced current arises instantaneously tending to hold the flux linkages of the field circuit constant.

At the first instant, assuming that the current is suddenly interrupted, the field current is

$$i_1 = I_0 - I_1\frac{x_m}{x_1} \qquad (6)$$

where x_m is the mutual inductance between the field circuit and the welding circuit and x_1 is the self-inductance of the field circuit. The interrupted arc current is I_1 and the initial field current I_0.

The instantaneous voltage rise is given in volts by

$$e_1 = \left(I_0 - I_1\frac{x_m}{x_1}\right)(K_1 + K_2) + E - K_2I_0 \qquad (7)$$

This expression gives practically all of the information desired, the subsequent slow exponential recovery being of no great importance.

The latter can be calculated by determining how the current i_1 behaves. From equations 1 and 2 when the armature circuit is open, there is only

$$E + K_2(i_1 - I_0) = (r_1 + x_1p)i_1$$

The decrement factor governing the field current is, from this equation

$$\alpha = \frac{r_1 - K_2}{x_1}$$

The sustained current is

$$I_1 = \frac{E - K_2I_0}{r_1 - K_2}$$

and the initial current is given by eq 6.

Therefore, the complete equation for the field current is

$$i_1 = \frac{E - K_2I_0}{r_1 - K_2} - \left[\frac{E - K_2I_0}{r_1 - K_2} - I_0 + I_1\frac{x_m}{x_1}\right]\epsilon^{\frac{-(r_1 - K_2)t}{x_1}} \qquad (8)$$

and the complete equation for the voltage recovery is given by

$$e = \frac{(K_1 + K_2)(E - K_2I_0)}{r_1 - K_2} - \left[\frac{E - K_2K_1}{r_1 - K_2} - I_0 + I_1\frac{x_m}{x_1}\right]\times (K_1 + K_2)\,\epsilon^{\frac{-(r_1 - K_2)t}{x_1}} \qquad (9)$$

For any open circuit voltage e_2,

$$I_0 = \frac{e_2}{K_1 + K_2}$$

When the arc length is suddenly changed, unless the arc is extinguished, the voltage must follow the arc characteristic and about as accurately as can be stated this is

$$e_2 = A - Bi_2$$

where A is the coefficient of the arc characteristic for the length to which the arc is suddenly changed, B is the slope of the same arc characteristic, and i_2 is the arc current given by equation 5.

This voltage expression is not necessary since equation 5 already indicates whether the arc will persist or go out. If it goes out the equation fails and equation 9 applies.

Equation 7 discloses the voltages immediately available to hold the arc and its value is the really important quality of voltage recovery.

Figure 2 shows the calculated and actual voltage recovery when the arc is drawn out and extinguished from short circuit, using a high speed breaker to interrupt the circuit. The machine is the same as in figure 1.

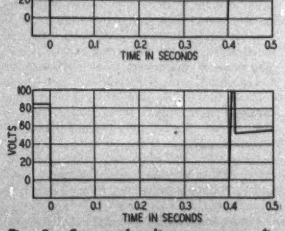

Fig. 2. Curves of voltage recovery after short circuit of the generator of figure 1.

Top: Maximum setting, calculated values from the equation $61 + 24\,(1 - \epsilon^{-2.5t})$

Bottom: Minimum setting, calculated values from the equation $52 + 33\,(1 - \epsilon^{-2.4t})$

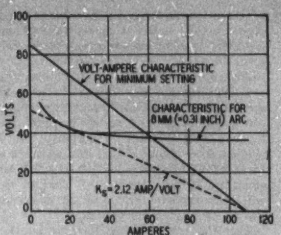

Fig. 3. Ease of ignition and arc stability of split pole welding generator on minimum setting

Arc voltage $= 15.5 + 2.5\,I + \dfrac{9.4 + 15\,I}{I}$

Ignition factor $= I_{SC}/K_S = 109/2.12 = 51$

Stability factor $= I_W/K_SE_W = 75/2.12 \times 25 = 1.4$

Transient Characteristics and Arc Stability

The foregoing has already indicated how the stability of the welding generator may be foretold from the surge current and voltage recovery calculations. It is possible to estimate the stability of the generator by a very simple calculation or test.

Inspection of equations 3 and 5 shows that the surge of current is always substantially proportional to the sudden change in the terminal or arc voltage. Therefore, the surge current can be expressed by

$$i_s = K_s\Delta e$$

where K_s is the amperes per volt and Δe is the sudden change in the voltage. The value of K_s can be determined most simply by measuring the peak short circuit current with an oscillograph or calculating it from equation 3 and dividing by the sudden change in terminal voltage which, in this case, is the initial voltage.

Having determined K_s it is possible to state what freedom of movement of the electrode is possible without extinguishing the arc. For example, in figure 3 of this discussion the volt-ampere characteristic for the generator of figures 1 and 2 is shown. For this generator, K_s is 16. To determine what maximum length and voltage the arc can have when drawn out from sustained short circuit, the slope, $K_s = 16$ amperes per volt, is drawn through the short circuit point on the volt-ampere characteristic. Then the arc characteristic, equation 4, is plotted tangent to the line K_s by trial and error. The value of L fitting the tangent characteristic is the maximum separation of the electrodes possible, without "fluttering" the arc. Actually, since the transient characteristic

of the arc is not identical with the static characteristic as given by equation 4, the electrode may be drawn somewhat farther from the work.

Although this method of determining stability may not give values of maximum arc length and voltage which can be accepted prima facie, it serves to show that K_s is a real measure of stability. It is evident from figure 3 that the position of the tangent arc characteristic is fixed not alone by K_s but also by the slope of the volt-ampere characteristic of the generator and by its open circuit voltage.

Therefore, the criterion for easy ignition for any welding generator, at any setting, is the sustained short circuit current divided by K_s. With those generators having the largest value, it will be easiest to strike the arc.

Likewise after the arc is struck and welding is in progress at any average current I_w and voltage E_w, the criterion is $\frac{I_w}{K_s E_w}$. In this, I_w/K_s is a measure of the permissible sudden change in the voltage of the arc. It becomes a definite criterion when it is related to the average arc voltage E_w. Those generators having the largest values will be able to withstand the greater variations of the arc, such as the passage of molten drops and the unsteady hand of the operator.

Comparison of Split Pole and Conventional Generators

Hornby states that the reactance of the split pole generator is greater than that of the conventional generator having a differential series winding. This difference is actually much greater than his remarks show.

The reactance elements and the total reactance have been carefully calculated for 2 generators and are shown for comparison in table I of this discussion. Generator A is a 2 pole generator with split poles and is self-excited. Generator B is an ordinary 4 pole generator having a differential series winding. Both machines have main pole pieces and armature cores which are exactly alike; both give almost identically the same efficiency; both give the same volt-ampere characteristic; and both require the same watts for excitation. Generator B is separately excited from a 125 volt exciter. Generator A is self-excited from a third brush giving a voltage of about 40 volts.

The inductance values are for the minimum setting of the 2 generators giving approximately 50 amperes at 25 volts. At this setting the series turns are all cut in resulting in the maximum magnetic coupling between the welding circuit and the field circuit. This setting creates the worst transients.

It may be noted that the total transient inductance of the welding circuit for the split pole generator A is 10 times as large as for generator B. The magnetic coupling between the welding circuit and the field circuit is very close (0.94) in the ordinary generator and fairly loose (0.64) in the split pole generator. These differences make it possible to operate the split pole generator without a transformer or series reactor.

The very close coupling (0.94) of the ordinary generator results because on the low current setting practically all of the inductance of the generator is from the series field winding which is wound encircling the same flux paths as the field winding encircles. The calculations were made with the 2 windings wound on the poles in the ordinary close proximity to each other. Of course, for higher current settings when some of the series turns are cut out, the coupling becomes looser in both generators.

Table I—Comparison of Generators

	Generator A Split Pole	Generator B Ordinary 4-Pole
Welding amperes (rated)	400	400
Welding volts (rated)	40	40
Open circuit volts	80	80
Poles	2	4
R.P.M.	1,785	1,785
Core diameter, inches	10	10
Core length, inches	5	5
Flux per pole, maxwells	2.6×10^6	1.3×10^6
Excitation watts	500	500
Self-inductance (henries) of		
Series field winding	0.0120	0.0080
Shunt field winding	1.24	12.5
Armature winding	0.0024	0.00054
Commutating pole winding	0.0030	0.00089
Mutual inductance (henries) between		
Series and shunt field winding	0.084	0.31
Armature and series field winding	0.0003	0
Armature and shunt field winding	0.0015	0
Armature and comm. pole winding	0.0017	0.00043
Total self-inductance of welding circuit (L_w)	0.0146	0.0086
Total self-inductance of field circuit (L_f)	1.24	12.5
Total coupling inductance of field and welding circuits (M)	0.086	0.31
Coefficient of magnetic coupling between the field and the welding circuit ($M/\sqrt{L_f + L_w}$)	0.64	0.94
Total transient inductance of welding circuit ($L_w - M^2/L_f$)	0.0087	0.00087

High Velocity Streams in the Vacuum Arc

Discussion of a paper by E. C. Easton, F. B. Lucas, and F. Creedy published in the November 1934 issue, pages 1454–60, and presented for oral discussion at the electric welding session of the winter convention, New York, N. Y., January 23, 1935.

L. R. Ludwig (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): Two very novel results have been presented by the authors, sufficiently so, that care must be used to be certain of their validity. First, the suggestion that the copper arc may exist in 2 conditions, calls for a little more complete explanation of the way the tests were made than has been given in the paper. Each point for copper plotted in the curves of figures 6, 7, and 8 is presumably the result of a single test. It would be of interest to know if there was any lapse of time, change of material, etc., between test points through which A_I and A_{II} were drawn which might explain the difference. Also, were there any measurements of arc drop? It seems that the tentative interpretation of the results, that is, the existence of the arc in 2 conditions, is too broad, even granting the factual evidence of the double curves. All that one could be certain of is that particles are projected with different mean velocities. They might also have different masses, and therefore not imply a different arc condition. Impurities in the copper or oxide could easily account for the result.

The second novel result is the anode stream. Some doubt seems to be cast on the evidence by the deposit of cadmium on the vane from the shielded electrode in a later test. The transient condition of the arc and the short spacing necessitated by striking the arc by contact also introduce uncertainties. The authors are inclined to a thermal theory of the origin of the streams because of the presence of the anode streams as well as that from the cathode. However, they also state that the velocity of the anode stream is independent of the current, and this is certainly surprising on the basis of a thermal theory. Hence, in following the argument, there seems to be a contradiction. In view of these facts, one cannot be certain of the existence of the anode stream from the data presented.

In the curves in figure 11, the fact that 2 curves are obtained suggests either that the attempted relation is meaningless, or that the relation is correct only in part.

Multiple Lightning Strokes

Discussion of a paper by K. B. McEachron published in the December 1934 issue, pages 1633–7, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935. Other discussions of this paper were published in the March 1935 issue, pages 332–3.

C. L. Fortescue (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The author has done a valuable service in presenting this study of lightning phenomena. It is true that while we are able to predict with some assurance the effect of direct hits on transmission lines and even protected apparatus, we know very little about the mechanism of the lightning stroke itself. The work of Schonland, later confirmed by Lloyd and Morris at Pittsfield, is a valuable contribution to our knowledge of the mechanism of lightning. It is interesting to note that a similar phenomenon has been recorded when a discharge takes place between a point and plane as reported by Allebone, Metro-Vickers. As McEachron says and as I have emphasized in the past, it is important that we increase our knowledge of the mechanism of lightning in order to increase our knowledge of the action and effects of lightning. The necessity of thoroughly shielding a transmission line is only now beginning to be appreciated. Some opposition has been experienced in the past when 2 ground wires instead of one have

been recommended to give good shielding.

It would be interesting to know whether multiple strokes occur mostly with severe strokes or with mild strokes. In connection with multiple strokes, I have been accustomed to say that the interval between successive strokes is about $^1/_{100}$ of a second. It is interesting to note that the smallest interval recorded is $^1/_{60}$ second.

Dr. Harold Norinder has made cathode ray oscillograms of lightning surge on transmission lines in which the effect of successive strokes seems to be indicated. Multiple strokes are certainly a factor which must be given consideration in the design of protector tubes.

C. F. Harding (Purdue University, Lafayette, Ind.): Although photographs and a few oscillographs in the past have indicated that some lightning discharges at least are of a multiple type, the data of this paper certainly confirm that fact and show rather surprising evidences of many more multiple paths than had been previously anticipated. Are we sure, however, that all of these records are actual discharges or may not some of the indications be those of reflections from the end of the line, from substation taps, or from the discharge of other protective devices upon the line?

As it is difficult at present to visualize the phenomena of from 30 to 40 discharges in a single so-called lightning stroke or surge, it is hoped that this valuable research may be continued and be accompanied with traveling wave calculations upon the lines thus recorded to determine, if possible, an adequate theory to explain such. Are such discharges the result of the residual charges upon the same cloud similar to those of the familiar Leyden jar experiment, is the cloud recharged in the interval, or are there a sufficient number of leader strokes to account for the many possible parallel paths to ground at relatively wide intervals of time?

It is not surprising that the negative discharges, which are always more numerous than the positive discharges, seek out the positive half cycles of the power supply. Negative surges have been shown by tests upon an experimental 600 kv tower line at Purdue University to attenuate more rapidly because of the neutralization of energy in corona when superimposed upon the positive half cycle. This is analogous to dumping a gas pressure into a vacuum instead of applying it to the back pressure or corona of a negative half cycle. However, is it not possible that such rapid attenuation may produce an oscillatory traveling wave at other points on the line which may account for some of the subsequent oscillographic records?

Furthermore, the methods of measurement described in this paper, which now bridge the previous time gap between 1,000 microseconds and 0.1 to 0.25 second, are of particular interest. The inability of any instrument to record adequately these time intervals has been a distinct deterrent to complete analysis of many phenomena in the past. R. H. George and C. S. Sprague of Purdue University have developed recently an oscillograph upon which the records of a surge of such a period from switching, accidental grounds, or other unstable operation, are magnetically recorded upon a steel tape which is constantly in motion but whose record is automatically and continuously erased until the surge occurs; at which time relays are set in operation to stop the tape after it has traveled about half its length, thus leaving a record of several seconds preceding and following the disturbance. The record is later reproduced from the tape by suitable amplifiers and the ordinary oscillograph.

With the general purpose cathode ray oscillograph developed by Professor George and described in his paper "A New Type of Hot Cathode Oscillograph and Its Application to the Automatic Recording of Lightning and Switching Surges," A.I.E.E. TRANSACTIONS, volume 48, July 1929, pages 884–90, such a surge record may be automatically initiated within $^1/_4$ microsecond and a length of film, if the recording drum be used, of over 12 feet may be traced by the electron jet to record the subsequent discharges. This paper should have been listed in the bibliography.

Overvoltages on Transmission Lines

Discussion of a paper by C. L. Gilkeson and P. A. Jeanne published in the September 1934 issue, pages 1301–9, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935. Other discussions of this paper were published in the March 1935 issue, page 327.

J. R. Eaton (Consumers Power Co., Jackson, Mich.): In the paper mention is made that the overvoltages on the Consumers Power Company isolated neutral system were of power frequency and could be calculated by the method of symmetrical components. The origin of these overvoltages may be somewhat clarified by reference to figure 1 of this discussion, which is a simplified diagram of a transmission system showing the line to ground capacitance of the conductors at 3 individual points. At a it is assumed that the Z conductor is faulted, and if the fault is assumed to be solid or voltage across the arc is neglected, the voltage of the Z conductor with reference to ground will be zero. The voltages of the X and Y conductors are as shown in the diagram. At point b the voltage of the Z conductor will not be zero but will be of some appreciable value due to the flow of fault current through the impedance of the line conductor between a and b. Therefore, at this point, the voltage of the Z conductor will be approximately as shown. Because the fault current is a capacitance current, the E_Z voltage vector will be in such a position that the delta of line to line voltages will not surround the ground point. At a point c still farther remote from the point of fault the magnitude of the vector E_Z will be increased to such an extent that it may be larger than the voltage of the unfaulted conductor E_X. As may be seen the voltage E_Y on the Y conductor is now several times the normal line to ground voltage. This voltage condition was recorded by many oscillograms during ground fault conditions.

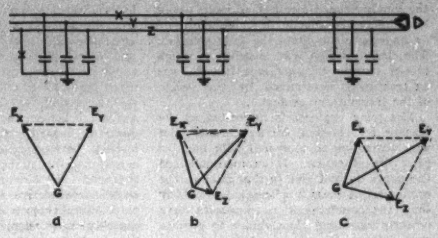

Fig. 1. Simplified diagram of transmission system

A Carrier Current Relay Installation

Discussion of a paper by O. A. Browne and W. L. Vest, Jr., published in the January 1935 issue, pages 109–15, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935. Other discussions of this paper were published in the March 1935 issue, pages 333–4.

H. P. Sleeper (Public Service Electric and Gas Co., Newark, N. J.): Like all new developments this one must be put through a period of trial and test. All operating engineers will be interested in the reasons stated for the changing of the relay system from a standard balanced and time element single line relay scheme to a high speed scheme. The authors state definitely that it was done to minimize damage to lines with resulting interruptions, principally caused by lightning flashovers. Of course, general service conditions would also be improved by the lessened system disturbances from reduced voltage dips as a result of the shortened time of clearing faults. It is also interesting to note that changing the relay scheme was decided to be the cheapest possible method of effecting these results. It is a progressive company indeed which will recognize today the wisdom of spending money solely for an improvement in quality of service to its customers.

It is probable that this particular installation did not offer a typical case where the costs of all available forms of relaying can be

compared directly, but was undoubtedly influenced by the presence of multiended lines, that is, lines with more than 2 terminals each. This, of course, would cause both balanced and distance relay schemes to suffer a disadvantage and cause the sequential clearing of many faults with a resultant increase in fault clearing times. Obviously, the only scheme which would cause the simultaneous clearing of all faults would be a differential scheme, of which pilot wire or its equivalent offers the only solution. The choice of pilot wire relaying, of which carrier current relaying is a branch, was automatically determined by the design of the transmission system.

The relay engineer is interested in the reasons for choosing carrier current pilot wire protection as compared with metallic pilot wire protection. It is unfortunate that the paper did not give further data on the economics of these 2 schemes, particularly since the communication companies have recently expressed their desire to acquire such business by offering attractive rates. Systems in other parts of the country, particularly the south, have found the economics to favor the metallic pilot wire scheme using cables leased from communication companies. It is hoped that the authors will present further data on this phase of the subject.

It is noted that the authors quote 8 cycles as the time setting on phase and ground relays at all terminals. This of course means a total clearing time of approximately 16 cycles (8 cycles breaker time) for any fault on the transmission system. This is a great improvement over the 50 to 60 cycles minimum time quoted for distance relays on the same system, and presumably even higher times with the superseded balanced and single line relaying. It may, therefore, seem trite for the writer to state that the time of 8 cycles for the relays seems long. It must, however, be recalled that modern high speed relays are now available to operate in a time of 1 to 3 cycles and therefore their average operating time is a quarter of that of the relays quoted. The effective reduction in fault clearing time would be, therefore, from 16 cycles to 10 cycles, or a reduction of about 38 per cent. While such time savings are small in magnitude, experience indicates that fault damage progresses as some power of time and can therefore be capitalized.

Scanning the operating results obtained, it will be noted that 87 per cent correct relay operation was obtained in the period indicated. It is appreciated that this covered the period of initial operation and therefore no doubt included many difficulties such as one experiences with any original installation. However, and with no thought of being critical but merely analytical, it would seem that this percentage is low when it is compared with the present day operating results of standard relay schemes, which on most large systems have the percentage of correct relay operations annually in the upper nineties. It would be interesting to relay engineers if the authors were to give further information as to the basic source of the failures and incorrect operations in order that those of us without close contact could more readily analyze the inherent failure probability of carrier current relaying as compared with other commercial relaying schemes.

From a general operating standpoint, it is noted that 51 per cent of all faults were double line faults. This seems very high to the writer and it would be interesting if the authors were to state the causes if data are available, and particularly whether the causes are believed to be mostly initial double faults or single faults communicated to the second line. This latter point is especially pertinent to relay engineers who will agree that modern relaying, with associated high speed circuit interruption, plus, of course, proper tower design, should eliminate almost completely communicated faults on double circuit towers.

Commenting on the relay scheme described, I believe there is an unnecessary operating hazard introduced in the 8 hour interim between the manual operating checks described in the paragraph on "Maintenance." All circuits of other types of standard protective relays are today capable of continuous supervision by proper control circuit design, at practically no additional expense. It would seem that this feature should be capable of incorporation in carrier current relay protection. Another undesirable feature of the equipment described is the necessity of using dynamotors to provide closely regulated alternating potential for the carrier equipment. It would seem that carrier current equipment could be designed so as to be capable of using potential with a commercial variation of ± 5 per cent.

Lastly, it is the writer's opinion that a relay scheme which requires all relays on the system to operate correctly for each fault is fundamentally wrong. The probability of failure is obviously increased directly with the number of relays installed and the percentage of correct operations is bound to be adversely affected, as compared with the scheme where only the relays on the affected section are involved. If such equipment is not commercially available it would seem that the desirability of research work by operating companies and especially manufacturers is indicated.

Lightning Performance of 220 Kv Lines

Discussion of a paper prepared by the lightning and insulator subcommittee of the A.I.E.E. committee on power transmission and distribution published in the November 1934 issue, pages 1443–7, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935.

C. L. Fortescue (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): Except for the Wallenpaupack line no performance records of 220 kv lines have been published. These records have been available to those interested in their performance, but should be published. Of the lines cited in this report, only the following were designed after the theoretical studies of direct stroke were made available:

1. New England Power Co., Comerford-Tewksbury line.
2. Pennsylvania Water and Power Co., Safe Harbor line.
3. Philadelphia Electric Co., 29.6 miles of Plymouth Meeting-Rosedale line.
4. City of Los Angeles line.

Other lower voltage lines which have been built more or less according to new ideas are:

1. Osage River line between St. Louis and Bagnall operating at 138 kv.
2. Cincinnati-Louisville line, 132 kv.
3. Circuit around Indianapolis, 132 kv.

All these lines have shown good lightning records during the short time they have been in service. In each of these, great care was taken to obtain good shielding.

The practice of insetting the ground wire is for economic reasons and the fear of dancing conductors. A small inset apparently does not appreciably reduce the shielding effect of 2 ground wires.

Regarding the matter of tower footing grounds, too much emphasis cannot be laid on the fact that with 220 kv insulation, 14 to 16 insulators, it is imperative to obtain 10 ohms or less if lightning proof operation is to be expected. The alternative is the use of counterpoises. The effect of counterpoises is not yet theoretically well understood, but more ample confirmation of their effectiveness seems to be at hand. I for one am glad that such ample confirmation that the requirement of 12 ohms or less for tower footing resistance is not too low has been presented of late ("Lightning Investigation on a 220 Kv System," Edgar Bell, ELECTRICAL ENGINEERING, August 1934, pages 1188–94, and "Lightning Investigation on Transmission Lines—IV," W. W. Lewis and C. A. Foust, same issue, pages 1180–6). So many engineers have thought in the past that these values were unreasonable and simply plucked out of the air. As an actual fact, quite early in the development of direct stroke theory they appeared as reasonable values for 220 kv lines approaching lightning proof characteristics. No doubt the addition of counterpoises would have a beneficial effect on lines where the tower footing resistances are high, such as the New England line. I wish to emphasize 2 points:

1. Low footing resistance with poor shielding will not give good performance.
2. Good shielding without low tower footing will not give good performance.

A balanced design requires good shielding and tower footing resistance below 10 ohms.

J. T. Lusignan, Jr. (Ohio Brass Co., Mansfield, Ohio): In table II of the paper the new Boulder Dam line of the City of Los Angeles is listed as number 18. While there is no service record to report as yet on this line, perhaps a discussion of the lightning protection and insulation arrangement chosen by the designing engineers would be of interest.

As noted in the table, each circuit is equipped with 2 ground wires. These are arranged, except with greater clearances, as on the Safe Harbor line of the Pennsylvania Water and Power Co., which has had a remarkable lightning record. The counterpoise system on the Boulder Dam line, however, is somewhat more elaborate than any used heretofore. As noted at the bottom of page 1445 it is a combination of both the radial and continuous or parallel types and in effect incorporates the advantages claimed for both of these types.

With the above network for receiving and carrying the currents of all lightning strokes directed toward the conductors, the engineers have calculated the approximate voltage wave which may appear across the insulator strings. In each case, obviously,

Fig. 1. Flashover between shields of insulator string

this will be the difference between the voltage wave of the tower top and the net wave induced on the conductor by the ground wire and counterpoise waves. Assuming a negative stroke of approximately 15,000 kv to be practically the most severe to be encountered, they have determined that the voltage wave from the conductor to the tower, and the one to be sustained by the insulators, rises abruptly to slightly less than 3,000 kv, remains flat for about 2 or 3 microseconds, and then drops rapidly to zero. Accordingly, in all laboratory flashover studies and measurements on line insulation a wave simulating the above was used.

The suspension string chosen, as noted in table II, consists of 24 insulator units of 10 inch diameter and 5 inch spacing. The grading shields finally selected, however, were not the ring arrangement indicated in the table, since at the time the table data were collected rings had only tentatively been chosen. As a result of laboratory studies conducted later a new form of shielding arrangement was developed which proved appreciably simpler, cheaper, and lighter than the rings originally considered. Briefly, the line shield is in the form of a figure 8 with the center line of the 2 loops parallel to and directly above the conductor. The ground electrode is merely a pair of strap horns with ends turned up to prevent corona and to possess as much mass as possible to resist arc fusion.

The above shielding arrangement was designed to perform the following principle functions: protect the conductor and insulator units from arc damage; and eliminate corona on the insulator units. The line and ground electrodes were so shaped and dimensioned that all flashovers occurred between their outer edges and free of the insulator units. The above calculated lightning wave conditions were simulated in these tests by removing all series resistance from the 3,000 kv impulse generator and

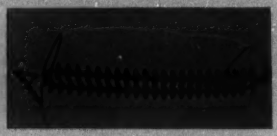

Fig. 2. Flashover test on shields of dead end insulator string

securing a practically flat top wave which reached crest in $^1/_2$ microsecond and caused flashover in approximately 3 microseconds. Figure 1 of this discussion illustrates a typical flashover secured under the above conditions. Since the relaying and switching arrangement of the line is designed so as to interrupt all flashovers within 6 cycles, it is apparent that there is little chance of the arc moving from its initial path between shielding electrodes and free of the insulators and conductor.

A simplified shielding arrangement was developed in the same manner for the dead end insulator strings. Figure 2 illustrates a typical flashover test on the final arrangement chosen. Shielding loops were used only on the upper sides of the strings since it was possible to establish flashovers between them under all circumstances. At the line end of the string the conductor jumper beneath it was found sufficient to provide the proper electrostatic field control on that side for reducing corona, thereby eliminating the need for a double shielding loop there.

Constant-Current D-C Transmission

Discussion of a paper by C. H. Willis, B. D. Bedford, and F. R. Elder published in the January 1935 issue, pages 102–8, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935. Other discussions of this paper were published in the March 1935 issue, pages 327–9.

Herman Halperin (Commonwealth Edison Co., Chicago, Ill.): In considering the use of d-c transmission on a metropolitan system such as that of the Commonwealth Edison Company, one of the first questions is the proper ratio of the direct to alternating voltage for a given thickness of insulation in underground cable. Based on short time breakdown tests at room temperature on either thin laboratory samples of impregnated paper insulation or on short samples of cable, the literature shows that various investigators have found ratios ranging from about 2 to 5. The Association of Edison Illuminating Companies cable specifications give a ratio of 2.4. There are no data for the proper ratios for operating conditions at various temperatures over periods of many years and it would be necessary to obtain such data before d-c transmission can be used on underground cable in a commercial manner on a large scale. Of course, the higher the ratio, the larger would be the increase in carrying capacity of an underground cable by the use of d-c transmission instead of 3 phase a-c transmission.

Assuming a d-c/a-c ratio of 3.0 for our 3-conductor 12-kv cables, the operating voltage may be increased from 12 kv, 3 phase, to about 40 kv for direct current. From what information we have available, it appears that this voltage can probably be satisfactorily withstood in the joints. However, if we assume the same ratio for 66 kv cable, it will probably be necessary to make the joints about 18 inches longer than they now are. This would require lengthening the manholes in many cases, if existing 66 kv lines were used for d-c transmission. Here again it appears that data on the proper d-c/a-c ratio over periods of years are necessary.

Assuming a 4 mile line of 500,000 circular mil 3-conductor 12-kv cable, and a d-c/a-c ratio of 3, then the carrying capacity of this cable in the winter would be increased from about 9,000 kva to about 20,000 kva by going to d-c transmission. The corresponding investment saving in lines would be, roughly, $70,000. This means that for d-c transmission to be economically attractive, the extra installed cost for the use of the conversion apparatus at the 2 ends of the line should be less than $70,000.

There are usually either 2 or 4 of our 66 kv lines between station terminals with the result that the 6 or 12 single conductor 750,000 circular mil cables could be split up into 3 or 6 new d-c transmission lines. Again, assuming a d-c/a-c ratio of 3, the carrying capacity for each cable could be increased in the winter from about 20,000 kva to about 65,000 kva by going to d-c transmission. Using our present costs for our new size of 2,100,000 circular mil 66 kv cables which have a carrying capacity of about 115,000 kva per line in the winter, the investment saving by going to d-c transmission on the existing 750,000 circular mil cables on a typical 6 mile line would be approximately $450,000 for the 2 cables that would be used in the d-c transmission for a converted line. The d-c terminal apparatus would have to be adequate for 230 kv between terminals and about 570 amperes for the d-c side, or about 130,000 kva. With the use of direct current on these lines it would be necessary for such apparatus not only to be satisfactory, but the extra installed cost of the new terminal apparatus including space for it to be less than about $375,000 for each new d-c line, allowing for the cost of rebuilding joints, lengthening manholes, and making changes at the ends of each line.

My impression from a study of the apparatus and from what general information I have received leads to the conclusion that considerably more progress will have to be made before the d-c transmission is economically attractive for converting existing Chicago lines or for the use of such transmission for new lines.

The d-c system does have better possibilities where the lines are longer and it ap-

pears to me that possibly, in time, sufficient progress will be made in reducing the cost that where there may now be a question, for example, as to whether overhead transmission should be used, it will be answered because of the economic gain of d-c transmission on long underground lines.

L. W. Chubb (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper is very interesting and shows some valuable oscillograms under operating conditions. Over 20 years ago, when it was thought that the electrolytic capacitor could be produced and operated at a low cost per kilovolt-ampere. I worked on various systems of d-c transmission, constant current transmission, and multiple power and lighting over the same supply lines. At that time, d-c transmission and constant current transmission seemed rather attractive. They required some type of an inverter; a great deal of work was done and the mercury vapor inverter was developed. At that time it was called a "vacuum type inverted converter" (U.S. patent number 1,347,804).

The monocyclic bridge was used in the constant current transmission system to convert from constant potential to constant current and *vice versa*. This was a single phase monocyclic square using electrolytic capacitors in the capacitance arms, instead of a 3 phase network as shown in the paper. I considered that d-c transmission at constant current would be of importance in transmitting power for great distances. However, the more practical engineers, who knew more about the problems of power transmission and distribution, soon pointed out some of the great disadvantages and we lost our enthusiasm for the various combinations.

Calculations showed no great advantage in line economies. For a direct and constant current, I suggested the use of a single transmission line and ground return. Ground return could, of course, be used, as there would be no telephone interference especially if sufficient inductance were inserted in the line. Then the disadvantages of line insulation were pointed out. A string of high voltage insulators on direct current service has the voltage divided, so that the sections of highest resistance must stand most of the voltage. Any equalization scheme results in some leakage current. Leakage at many points will, of course, be a great disadvantage in a constant current system. Another great disadvantage in the constant current d-c system is that the circuits cannot easily be arranged so that power can be taken off at intermediate points.

After reviewing the features of the constant current and constant potential systems and doing a great deal of experimental work on inverters, electrolytic capacitors, and constant current systems, we came to the conclusion that constant potential alternating current seemed the most practical system, in view of the above disadvantages and the fact that the high power electrolytic capacitor did not give as expected low power factor at reasonable cost per kilovoltampere. The inverter at that time was also new and the development far from complete. With the tools of today, a system such as described by the authors may have some specific applications, such as cable crossings. Here again it seems as though the constant potential d-c system will be the more economical, and safer because overloads with the constant current system result in high voltage on the cable.

On page 107 the authors state that the monocyclic networks cause no undesirable transient conditions. I can remember that this was not true in the case of the constant current systems using single phase monocyclic networks. Under overload conditions the voltage of the constant current side of the network will go up to a high value. On short circuit there must be some such protection as allowing the line to short circuit through a spark gap, or overload breakers in the constant potential line (U.S. patent number 1,270,785).

When the high-voltage constant-current circuit is thus short circuited, on overloads, the condensers in the arms of the monocyclic network are charged to a high voltage and this high impulse voltage is suddenly impressed upon the constant potential circuit. During our experimental work, this serious impulse transient was so severe that it caused sparkovers or breakdown in the constant potential circuit.

The severe voltage kick suggested a similar circuit for making an impulse generator giving definite amplitude. It seems that the 3 phase system will be subject to the same difficulty and give serious punishment to the constant potential circuit and tubes.

It would seem as though in spite of the further development of high voltage rectifiers and inverters, the great disadvantages of the high voltage constant current system are still with us and it is felt that it will not prove economical, except in specific applications, because of the high cost of the static capacitor and inductor kilovoltamperes required.

R. D. Evans (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): In the introductory part of the paper there is some speculation as to the possibilities of d-c transmission. In this connection it may be of interest to review briefly the results of a study made some time ago on d-c versus a-c transmission by aerial lines. An economic comparison was made for transmission over distances from 100 to 400 miles using (1) the conventional a-c system and (2) high voltage d-c transmission with a-c generation and a-c utilization. The comparison was made on the basis of a 2-circuit a-c system and a 3-circuit d-c system, which made it possible for the transmission line to be identical, thus avoiding the possibility of error in figuring the cost of the principal item, the line itself. The a-c system was designed for 230-kv 3-phase 60-cycle operation; the d-c system was designed for operation at 376 kv between lines. Thus the d-c system voltage to ground was taken as equal to the crest of the a-c system voltage to ground, though many engineers question whether so favorable a ratio will actually be obtained. The comparison was based on the transmission of large blocks of power using the most economical loading per circuit and a relatively large conductor.

In view of the fact that rectifiers and inverters of high capacity and voltage are not available commercially, it was decided to express the results of the study in the terms of the maximum permissible cost of the rectifiers and inverters at each end which would make the d-c system competitive with the a-c system. The results are given in the accompanying table.

Transmission Distance, Miles	Maximum Permissible Cost of Conversion Equipment at Each End, Dollars per Kilowatt
100	2.70
200	8.70
300	15.20
400	22.20

These figures were based on the cost of transmission line with capitalized values for losses at $140 per maximum kilowatt plus $160 per average kilowatt assuming a 60 per cent load factor. Transmission costs for the a-c system were based on the line with sectionalizing circuit breakers and intermediate and receiver condensers as required. The transmission costs for the d-c system were based on the line and the conversion apparatus at each end including receiver condensers. The losses chargeable to conversion were estimated at 1 per cent at each end, which incidentally is the figure mentioned by the authors. The conversion losses include not only those in the conversion apparatus itself but also the losses in filters, voltage dividers, exciting transformers, and accessories, and additional losses in the associated transformers.

It is to be noted that the maximum permissible cost for conversion equipment must include not only the first cost of the apparatus but also installation and capitalized figures for maintenance and replacement, since they have no corresponding elements in the a-c system.

With the constant current system described by the authors, it is obvious that the cost elements of the constant potential system are involved and the monocyclic equipment in addition.

C. L. Fortescue (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): For the transmission of large blocks of power over long distances by overhead lines, I think that constant potential d-c transmission will prove to be more economical than constant current transmission. Such lines when laid out with due regard to protection against lightning will rarely suffer short circuits, and, therefore, the advantages of the constant current system in limiting fault currents do not appear to be of much importance.

The authors have stressed the inherent reversibility of power flow in the scheme described in the paper. There are, however, some requirements as to kilovolt-ampere capacity which limit the value of this feature. In a monocyclic square the kilovoltampere capacities in the reactors and capacitors depend upon the network used and the direction of power flow. The networks assumed in the paper include (1) the network of figure 4 for the inverter and (2) the same network for the rectifier but with reactors and capacitors interchanged. The authors point out that the networks for

the rectifier and inverter are not the same and that the preferred network takes less kilovoltampere capacity in inductors and reactors. For unity power factor it is stated that the total kilovoltampere in inductors and in capacitors each amounts to 57 per cent of the transmitted load, these kilovoltampere capacities being required at each end. The authors do not, however, point out that if the direction of power flow is reversed the total kilovoltampere capacity in reactors and capacitors is increased from 57 per cent to 173 per cent at each end. Consequently, the apparatus has a much lower rating for power flowing in the reverse direction than for power flowing in the normal direction. This constitutes a serious limitation in the scheme from the standpoint of inherent action as to reversibility of power flow. With lagging power factor load the kilovoltampere capacities of reactors and capacitors are altered, some being increased, others being decreased. However, the ratio of maximum capacity for the reversed direction of power flow may become many times the kilovoltampere capacity for the normal direction.

It is, of course, possible to perform switching operations and to use the more efficient type of network for each direction of power flow. However, such a system loses some of the apparent advantages of inherent reversibility. These considerations indicate that control of grid potentials will in the future probably be relied upon to provide for reversibility.

R. E. Hellmund and C. F. Wagner (both of Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The possibility of d-c high-voltage transmission has been an interesting speculation for a great many years; however, practical applications have not been forthcoming for the following reasons:

1. Commercial apparatus for the purpose has not been available. (This applied not only to the conversion apparatus but also to other factors, such as relay protecting schemes, lightning arresting devices, line insulators proved to be suitable for a given continuous voltage, etc.)

2. Extensive investigations of the system from an economic point of view indicate that at present d-c transmission has little chance of competing successfully with a-c systems, except perhaps in the transmission of large blocks of power over long distances and possibly in some exceptional cases where transmission by cable is necessary.

This paper points out correctly that some of the problems that have confronted engineers in constant voltage systems present lesser difficulties in the case of a constant current system. The principal advantage of the latter is its relative stability under various load and fault conditions either in the line or in the converting equipment, and from this point of view it appears to be very attractive indeed.

It is pointed out in the paper that the occurrence of a short circuit will result in no damage to any equipment on the line even though it should persist for a considerable period. It must not be overlooked, however, that even though a short circuit in the line does not cause any damage, it nevertheless means a service interruption; as a matter of fact, for all practical purposes no more power can be transmitted during a complete short circuit than is possible with the line completely disconnected. Again, there is the question of how an arc on the line, which may have been caused either by lightning or perhaps by a temporary short circuit resulting from birds or branches contacting the line, will act under varying line conditions. Although the short circuit can be easily interrupted by a switch, as described in the paper, there may be instances, especially with the higher voltages, where the arc is likely to persist and clearing of the line may be necessary to interrupt it. On the whole, it is likely that the problem of short time fault currents, especially those involving an arc, can be handled about as well in a constant voltage system. It seems relatively easy to clear such faults by having the converter grids block conduction for a few cycles, which would have the effect of a circuit breaker opening and reclosing in an extremely short time.

Another advantage of the constant current d-c system mentioned in the paper is that a change from conversion to inversion in the converting apparatus takes place automatically. This is interesting, but in the majority of transmissions where power usually is transmitted from a mouth of mine steam plant or a hydroelectric plant, such a change is not often found to be a practical requirement.

It is indicated further that a constant current system is advantageous in overcoming certain difficulties encountered in connection with hot cathode devices. This is a very desirable characteristic, but the same difficulties might be overcome also by other types of converting apparatus which are more suitable for operation as inverters because of the shorter deionizing time.

It is stated in the paper that the losses in the conversion devices of the constant current d-c system can be held relatively low, i. e., in the order of 2 per cent of the power transmitted. At full load this is not any different from what would be found in the constant voltage system. However, in the constant current system the losses in the line, which constitute the greater part of the total loss, remain constant with changes in load and this in turn means that the all day efficiency may become rather low unless the load factor of the line is very good. In this respect the system is at a disadvantage in comparison with the constant voltage system.

It appears from the foregoing that the advantages of the constant current system in comparison with those of the constant voltage system may not necessarily be of great practical importance. It therefore seems that the very appreciable increase in cost caused by the addition of the apparatus needed for the monocyclic square, together with the reduced average efficiency, is too high a price to pay for the advantages claimed. Consequently, from an economic point of view, the chances of the d-c system in competition with the a-c system are not enhanced by the use of the constant current feature.

At present it seems that the economic limitations will not permit many practical applications of the d-c system in the near future. One of the reasons for this is that in actual practice applications are very rare where appreciable amounts of power have to be transmitted over great distances and where, therefore, direct current compares reasonably well with alternating current. In the majority of cases having several points of power supply and many points of power delivery, the cost of the necessary conversion apparatus is rather unfavorable for the use of d-c transmission systems. Studies have been made of the possibility of combining transmission with frequency changing, such as might be done when power from a 60 cycle system is delivered at some distance to a single phase railway system. Here the conversion apparatus for the d-c transmission would at the same time take the place of the frequency changing apparatus, which might lead to a rather economical system. However, it was found that even in such cases there is usually a need for 60 cycle ties at the far end of the line in addition to the 25 cycle load, thus causing additional complications.

It is not intended to detract in any way from the merits of a study as covered in the paper as it is only through such efforts that progress can be made in furthering any arrangement departing appreciably from existing standards. Moreover, economic relations are changing continually and schemes that are not competitive today may be in the future. There is also a wide variation in conditions to be met and it would not be surprising if d-c transmission of some kind or other would work out both advantageously and economically in such cases, for instance, as in the transmission of power from Scandinavia to Germany by means of cables across the Baltic Sea. In an instance like this the investment for the cable may prove to be such an important factor that the extra cost for the conversion apparatus at the terminals will be of secondary importance. Other economical applications of d-c lines may be found in connection with weak tie lines between large a-c systems.

The possibility of using conversion apparatus other than that of the hot cathode type has been suggested in the previous remarks. Mention might be made of the rectifier developed by Professor Marx in Germany. In this device the arc, instead of being operated in vacuum, vapors, or low pressure gases, is operated in air with air currents flowing between the electrodes. The air currents move the arc continuously on the electrodes, thus minimizing the burning and also serving to extinguish the arc at the end of each cycle. Superimposed high voltages are used to reëstablish the arc when desired. Professor Marx feels that his device is especially suitable for high voltage d-c transmission. However, since his device has a relatively high arc drop and consequent high losses, it does not appear to be very suitable for a constant current system. In view of the fact that such high losses would remain constant for varying loads, the all day efficiency would be very unfavorably influenced by the high arc drop.

In considering the suitability of various types of devices for conversion, great importance must be attached to the economic application of such devices for various current and voltage ranges. It would, therefore, be of interest to have a statement from the authors as to what they consider the limiting values of the tubes under present conditions and, more particularly, whether they believe that cascading of the tubes will be necessary for voltages needed in power transmission.

News
Of Institute and Related Activities

The Summer Convention at Cornell University

Attractive plans which will be of interest to a large number of the Institute's membership are in progress for the 51st annual summer convention to be held on the campus of Cornell University at Ithaca, N. Y., June 24–28, 1935. The campus, situated on a hill at an elevation of about 500 feet above Cayuga Lake, and the surrounding country are well known for their scenic beauty and they provide an ideal setting for the convention. An enlarged program consisting of 10 technical sessions and a number of informal conferences or round table meetings, some of which will be of special interest to Students and the younger members, will be held. The evenings will be devoted mainly to social functions.

Aside from the usual business features and the professional sessions good facilities for golf and tennis will be available. Also, other features, including an outing to Taughhannock State Park with a shore dinner, and a trip to the Corning Glass Works, are being planned. Taughhannock Falls is the highest falls east of the "Rockies."

A.S.M.E. to Meet the Preceding Week

The semi-annual meeting of The American Society of Mechanical Engineers will be held in Cincinnati, Ohio, June 19–21, 1935. These dates are Wednesday, Thursday, and Friday, of the week immediately preceding the Institute's summer convention at Ithaca. Inasmuch as there are many engineers who hold membership in both organizations, the A.S.M.E. has purposely departed from its usual practice of scheduling meetings to begin on Monday, in order to accommodate those who may wish to attend both meetings. Technical papers on a variety of subjects will be presented at the A.S.M.E. meeting, and a side trip to Norris Dam is scheduled by the A.S.M.E. for June 22. Members making this inspection trip should be able to arrive at Ithaca, in time for the beginning of the A.I.E.E. meeting.

A.I.E.E. Program

The papers for the 10 technical sessions are being published in Electrical Engineering. In addition to the 4 papers published in the February issue which deal with protective devices, 2 timely papers on this subject have been added to the program. One of these treats the new high speed impulse oil circuit breaker for the Boulder Dam–Los Angeles transmission line, and the other which is a companion paper adds valuable information for the determination of circuit recovery rates. These 2 papers, in conjunction with 2 other papers in the session on power transmission, which give the general features and the engineering features of the Boulder Dam–Los Angeles transmission system, should prove of unusual interest.

For those theoretically inclined and interested in electrical machinery and measurements several very good papers appeared in the March issue. Two of the machinery papers have to do with saturated synchronous reactance and commutation, while the measurements paper treats the precise speed control of d-c machines. Another paper also in the March issue explained the objectives and practical value of the advanced course in engineering given by the General Electric Company. This paper should prove of interest to many educators. Several other papers on the program appear in this issue and the publication of these and other papers considerably in advance of the convention will permit time for the careful preparation of good discussion.

As many as 13 informal conferences or round table meetings now are being planned on various subjects. Some of these will be of particular interest to students and members of faculties, as they will consider such matters as research in engineering schools, engineering education, the future of the electrical industry and opportunities for students. Others will have to do with electrical machinery, noise, and research on insulating oils.

More complete information on various features of the convention will appear in subsequent issues. Arrange your plans now so as to be able to attend the annual summer convention during the week of June 24 at Ithaca, N. Y., the home of Cornell University. The dormitories and the Cornell cafeteria will be open, as well as the hotels, and they will provide good facilities at moderate prices.

General Committee Appointed

President J. Allen Johnson has appointed the members of the general committee in charge of arrangements for the 1935 summer convention. These members are as follows:

R. F. Chamberlain, *chairman*
W. H. Timbie, *vice chairman*
A. C. Stevens, *secretary-treasurer*

P. L. Alger	M. G. Malti
W. C. Ballard	True McLean
C. H. Bissell	W. E. Meserve
L. A. Burckmyer	B. K. Northrop
R. N. Conwell	A. C. Stallman
E. P. Harder	I. Melville Stein
V. Karapetoff	E. M. Strong
P. M. Lincoln	J. O. West
J. T. Littleton	J. P. Wood

W. M. Young

Membership—

Mr. Institute Member:

The bogey of the membership committee is to do better each month than in the corresponding month of the previous year. For February the results were as follows:

	February 1935	February 1934
New member applications received (from other than enrolled Students)	61	43
New member applications received from enrolled Students	349	275
Members reinstated	51	27

In new member applications we have passed the thousand mark, 1095 applications having been received as of March 1, 1935, with 2 more months to go this fiscal year. And better still, new member applications have been received from every one of the 61 Institute Sections.

Ernest H. Vogt

Chairman National Membership Committee

Pacific Coast Convention Committee Appointed

The general committee in charge of arrangements for the Institute's 1935 Pacific Coast convention to be held at Seattle, Wash., August 27–30, 1935, has been appointed by Pres. J. Allen Johnson, and the members are already busy with arrangements which will insure a successful convention.

In the following list are given the chairman, vice chairman, secretary, and the members of the committee; of these, 7 are chairmen of subcommittees, as indicated.

H. A. Loew, *chairman*
L. B. Robinson, *vice chairman*
G. H. Walker, *secretary*
F. J. Bartholomew
A. M. Bohnert
Walter Brenton
Fred Garrison
R. H. Hull
G. L. Hoard, meetings and papers
H. B. Hansen, hotel and registrations
L. B. Robinson, finance
R. U. Muffley, entertainment
Wellington Rupp, transportation
G. E. Quinan, golf
J. H. Kelly, publicity
F. O. McMillan
H. T. Plumb
C. E. Rogers
R. W. Sorenson
J. A. Thaler

Engineering Society Officers to Hold Joint Meeting

Officers and directors of the national societies of civil, mining and metallurgical, mechanical, and electrical engineers, and of their several jointly sponsored functional organizations will all meet together for dinner Monday, May 20, 1935, at the Engineers' Club in New York, N. Y., according to plans recently announced by United Engineering Trustees, Inc., acting for the societies in sponsoring the proposed meeting. This is the first time in the history of the engineering societies that any such meeting has been undertaken and it is considered to be an important and significant step toward the establishment of a broader and clearer understanding of the scope and significance of the work carried on jointly by the several participating societies.

A wide variety of technical and other activities of importance to every branch of the engineering profession is now, and for many years has been, carried on by the agencies jointly created and sponsored by the engineering societies: United Engineering Trustees, Inc., and its 2 departments, The Engineering Societies Library and The Engineering Foundation; American Standards Association; the Division of Engineering and Industrial Research of the National Research Council; Engineering Societies' Employment Service, and Engineers' National Relief Fund; American Engineering Council; and, more recently, Engineers' Council for Professional Development. The activities, ideals, and procedures of each of these agencies will be described and explained concisely by society representatives long associated with the work in each case.

With a better understanding thus established among the personnel of the governing bodies of the several societies, it is hoped that more direct channels will be established through which the individual members of the societies may become better acquainted with the variety of professional services actually directly available to them. This, in turn, is important from at least 2 angles: first, in order that each member may know how to make use of these services, and second, that each member may realize the extent to which his own small contribution is magnified through effective coöperation.

Plans for this joint dinner meeting have grown out of discussions between the United Engineering Trustees and the secretaries of the founder societies that began in January. The committee in charge of the affair includes Dr. Alfred D. Flinn, director of The Engineering Foundation, *chairman;* H. V. Coes, president of United Engineering Trustees, Inc., *honorary chairman;* George T. Seabury, secretary, American Society of Civil Engineers; A. B. Parsons, secretary, American Institute of Mining and Metallurgical Engineers; C. E. Davies, secretary, American Society of Mechanical Engineers; H. H. Henline, Secretary, American Institute of Electrical Engineers; and John Arms, secretary, United Engineering Trustees, Inc.

Headquarters for the 1935 Summer Convention

MAIN entrance to Willard Straight Hall on the campus of Cornell University, Ithaca, N. Y. This building will be used as the headquarters for the A.I.E.E. 1935 summer convention, to be held in Ithaca, June 24–28. During the college year, this building serves as a social center for students and faculty. It contains dining rooms, large and small rooms for reading, conversation, and games, hotel facilities, theater, soda bar, and barber shop.

Great Lakes District to Meet at Purdue

Announcement has been made that the meeting of the Great Lakes District of the A.I.E.E. scheduled for October 24–25, 1935, will be held on the campus of Purdue University at West Lafayette, Ind. A student convention will be held in conjunction with the District meeting. The principal meetings will be in the electrical engineering building.

The general committee in charge of arrangements for this meeting is as follows:

G. G. Post, vice president, Great Lakes District (number 5)
A. G. Dewares, secretary, Great Lakes District (number 5)
F. R. Finehout
D. H. Hanson
C. F. Harding
T. F. Irvine
O. Kiltie
E. B. Kurtz
C. V. Mueller

South West District Meeting Fully Arranged

All is in readiness for the South West District meeting of the Institute to be held on April 24–26, 1935, at Oklahoma City, Okla., with headquarters at the Skirvin Hotel.

The committee has arranged a program of 5 technical sessions covering a variety of interesting subjects. There will be a session on distribution and transmission, involving the economics and application of regulating and circuit interrupting devices. A session is being arranged on coördination of insulation and surge protection of lines and equipment, including a paper on field testing of insulation. Papers will be presented on new metering practices, involving economic and engineering trends. There will be a symposium on the subject of engineering education. Other interesting topics that will be presented are relays, communication, cable sheath corrosion, regulators, and vacuum tubes. In connection with the presentation of the paper on vacuum tubes there will be a demonstration of d-c power transmission.

It is the intention to allow as much time as possible for the discussion of the technical papers. All who are in position to contribute to the discussion are urged to come prepared to do so.

On Thursday evening the convention banquet (informal) will be held, followed by dancing and bridge. Four inspection trips and a golf tournament are scheduled on Thursday afternoon. Special entertainment will be provided for the visiting women.

The complete program, with other information relative to the inspection, recreation, and social events was given in ELEC-

TRICAL ENGINEERING for March 1935, page 336–8. Complete your plans now to attend this meeting. A registration card is being mailed to all members in the South West District and nearby Sections, which should be filled in and returned promptly.

E.C.P.D. Embarks Upon Student Guidance Program

In furtherance of its charter objective "to enhance the professional status of the engineer through educational activities, "the Engineers' Council for Professional Development is now placing in operation another important part of its program. Recognizing that the first essential in improving the status of the engineering profession is improvement in the quality of men entering the profession, E.C.P.D. through its committee on student selection and guidance has entered upon a program designed to provide opportunity for boys in secondary schools who may be interested in engineering to make direct contact with individual members of the several participating professional societies who can give them sympathetic advice in the matter of the choice of their career.

The Engineers' Council for Professional Development is an agency created and jointly sponsored by the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, The American Society of Mechanical Engineers, the American Institute of Electrical Engineers, the Society for the Promotion of Engineering Education, the American Institute of Chemical Engineers, and the National Council of State Boards of Engineering Examiners. It was organized October 3, 1932, and functions through 4 standing committees: student selection and guidance, engineering schools, professional training, and professional recognition. The intended field of service of each of these committees corresponds to 1 of the 4 major periods in the development of an engineer: first, the selection of a career; then the acquisition of technical training of recognized merit; then, after graduation, the period of first practical experience as a junior engineer; and finally the certification as a full-fledged and qualified engineer.

The personnel of the committee on student selection and guidance is as follows: R. L. Sackett, dean, college of engineering, Pennsylvania State College, State College, *chairman;* O. J. Ferguson (A'05, F'13), dean, college of engineering, University of Nebraska, Lincoln; W. B. Plank, professor of mining engineering, Lafayette College, Easton, Pa.; H. N. Davis, president, Stevens Institute of Technology, Hoboken, N. J.; T. Keith Legaré, secretary, N.C.S.B.E.E., Columbia, S. C.; R. H. Jacobs, Englewood, N. J.; and V. M. Palmer, industrial economy engineer, Eastman Kodak Company, Rochester, N. Y.

Through the instrumentality of this committee, officers of the local units of the participating societies throughout the United States have been called upon to form in each locality "a sympathetic, understanding committee, which will actively promote guidance through contact and advice with the students, high school principals, vocational counselors, and others." Engineering schools throughout the country also are being asked to cooperate. The detailed program of each local committee of course will depend upon local conditions, but all will be guided by the common objective; a better understanding of the educational requirements of and vocational opportunities for engineers "in order that only those may seek entrance to the profession who have the high quality, aptitude, and capacity which are required of its members."

To meet the need for information written in terms and forms understandable and appealing to the immature and inexperienced student, to his high school teacher, and to his parents, the E.C.P.D. committee on student selection and guidance has, after a wide canvass, selected the booklet "Engineering, a Career—a Culture" as the most satisfactory pamphlet for guidance use. This attractive 64 page pamphlet was prepared by the educational research committee of The Engineering Foundation late in 1932, and already over 50,000 copies have been distributed to engineers, teachers, and others interested in the subject. This pamphlet is descriptive of the profession of engineering—of its spheres of action, of the training and the qualities required for successful pursuit; of the obligations which it imposes, and the rewards which it affords. Also, the practical usefulness of an engineering education in vocations other than engineering is illustrated by the experiences of many men in divers callings. Copies of this pamphlet are still available and may be obtained from The Secretary, Engineers' Council for Professional Development, 29 West 39th Street, New York, N. Y. (prices: 15 cents per copy, 10 cents in lots of 50).

Other articles on specific activities of the E.C.P.D. are contained in this and the 2 preceding issues of ELECTRICAL ENGINEERING, additional articles being scheduled for future issues. This information is presented to members of the Institute in order to keep them acquainted with the progress of the E.C.P.D.

Local E.C.P.D. Meeting Held in New York City

Four eminent engineers discussed the aims and achievements of the Engineers' Council for Professional Development at a meeting of the New York metropolitan sections of the 5 national engineering societies representing the civil, mining and metallurgical, mechanical, electrical, and chemical engineers. The meeting was held on March 6, 1935, in the Engineering Societies Building in New York City. The E.C.P.D. is an agency created and jointly sponsored by these 5 societies and by the Society for the Promotion of Engineering Education and the National Council of State Boards of Engineering Examiners.

The meeting was presided over by Mr. Gano Dunn (A'91, M'94, F'12, past president and life member) president of the J. G. White Engineering Corporation, and recently elected chairman of the board of trustees of Cooper Union. The speakers

Oklahoma City, Scene of a Forthcoming Meeting

AN aerial view of the downtown business section of Oklahoma City, Okla., where the South West District of the Institute will hold its meeting April 24–26, 1935. The 2 large buildings in the center of the picture are, right, the First National Bank building, and left, the Ramsey Tower. The 3-section building just to the right and above the bank building is the Skirvin Hotel, headquarters for the South West District meeting. The program for this meeting was given in ELECTRICAL ENGINEERING for March 1935, page 336–8.

were Dr. C. F. Hirshfeld (A'05) chairman of the E.C.P.D., and chief research engineer, Detroit (Mich.) Edison Company; Gen. R. I. Rees, chairman of the E.C.P.D. committee on professional training, and assistant vice president of the American Telephone and Telegraph Company; and Dean J. W. Barker (M'26, F'30) member of the E.C.P.D. committee on professional recognition, and dean of the school of engineering at Columbia University.

In introducing the meeting, Mr. Dunn referred to the apparent diversity of engineering occupations which have followed in the wake of science and invention, and emphasized the essential unity of all engineers in their methods of attacking problems. Pointing out that the E.C.P.D. rests upon and derives its strength from the whole profession, Mr. Dunn stated that he saw in the E.C.P.D. "the dawn of a professional self-consciousness among engineers, the effects of which on the engineer's status in society and on his satisfactions in life may be profound."

Doctor Hirshfeld discussed the philosophy underlying the relations of an engineer to society, and pointed out that if the engineer makes himself a sufficiently well trained, broad visioned, generally capable person, recognition by the world at large is bound to occur; stating further that the engineer will be recognized in proportion to his ability to serve society broadly and not alone in a narrow technical sense. Doctor Hirshfeld outlined the organization of the E.C.P.D. with its 4 working committees, namely, the committees on student selection and guidance, engineering schools, professional training, and professional recognition, pointing out that it is the purpose of these committees to assist and guide the engineer in achieving the personal development necessary for his recognition by society.

General Rees and Dean Barker outlined the policies of their committees, and told of work which they were doing.

Ambrose Swasey Receives Washington Award

The Washington Award for 1935 was formally presented to Dr. Ambrose Swasey (HM'28) at ceremonies held in Chicago, February 20, 1935. This award "presented annually to an engineer whose work in some special instance, or whose services in general, have been noteworthy for their merit in promoting the public good" was made to Doctor Swasey "for his distinguished contributions as a builder of instruments, institutions, and men."

The Washington Award was founded in 1916 by John Watson Alvord, to be awarded annually by the Western Society of Engineers (Chicago) upon the recommendation of a commission composed of 9 representatives of that society and 2 representatives of each of the 4 national engineering societies representing the civil, mining and metallurgical, mechanical, and electrical engineers.

Doctor Swasey, chairman of the board, The Warner-Swasey Company, Cleveland, Ohio, long noted as a maker of precision machine tools and instruments, is perhaps best known to and beloved among the engineering fraternity for his foresight, humanitarianism, and inspiring leadership. It was his substantial financial backing that led in 1914 to the formation and successful development of The Engineering Foundation "for the furtherance of research in science and engineering, or for the advancement in any other manner of the profession of engineering and the good of mankind."

An outline of Doctor Swasey's career and the many honors that have been accorded to him was presented in ELECTRICAL ENGINEERING for May 1934, page 815, and for November 1934, page 1552. The latter item is a report of the tribute paid to him upon the 20th anniversary of his creation of The Engineering Foundation, and in celebration of his approaching 88th birthday. It is also interesting to note that upon the occasion of his 88th birthday in December, Doctor Swasey received the unusual distinction of having an asteroid, discovered by Dr. Otto Struve, director of Yerkes Observatory, named "Swaseya" in his honor. Doctor Swasey's firm has been the builders of some of the world's greatest telescopes.

Future AIEE Meetings

South West District Meeting,
Oklahoma City, Okla., Apr. 24–26, 1935

Summer Convention,
Ithaca, N. Y., June 24–28, 1935

Pacific Coast Convention,
Seattle, Wash., Aug. 27–30, 1935

Great Lakes District Meeting,
West Lafayette, Indiana, Oct. 24–25, 1935

Winter Convention,
New York, N. Y., Jan. 28–31, 1936

North Eastern District Meeting,
New Haven, Conn., May 1936

Summer Convention,
Los Angeles, Calif., June 22–26, 1936

Middle Eastern District Meeting,
Akron, Ohio (date to be determined)

Suggestions for Research Projects

The number of requests received for copies of the list of suggestions for research projects prepared by the committee on research of the Institute has been very encouraging in view of the fact that the announcement of the availability of such a list was made only last November in ELECTRICAL ENGINEERING for that month.

For the benefit of those who may not have seen it at that time, it is repeated here.

With the object of stimulating interest in research work, the committee on research of the Institute has collected from electrical engineers in the industry suggestions for research projects suitable for advanced or graduate students and others in the engineering schools who are desirous of undertaking some kind of research work in the electrical engineering field.

A first list of over 100 such research suggestions in 13 branches of electrical engineering has been assembled. A widely varying range of experimental facilities is involved, from the simplest equipment found in any electrical laboratory to highly special facilities which would be available only in a very comprehensively equipped laboratory.

Copies of this list in mimeographed form may be obtained by any member of the teaching staff of an engineering school by merely addressing a request for a copy (or copies) to the committee on research at Institute headquarters, 33 West 39th Street, New York, N. Y.

The committee is planning to issue another list, number 2, early this fall. A copy will be sent to each recipient of the first list.

To Institute Members Planning Trips Abroad

Members of the Institute who contemplate visiting foreign countries are reminded that since 1912 the Institute has had reciprocal arrangements with a number of foreign engineering societies for the exchange of visiting member privileges, which entitle members of the Institute while abroad to membership privileges in these societies for a period of 3 months and members of foreign societies visiting the United States to the privileges of Institute membership for a like period of time, upon presentation of proper credentials. A form of certificate which serves as credentials from the Institute to the foreign societies for the use of Institute members desiring to avail themselves of these exchange privileges may be obtained upon application to Institute headquarters, New York. The members should specify which country or countries they expect to visit, so that the proper number of certificates may be provided, one certificate being addressed to only one society.

The societies with which these reciprocal arrangements have been established and are still in effect are: Institution of Electrical Engineers (Great Britain), Société Française des Electriciens (France), Association Suisse des Electriciens (Switzerland), Associazione Elettrotecnica Italiana (Italy), Koninklijk Instituut van Igenieurs (Holland), Verband Deutscher Elektrotechniker E. V. (Germany), Norsk Elektroteknisk Forening (Norway), Svenska Teknologforeningen (Sweden), Stowarzyszenie Elektrykow Polskich (Poland), Elektrotechnicky Svaz Ceskoslovensky (Czechoslovakia), The Institution of Engineers, Australia (Australia), Denki Gakkwai (Japan), and South African Institute of Electrical Engineers (South Africa).

New Subjects Added at M.I.T. In addition to the recently extended program of graduate study in electrical engineering at Massachusetts Institute of Technology, Cambridge, 3 new subjects are being offered during the current year and a fourth is announced for next year. These are: vibration phenomena and oscillations, engineering electronics, mathematical analysis by mechanical methods, and super high voltage engineering and vacuum electrostatic machinery.

Special Technical Meetings Prove Successful in San Francisco Section

An innovation in Section meetings modestly introduced last year by the Institute's San Francisco Section has been received with such growing enthusiasm by members in that Section, that an outline of the plan is presented here for the benefit of other Sections that may be interested. This innovation consists of the scheduling of special informal discussion meetings approximately once a month, between the regular Section meetings.

Evolution of the Special Meetings

It has been the experience in San Francisco that when regular Section meetings on more specialized engineering subjects have been held, only those engineers interested in the particular subject will attend. During the last 2 years, therefore, engineering subjects of a more general nature have been scheduled with consequent increase in average attendance. Subsequent adverse comment, however, pointed out that the meetings were getting away from electrical engineering subjects, and that little opportunity was afforded for detailed discussion of specific problems. This led to the innovation of scheduling between the regular Section meetings on general subjects, special technical meetings which consist principally of informal discussions. It is thus possible to have at the regular meetings a well balanced program that will attract a large number of members, and to present at the special meetings more technical information in specialized fields and to afford opportunities for informal round table discussion with other engineers interested in the same problems.

Attendance at the Special Meetings

Although a preliminary survey indicated that only 15 or 20 members of the Section were at all interested in the special technical meetings, it was decided to try them, and the first special meeting was held on February 9, 1934. A record of the results obtained with the special meetings speaks for itself:

Date	Subject	Attendance
February 9, 1934	Decrement Curves for Power Systems	23
March 9, 1934	Communication by Carrier in Cable	24
April 13, 1934	Symmetrical Components	36
May 11, 1934	Electric Corrosion of Pipe Lines	37
October 12, 1934	Synchronous Machines	30
November 9, 1934	Lead Cable Sheath Research	37
January 11, 1935	Overloading Power Transformers	31
February 8, 1935	Elements of Operational Calculus	35
March 8, 1935	Coaxial Communication Lines	31

During 1934, the following topics have been presented at the regular Section meetings: "Survey of Various Television Systems," "Television With Cathode Ray Tubes," "Radium and Its Modern Applications to Science and Technology," "Liquid Dielectrics," "High Voltage Underground and Overhead Cables," "The Modern Physical Conduction of Electricity Through Gases," and "Recent Engineering Developments." Also, a joint meeting with 3 student Branches, and a 50th Anniversary celebration meeting, were held as regular Section meetings. Attendance at the regular Section meetings has been maintained in spite of the special meetings.

It is now difficult to tell which of the 2 types of meetings is the more important, for they seem to serve largely different groups, thereby in effect practically doubling the total attendance per month. Also, it has been found, as expected, that with the exception of a few "regulars" which attend all the meetings, different groups attend the different special meetings.

Selection of Subjects

In selecting subjects, the tendency has been to select some subject which the practicing engineers feel they need to know more about, and then to find a speaker who can lead the discussion and answer questions on that topic. Frequently, a paper or group of papers previously published in Electrical Engineering are made the subject of the meeting. This has been found to help those who do not read many of the published articles, as well as those who, to clarify their own understanding, would like to discuss articles they have read.

No difficulties have been experienced in obtaining good subjects or good speakers, and it is possible to schedule meetings well in advance. Very little burden devolves upon the committee responsible for arrangements, for many suggestions are received from members as to discussions of detailed subjects desired.

It is obvious that many types of talks can be scheduled for special meetings that would not be suitable for general meetings. In this connection it might be mentioned, however, that particular attempts are made to prevent manufacturers or manufacturers' representatives from using the special meetings as opportunities to give talks with a "sales flavor."

Informality Stressed

Although the regular Section meetings are quite formal, the special technical meetings are most informal; this is believed to be one of the reasons for their success. As money is not available to spend on these special meetings, they are held in power or communication company buildings, or some other place where no charge is made. Advance announcement in the Section's monthly *Bulletin* gives the date, subject, and location of the scheduled meeting, and indicates where members will gather informally for dinner. No dinner reservations are made, and attendance varies with circumstances.

The usual method of procedure at these special meetings is for the chairman to call the meeting to order and introduce the speaker who then runs the meeting. The talks usually are given most informally, and the speaker usually tells the audience to interrupt him when any one has any question, or wants to say anything. This has worked out very well, and with the result that every one, young or old, who is at all interested in doing so, gets an opportunity to be a "doer" rather than just a listener.

Individual and Section Are Benefited

In short, both the individual member and the Section have benefited from these informal discussion meetings. The individual gets more out of his connection with the Institute through enhanced opportunities for actual participation and for getting timely information along definite lines in which he may be interested. From the Section point of view, more is being given to members, the over-all attendance at meetings is improved, and a greater interest in the Institute is created, thus giving the membership committee a supporting incentive.

Related Activities of This Section

Members of the San Francisco Section take a great deal of interest in the numerous activities of this Section, some of which are related to the special meetings. In addition to the regular and special meetings, which are each held once a month, an informal luncheon is held every Tuesday at a special table in the Engineers' Club, which will accommodate 35 members and which is usually filled to overflowing. Consideration also is being given to the scheduling of a certain number of inspection trips, but for fear of having too many activities going on at once, this suggestion has not yet been acted upon.

In addition to the above, the previously mentioned Section *Bulletin* is mailed to members every month. It consists of a (5 by 7 inch) 4-page inexpensively printed pamphlet combining notices of future meetings, reports of past meetings, "personal" items, reports of local committees, references to national activities, and other pertinent information. Although the preparation of this bulletin takes considerable time, it is an effort that has brought great returns.

For the past few years a steadily increasing feeling of friendship among the membership of the Section has been noticed and freer contacts between the more prominent engineers and the younger men have been brought about.

The results of these various activities are regarded as ample compensation for the tremendous amount of work done by the Section's executive committee. Since the activities have expanded, the Section has been fortunate in having an active group on its executive committee. It is felt that this may be due to the particular system for selecting officers adopted by this Section 5 years ago, which requires the rotation of officers so as to insure that all the principal offices are held by men having previous Section experience, and which makes it impossible for a person to hold any particular office for a long time. More of the younger men are thus given Section offices. These offices require considerable work and cannot be considered as purely honorary positions; it is considered vital to Section welfare that they be filled by active men.

A Message to Students of Electrical Engineering

A message to electrical engineering students prepared by the Institute's committee on research follows:

"Research is an activity of vital importance to the electrical industry. Electrical engineering was founded on research, its rapid and extensive development was made possible through the results of research, and research is essential to its further progress. At least 50 per cent of the papers presented before the Institute during recent years are definitely of a research character, under the definition of research, namely, "A systematic investigation of some phenomenon or series of phenomena by the experimental method to discover facts or coördinate them as laws." Incidentally, however, it should be noted that there is always plenty of opportunity for valuable research that does not involve "experimental methods." For example "library research" that is a critical review of existing literature which reports the results of studies and investigations on a given subject may permit crystallizing existing knowledge and facts which can be coördinated into laws.

"Progress in electrical engineering research and, therefore, progress in the electrical art will be greatly influenced by the young engineers coming into the profession. The following resolution passed by the committee on research of the Institute at a recent meeting carries a message to students (and also incidentally to their teachers):

"'It is the opinion of the A.I.E.E. committee on research that, exclusive of immediate problems to be handled by the existing specialists, the general progress of engineering research primarily will depend upon general interest and thorough training of the young engineers in the principles of physics, mathematics, mechanics, and chemistry, including both theoretical principles and experimental technique.'"

A.S.C.E. Appoints Field Secretary

The American Society of Civil Engineers has created the new and important post of field secretary, and has appointed Walter E. Jessup, member of A.S.C.E. and since 1930 editor of *Civil Engineering*, to that position. When *Civil Engineering* was initiated in 1930, Mr. Jessup came to New York from his home in Los Angeles, the intent at that time being that as soon as the character of that publication should be established and he might turn the work over to some one else, he would take on just such duties as have now been defined as for a field secretary. Society finances heretofore had not permitted the expansion then in mind. Two younger men will be selected to assist in the editorial department, and *Civil Engineering* will devote more space to information about society affairs.

Mr. Jessup was born in Pasadena, Calif., May 25, 1888, the son of a civil engineer. He received the degree of bachelor of arts from the University of Southern California in 1910, and that of civil engineer from the University of Wisconsin in 1912, being appointed student assistant in railway engineering while at Wisconsin. He was elected president of the local chapter of Tau Beta Pi in 1912. Following graduation he was engaged in field engineering in connection with the construction of the Los Angeles Aqueduct, the hydroelectric development at Big Creek, Calif., highways for the state of California, and the Salt River project, Arizona, of the U. S. Reclamation Service. In 1917, he was resident engineer on the ballasting and bridge replacement program of a railroad in California and Nevada, following which he was in army service for 2 years, spending 16 months in France as first lieutenant with the 39th Engineers. He now holds a reserve commission as major of engineers.

Following the war, Mr. Jessup entered the employ of a firm of consulting engineers in Los Angeles, and in 1924 opened a consulting office in that city, in partnership with H. Z. Osborne. This partnership was dissolved in 1930 to permit him to take up his duties as editor of *Civil Engineering*. Mr. Jessup joined the Los Angeles Section of the society in 1914, editing its publication, the *A.S.C.E.*, for a number of years, and serving as its president in 1929. He was also a member of the Pasadena Engineers' Club and the Joint Technical Society of Los Angeles, being secretary of the latter organization in 1930. He was one of the founders of the Los Angeles Alumni Club, Tau Beta Pi, serving as its secretary-treasurer for 14 years.

Walter E. Jessup

Student Branch Sponsors Public Meeting

The University of Alabama Branch of the A.I.E.E. located at University, Ala., in connection with the local student branch of the Illuminating Engineering Society, arranged an address to be presented to the public on February 19, 1935. In departing from the usual practice of holding meetings for engineers and engineering students only, it was felt that a service was rendered to the public through the dissemination of information which had been collected by engineers.

The subject selected for this public meeting was "The Science of Seeing," the lecture being delivered by Alston Rodgers, illumination engineer of the General Electric Company. Considerable equipment was available to assist in clarifying the lecture and making it interesting to the public. Approximately 300 persons were present in the university auditorium to hear the lecture.

Electronics and Electron Tubes

Three related publications on theoretical and experimental electronics and electron tube applications, originally intended for educational institutions, are now available to the public. One of these, "Electronics and Electron Tubes" was written by E. D. McArthur of the vacuum tube engineering department of the General Electric Company, in response to requests from schools and colleges for a publication giving, in easily understood language, the fundamentals underlying the vacuum tube, and including simple experiments to illustrate these fundamentals. References are included which enable the reader to delve more extensively into many of the subjects which are treated in this 48 page booklet, 8 x 10½ inches in size. Designated as publication GET-568-A, it may be obtained from the educational section, General Electric Company, Schenectady, N. Y., at a cost of 25 cents.

The other 2 publications, designated GET-566 and GET-620, deal with laboratory experiments on electron tube theory, and on electron tube applications, respectively. The former describes experiments and is intended as a supplement to "Electronics and Electron Tubes," while the latter is a laboratory manual covering a number of fundamental electron tube applications. The 2 booklets are obtainable as a combination priced at 25 cents.

California Pacific International Exposition

The California Pacific International Exposition will open in San Diego, Calif., on May 29, 1935. Officials of the exposition announce that impressive and instructive displays of many leading electrical manufacturing companies, as well as light, power, and communication companies, many already under construction, and many others in various stages of planning and negotiation, will result in an aggregate showing of the electrical industry which will be the most spectacular ever witnessed on the Pacific Coast.

The majority of these exhibits will be housed in the impressive Palace of Electricity, one of the many display buildings erected along the acacia lined Avenue of Palaces, the principal thoroughfare running through the fair grounds. The Palace, 388 x 118 feet, is a low oblong building designed in a modern adaptation of the adobe style of architecture.

The high mesa in the center of historic Balboa Park in San Diego will serve as the setting for the exposition. This was the

A Reading List for Junior Engineers

A LIST of books recommended for reading by junior engineers has been prepared by a number of eminent men, many of them distinguished in the engineering profession. Previous sections of this list have been published in ELECTRICAL ENGINEERING for December 1934, page 1667, January 1935, page 133, and March 1935, page 345. Two additional sections are published herewith, and others are scheduled to follow in subsequent issues. The complete list includes more than 100 titles.

Systematic reading of worth while books adds breadth and vision to the background of an engineer and should be considered a part of the intellectual development designed to fit the young engineer for full professional recognition. It is suggested that over a period of about 4 years a minimum of about 25 of these books might be selected and read, with the limiting recommendation that the selection made will include at least one book in each classification, preferably in accord with the individual engineer's most vital interests.

Business and Industrial Management

Studies in the Economics of Overhead Costs, J. M. Clark. University of Chicago Press, 1923. Studies of the discrepancies between supply and demand. Unused capacity is the central theme.

The Young Man in Business, Howard L. Davis. Wiley, 1932. Simply written book on vocational guidance by a director of such activities in industry; of particular interest to young people.

Organization Engineering, Henry Dennison. McGraw-Hill, 1931. Well written and shows original observation and analysis. Intended as an over-all picture of the whole problem, rather than as a discussion of specific situations. Intent is to encourage further systematic development of the art and science of organization engineering.

Economic Control of Engineering and Manufacturing, F. L. Eidman. McGraw-Hill, 1931. Purpose of this book is to focus attention on economic aspects of engineering. It presents practical methods and techniques for solution of major industrial problems.

Principles of Industrial Organization, Dexter S. Kimball. McGraw-Hill, 1933. New edition fully revised and containing new material on such subjects as measures of management, mechanization of industry and factory arrangement, and production control.

Business Leadership, H. C. Metcalf. Isaac Pitman, 1931. A series of 25 lectures by various writers on biological, engineering, psychological, industrial, political, and educational problems of management.

Technique of Executive Control, E. H Schell. McGraw-Hill, 1930. Straight thinking applied to the duties and difficulties of the executive, with stimulating questions based upon the problems presented.

Human Nature and Management, Ordway Tead. McGraw-Hill, 1929. Book addressed primarily to the factory manager. Tells what psychology means, giving outline of mechanism of emotions, habits, tendencies, and learning process.

History

Epic of America, James T. Adams. Little, Brown, 1931. An inspiring narrative of the evolution of the American nation.

Century of Progress, edited by C. A. Beard. Harper, 1933. A summary of outstanding events of the last 100 years in American history.

Conquests of Civilization, J. H. Breasted. Harper, 1926. A summary of human progress from the crude beginnings of civilization to the fall of Rome.

Modern Democracies, Viscount James Bryce. 2 volumes, Macmillan, 1924. Analytical summary of general principles of democracies as shown in France, Switzerland, Canada, United States, Australia, and New Zealand.

Europe: A History of Ten Years (1918–1928), R. L. Buell. Macmillan, 1929. An account of the drift of Europe during this time, by the research staff of the Foreign Policy Association. Traces history of Paris peace treaties and the internal development of leading countries and attempts to interpret bolsheviam and facism.

Soviet Russia, W. H. Chamberlain. Little, Brown, 1930. Impartial interpretation of happenings in Russia during the 7 years before 1930 during its transition from tsarism to communism. Gives historical background of the revolution and its personalities and discusses the social leveling, cultural and religious questions, and the woman movement.

Historial Evolution of Modern Nationalism, C. J. H. Hayes. R. R. Smith, 1931. Discussion of nationalism as a political philosophy formulated by leaders of thought and opinion, instead of a social process or a popular movement.

Outline of History (new and revised), H. G. Wells. Garden City Publishing Company, 1931. A readable commentary on the life of man from time of the stone age.

site of San Diego's portion of the historic Panama Pacific Exposition in 1915. On this site, many huge exposition palaces already have been completed and the "midway" and amusement park with the "foreign villages" are under construction. The impressive Ford Building, Federal Building, and other buildings are now being erected. It is estimated that the entire exposition, when completed, will represent an investment of more than $16,000,000.

It is reported that the entire U. S. Fleet will make San Diego its headquarters during the period of the exposition, and massed maneuvers of the combined army, navy, and marine air services will be one of the features of the military and naval displays.

Lewis Institute Director Resigns. Information received from Fred A. Rogers (A'06, M'28) dean of engineering and professor of physics and electrical engineering at Lewis Institute, Chicago, Ill., indicates the resignation of G. N. Carman as director of that institute after 40 years of service. The resignation is effective September 1, 1935. Mr. Carman worked with the trustees in planning the school as it had been conceived by Allen C. Lewis, the founder, in 1895.

Physical Society to Meet. The 198th regular meeting of the American Physical Society will be held in Washington, D. C., April 24–27, 1935. The Thursday and Friday sessions will be at the Bureau of Standards, and the Saturday sessions at the National Academy Building. The headquarters' hotel is The Raleigh.

Innovations Introduced at Purdue University. Three announcements of changes affecting teaching for next year at Purdue University, Lafayette, Ind., have been made. One of these is the appointment of Dr. Lillian M. Gilbreth, consulting engineer in management, of Montclair, N. J., as professor of management at Purdue University, effective September 1935. Doctor Gilbreth is recognized as one of the world's most eminent management engineers. The second announcement is the offering of a new curriculum in public service engineering beginning September 1935, having as one of its major objectives the preparation of engineers capable of dealing with the technological problems of government. The third announcement, also effective September 1935, is the initiating of a combined 6-year course in engineering and law at Purdue University and Indiana University, for those interested in an engineering background for law practice.

Radio Club of America Celebrates 25th Anniversary

Dedicated to the "spirit of good fellowship and the free interchange of ideas among all radio enthusiasts" the Radio Club of America, Inc., has issued a special Year Book in commemoration of its 25th anniversary. Among the names appearing in the roster of present and past leaders of this pioneer club (said to be the oldest radio club in the world) are to be found many long since prominent in the world of radio communication as it is known today, and several now appearing on the roster of active members of the A.I.E.E.

Quoting from opening paragraphs of the Year Book:

"The story of the Radio Club of America begins over a quarter of a century ago, during the really dark ages of the radio art, about 1907. . . . Here we find a group of small boys who, according to the true American spirit, were so interested in flying that they formed the Junior Aero Club of U.S.

"In conjunction with their experiments in aviation, these youngsters had, for some time, also been interested in what was then known as wireless. In fact, the new idea of sending messages without wires had proved itself so fascinating, that they found themselves actually devoting most of their spare time to tinkering with wireless apparatus. There were at this time a

small number of so-called amateur wireless experimenters in and about New York City, so the boys decided to form a new club with wireless as an object."

"Accordingly, . . . a special meeting of the Aero Club, for the purpose of forming a new club, with wireless telegraphy and telephony as its main interest. . .was held at the Hotel Ansonia in New York City on January 2, 1909. . . . Thus, the Junior Wireless Club Limited was founded," and bore that name until October 21, 1911, when it was changed to the Radio Club of America in recognition of its expanding membership and interests.

The Year Book presents a comprehensive outline of the history of the club, lists the major contributions of its members to communication literature, and includes a roster of members and of past and present officers. Copies of the Year Book are said to be available at the club's executive headquarters, 11 West 42nd Street, New York, N. Y.

Among the present and past officers of the Radio Club of America are noted the following members of the Institute:

Ernest V. Amy (A'19, M'28) consulting engineer, Amy, Acebes and King, Inc., New York, N. Y.
Carl Dreher (A'23, F'33) sound director, RKO Studios, Inc., Los Angeles, Calif.
George J. Eltz, Jr. (A'21) co-owner, Continental Sales Company, Hartford, Conn.
Lawrence C. F. Horle (A'20, M'22) consulting radio engineer, Newark, N. J.
Harry W. Houck (A'21) consulting engineer, Camp Hill, Pa.
Theophilus Johnson, Jr. (A'18) commercial engineer, General Electric Company, Schenectady, N. Y.
Ralph H. Langley (M'34) consulting engineer, New York, N. Y.
Louis G. Pacent (M'18, F'30) president and technical director, Pacent Engineering Corp., New York, N. Y.

United Engineering Trustees, Inc.

The Joint Engineering Organizations

United Engineering Trustees, Inc., organized in 1904, is now the joint agency of the 4 national societies representing the civil, mining and metallurgical, mechanical, and electrical engineers. It is organized in 3 departments, namely, the administrative department, The Engineering Foundation, and the Engineering Societies Library.

The administrative department manages the Engineering Societies Building and all trust funds placed in the hands of the United Engineering Trustees, Inc. The Engineering Foundation, founded by Ambrose Swasey (HM'28) in 1914, is entrusted with the expenditure of the income from endowments and other funds, its present preferred activity being engineering research. The Engineering Societies Library is a free public library which, with its numerous activities, is operated for users at a distance, as well as for those who visit its rooms in the Engineering Societies Building.

Inasmuch as a brief résumé of the organization of the United Engineering Trustees, Inc., and the 3 departments enumerated above, was given in ELECTRICAL ENGINEERING for April 1934, page 632, further details will not be given here. In the accompanying article will be found announcements of elections and abstracts of the annual reports of these organizations.

Election of United Engineering Trustees, Inc., Held

At the annual meeting of United Engineering Trustees, Inc., which was held in the Engineering Societies Building, New York, N. Y., January 24, 1935, officers to serve for 1935 were elected. H. V. Coes was reelected president, to serve for the period ending at the annual meeting in October 1935. G. L. Knight (A'11, F'17) was reelected first vice president, also serving until October 1935. H. G. Moulton was elected second vice president to serve for the period ending October 1936. Also, John Arms was elected secretary, C. P. Hunt, treasurer, and O. E. Hovey, assistant treasurer, all to serve until October 1935.

The names of the members of the board of trustees of the United Engineering Trustees, Inc., are given in the following tabulation. Those members having terms expiring in October 1935 and October 1936 hold over from previous elections. Those shown having terms ending in October 1937 and October 1938, took office at the January 24, 1935, meeting, as a result of appointment or reappointment.

Terms expiring in October 1935	
C. W. Hudson	A.S.C.E. representative
George A. Easley	A.I.M.E. representative
Harold V. Coes	A.S.M.E. representative
H. P. Charlesworth (M'22, F'28 and junior past president)	A.I.E.E. representative
Terms expiring in October 1936	
John P. Hogan	A.S.C.E. representative
H. G. Moulton	A.I.M.E. representative
D. R. Yarnall	A.S.M.E. representative
H. R. Woodrow (A'12, F'23)	A.I.E.E. representative
Terms expiring in October 1937	
Otis E. Hovey	A.S.C.E. representative
William L. Batt	A.S.M.E. representative
Terms expiring in October 1938	
A. L. J. Queneau	A.I.M.E. representative
G. L. Knight (A'11, F'17)	A.I.E.E. representative

In accordance with the 1934 revision of the by-laws, the terms of officers and members of the board of trustees have been changed so as to expire each year on the first of October, instead of in the following January. Also, the terms of members of the board of trustees are being changed from 3 year to 4 year terms. During the period of transition to the 4 year term basis, some of the societies will elect members for 3 year terms and others for 4 year terms. Starting with the official year beginning October 1, 1938, all elections will be for 4 year terms. In 1935, 1936, and 1937, the civil and the mechanical engineers shall each appoint or elect one trustee for a 3 year term, and the mining and electrical engineers one trustee each for a 4 year term. In 1938, the civil and mechanical engineers shall each appoint or elect one trustee for a 4 year term, but the mining and electrical engineers shall not appoint or elect any trustee. In 1939 and 1940 every founder society shall appoint or elect one trustee for a 4 year term. Thereafter, as each term is completed, the appropriate founder society shall appoint or reappoint, elect or reelect, as provided in these by-laws, a trustee for the succeeding 4 year term.

This means that for the 4 year term beginning October 1, 1938, the terms beginning October 1, 1942, and every fourth year thereafter, the mining and electrical engineers will not appoint or elect any trustee. For the 4 year term beginning October 1, 1941, and every fourth year thereafter, the civil and mechanical engineers will not appoint or elect any trustee.

COMMITTEES APPOINTED

President Coes appointed the following committees: finance committee, G. L. Knight (A'11, F'17) *chairman*, Otis E. Hovey, H. G. Moulton, W. L. Batt, and H. V. Coes, *ex-officio;* real estate committee, H. R. Woodrow (A'12, F'23) *chairman*, John P. Hogan, A. L. J. Queneau, H. V. Coes, and the secretaries of the 4 societies, George T. Seabury, A. B. Parsons, C. E. Davies, and H. H. Henline.

Election Held by Engineering Foundation

The board of directors of The Engineering Foundation at its annual meeting held in the Engineering Societies Building, February 21, 1935, reelected as its chairman H. P. Charlesworth (M'22, F'28, and junior past president) assistant chief engineer, American Telephone and Telegraph Company, New York, N. Y. Mr. Charlesworth is a representative of the A.I.E.E. on the board. He was previously elected chairman, as announced in ELECTRICAL ENGINEERING for January 1935, page 134, to fill the unexpired term caused by the death of George W. Fuller. D. Robert Yarnall, a representative of The American Society of Mechanical Engineers, and a member of the firm Yarnall-Waring Company, Philadelphia, Pa., was reelected vice chairman. The executive committee is composed of these 2 members, together with the following 3 persons: J. V. N. Dorr, member-at-large, president, The Dorr Company, engineers, New York, N. Y., and a representative of the American Institute of Mining and Metallurgical Engineers; Edwards R. Fish, member-at-large, chief engineer, boiler division, Hartford Steam Boiler Inspection and Insurance Company, Hartford, Conn., and a representative of The American Society of Mechanical Engineers; and O. E. Hovey, consulting engineer, American Bridge Company, New York, N. Y., and a representative of the American Society of Civil Engineers. Dr. A. D. Flinn was reelected director and secretary.

The officers and executive committee of

Engineering Foundation are elected by The Engineering Foundation board from among its own members. The Engineering Foundation board is itself elected by the board of trustees of United Engineering Trustees, Inc. Members of The Engineering Foundation board who were elected at the meeting of United Engineering Trustees, Inc., on January 24, 1935, and who serve for terms of 4 years expiring at the annual meeting in 1938, or upon expiration of terms as trustees are as follows:

Otis E. Hovey, trustee, to succeed Arthur S. Tuttle, A.S.C.E.
A. L. J. Queneau, trustee, to succeed R. M. Roosevelt, A.I.M.E.
Langdon Pearse, nominated by A.S.C.E. to succeed Otis E. Hovey
E. DeGolyer, nominated by A.I.M.E. to succeed himself
Frederick M. Becket, to succeed George Gordon Crawford, member-at-large
Harold V. Coes, *ex-officio*, president, United Engineering Trustees, Inc.

The complete membership of The Engineering Foundation board, consisting of the above mentioned newly elected members, and the members holding over from previous elections, is given in the following list:

Four Trustees of U.E.T. Inc.		
Otis E. Hovey	A.S.C.E.	1937
A. L. Queneau	A.I.M.E.	1938
D. Robert Yarnall	A.S.M.E.	1936
H. P. Charlesworth (M'22, F'28, and junior past president)	A.I.E.E.	1935
Eight Members Nominated by Founder Societies		
George E. Beggs	A.S.C.E.	1935
Langdon Pearse	A.S.C.E.	1938
George D. Barron	A.I.M.E.	1936
E. DeGolyer	A.I.M.E.	1938
Albert E. White	A.S.M.E.	1935
W. H. Fulweiler	A.S.M.E.	1936
C. E. Skinner (A'99, F'12, and past president)	A.I.E.E.	1935
W. I. Slichter (A'00, F'12, and national treasurer)	A.I.E.E.	1936
Three Members-at-Large		
Frederick M. Becket		1938
J. V. N. Dorr		1935
Edwards R. Fish		1935
Ex-officio, President, U.E.T., Inc.		
Harold V. Coes		

The new chairman of Engineering Foundation, H. P. Charlesworth, was also elected as the Foundation's representative on the executive board of National Research Council.

At this meeting, the chairman was authorized to appoint a committee of 3 to consider the subject of platform and general program for the Foundation, utilizing the results of previous studies, and if practicable, reporting to the board in advance of the next meeting. Subsequently the chairman appointed the following to this committee: Otis E. Hovey, chairman, D. Robert Yarnall, and H. P. Charlesworth.

Annual Report Issued by United Engineering Trustees, Inc.

The annual report of United Engineering Trustees, Inc., for 1934 has been submitted by its president, Harold V. Coes. In this report, it is pointed out that properties for which the corporation is responsible (real estate at cost, funds at book value, and library as appraised) total nearly $4,000,000. The aggregate value of investments on December 31, 1934, was $1,338,852.98, and the market value was $1,236,677.25.

As previously announced, Dr. Alfred D. Flinn resigned as secretary (although continuing as director and secretary of The Engineering Foundation) general manager John Arms being elected to the office of secretary in addition to holding that of general manager. This change necessitated other changes in the methods of carrying on the corporation's activities.

During the year, improvements were made in the Engineering Societies Building, desirable changes were made in the by-laws, the arrangements for fire insurance coverage for the building were changed so as to result in appreciable saving, and other work necessary for the maintaining of the Engineering Societies Building, and the handling of the funds entrusted to United Engineering Trustees, Inc., was carried on. The trustees found the time inopportune to restore the salary cuts in effect for the staff, so that this economy remains in the 1935 budget.

A summary of the report for 1934 of the finance committee of this corporation appears in table I.

Table I—Summary of U.E.T. Finance Committee Report for 1934

Operation of Building		
Gross Operating Revenue	$85,160.11	
Less Operating Expenditures	93,853.96	
Net Operating Loss	8,693.85	
Uncollectable Accounts Written Off*	2,916.00	
Net Decrease for Year	11,608.85	
Transfer of Revenue to Depreciation and Renewal Fund	0.00	
Net Decrease for Year	11,608.85	
Credit Balance in Activity Account Jan. 1, 1934	13,276.08	
Credit Balance in Activity Account Dec. 31, 1934		$1,667.23
Operation of Library		
Maintenance Revenue	$40,444.68	
Maintenance Expenditures	39,398.01	
Credit Balance for year 1934	1,046.67	
Transferred to Search Bureau	771.03	
Net Credit Balance for year 1934	275.64	
Credit Balance from previous year	3,422.19	
Credit Balance Dec. 31, 1934		$3,697.83
Service Bureau Revenue	$7,766.78	
Service Bureau Expenditures and Adjustments	8,537.81	
Debit Balance (Deficit)	771.03	
Transferred from Library	771.03	
Balance in Activity Account for year 1934	0.00	
Balance in Activity Account Dec. 31, 1934	0.00	0.00
Total net operating credit balance cumulated to Dec. 31, 1934		$5,365.06
Funds and Property		
Funds held by U.E.T., Inc., Dec. 31, 1934 (book value)		
Henry R. Towne Engg. Fund		$50,000.43
** Combined Fund: including		
Depreciation and Renewal	$332,443.80	
General Reserve	0.00	
Engineering Foundation	783,101.31	
Library Endowment	174,544.32	
Edward Dean Adams	100,000.00	
	$1,390,089.33	
Less deferred charge representing net loss from sale of securities from Dec. 31, 1929 the date of establishment of the Combined Fund to Dec. 31, 1934	94,905.46	1,295,183.87
Real Estate, cost to Dec. 31, 1934		$1,987,793.92
Operating Cash	$6,297.97	
Petty Cash	250.00	6,547.97
Accounts Receivable		1,261.61
Library as appraised for fire insurance		480,800.00
Total		$3,821,587.80
John Fritz Medal Fund (Custodian)		3,500.00
		$3,825,087.80

* Personnel Research Federation, $2,901.00; halls revenue, $15.00; total, $2,916.00.
** A group of funds managed as if one for convenience and economy in investment transactions.

Annual Report Issued by Engineering Foundation

The annual report of The Engineering Foundation for 1934 has been submitted by H. P. Charlesworth (M'22, F'28, and junior past president) chairman of The Foundation, and Dr. Alfred D. Flinn, its director. The Engineering Foundation was founded by Ambrose Swasey (HM'28) in 1914; Doctor Swasey has made 3 bequests to Foundation, totaling $750,000.

In the report it is shown that the capital

fund of The Engineering Foundation consists of endowments having a total book value on December 31, 1934, of $882,000, and the E. H. McHenry bequest, in the hands of executors during the lives of 2 beneficiaries, appraised in 1931 at approximately $400,000. During 1934, the income from the endowment, temporary investment of income balance, and minor items, totaled $44,061.38; and expenditures for research projects, promotion of research, and administrative expenses totaled $33,482.99. This excess of income over expenditures during 1934 resulted in an increase of balance from $11,202.75 to $21,781.14.

The following brief summary of activities during 1934 was given:

"Activities in 1934 included investigations of concrete and reinforced concrete arches, earths and foundations, and plastic properties of concrete, in the civil engineering field; critical review of the world's literature on alloy irons and alloy steels since 1890, and barodynamic research, both sponsored by the American Institute of Mining and Metallurgical Engineers; in coöperation with committees of The American Society of Mechanical Engineers, studies of effects of temperature on properties of metals, cutting of metals, thermal properties of steam, mechanical springs, riveted joints, and wire rope; under sponsorship of the American Institute of Electrical Engineers, an electric welding research on pure iron electrodes. Assistance was given also to Engineers' Council for Professional Development, Personnel Research Federation, and an investigation of The Engineering Index."

American Engineering Council

A.E.C. Reports From Washington

FOLLOWING are excerpts from the current news letter released by American Engineering Council, the "Washington Embassy" of engineers, which appear to be of particular interest to members of the Institute:

Procedure as to Legislation

With so much of engineering interest at stake in the current session of Congress, it seems timely to summarize the policies and methods followed by Council in legislative matters. The staff has for its guidance:

1. Policies adopted by the assembly and administrative board at annual meetings.
2. Advice on new matters from special and standing committees.
3. Precedent of several years on matters which do not require new rulings.
4. The viewpoint of public interest as a fundamental reason for participating in legislative activities.
5. The corollary viewpoint of advancing the economic status of the profession.

The factors of public interest and the status of the profession are closely related in problems constantly arising in connection with the federal program, due to the extraordinary relation of government to business at present. Competent engineers must be employed where engineers belong if the public interest is to be protected against faulty planning and wasteful execution.

Although the "Washington Embassy" of engineers may not jump into drastically new lines of action in the name of the profession without due consultation and approval, it is not hemmed in by ponderous procedure. The precedent set on past work, recognized as in the interest of the profession, gives sufficient latitude for quick action on immediate, practical steps and leaves only the long-range phases for more deliberate action.

Legislation which Council follows for engineers includes the following general categories:

1. *Construction.* Federal appropriations and administrative machinery for construction. (The work-relief bill.)
2. *Development of Industries.* Amendments to the National Industrial Recovery Act, new patent legislation, etc.
3. *Development of Natural Resources.* Bills relating to water power, navigation, reclamation, soil erosion control, surveys and maps, and similar public activities wherein the engineer serves in the development of "our national plant."
4. *Engineers' Welfare.* General legislation in the field of unemployment insurance, old-age pensions, etc; bills such as civil service measures, engineers' compensation on federal and relief work, etc., more directly affecting the engineer.

Scores of bills under each of the above headings are under consideration. With its limited staff Council is obliged to concentrate on those of the greatest importance to the profession. Where needed, information and arguments are presented to Congressional committees in open hearings or otherwise. Council fills frequent requests from federal agencies setting up programs along engineering lines, for information as to features of concern to the profession. The public affairs committee and its subcommittees are sent copies of important bills and documents and are kept generally informed.

Work Relief Bill

Council has been following the federal work relief bill in Congress, and has been coöperating with some of the planners of this bill. It is pointed out that jobless engineers are at a disadvantage in seeking placement under the program until it is revealed just which agencies will handle the various projects; present steps may include registration with the nearest U.S. employment office, securing of political endorsements from county chairmen upward, filing applications with federal agencies in Washington or in field offices, and taking civil service examinations.

Survey of the Engineering Profession

Work is being carried forward on the survey of the engineering profession being made by the U. S. Department of Labor in coöperation with A.E.C. and the national and local engineering societies. An item on this census of engineers was given in ELECTRICAL ENGINEERING for December 1934, page 1677, with shorter items in the January and February 1935 issues, pages 135 and 252, respectively. The list of engineers to whom the questionnaires will be sent has now been compiled, this work having taken longer than expected due to the fact that the engineering societies coöperated so well that a list of upward of 170,000 names has been compiled, instead of the expected list of 100,000. This work has been carried on with the assistance of 12 relief workers in New York City, and it is expected that the questionnaires will be sent out soon. All members receiving these are urged to fill them out and return them promptly, as the survey will be valuable in any analysis of the status of members of the engineering profession.

Other Items

The plan for public affairs committees of Council in each locality (see ELECTRICAL ENGINEERING for February 1935, page 251) may be accelerated in cities having sections of national engineering societies. The sections may appoint representatives on a central committee to handle matters of joint interest. Also, considerable interest in Council's new membership plan has been shown by several local societies.

The National Bureau of Economic Research in whose work A.E.C. is a coöperating agency, reported noteworthy progress and good financial condition at its annual meeting in February. A number of studies and reports relating to engineering and industry have been made by this bureau. Detailed information may be secured by writing the bureau at 1819 Broadway, New York, N. Y.

The holding company bill now before Congress, as phrased at present, tends to extend federal jurisdiction over the practice of engineering under contract with utility firms, according to a resolution by the American Institute of Consulting Engineers, asking Council to intervene.

L. W. Wallace, formerly executive secretary of A.E.C., and during the past year vice president of the W. S. Lee Engineering Corporation, located at Washington, D. C., is now in Chicago, Ill., as director of equipment research for the Association of American Railroads.

The office of the American Engineering Council, at 744 Jackson Place, Washington, D. C., will gladly supply material to individuals wishing to give talks on what A.E.C. is doing for the engineer. It also will supply, upon request, copies of the minutes of the secretaries' conference and of the symposium on federal activities presented at the annual meeting of A.E.C., which was reported in ELECTRICAL ENGINEERING for February 1935, page 251–3.

According to a recent newspaper account

which credits the National Society of Professional Engineers with starting a movement to call the operators of locomotives "engine men" rather than "engineers," Casey Jones is rotating in his grave. The story neglects to say that Council has supported this nomenclature for a good many years and that federal classifications consequently have noted the change long before now.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or to reject them entirely.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

CORRECTION—Figures 2 and 3 in the "Letter to the Editor" by E. H. Nelson and Sidney Rock entitled "Over-compounded D-C Generators in Parallel Without an Equalizer" in the March 1935 issue of ELECTRICAL ENGINEERING, page 347–8, should have been interchanged. In further explanation of the text, the point on these 2 reproductions of oscillograms at which the equalizer was opened is about $^1/_4$ inch from the left-hand side, and the point at which the equalizer was closed is at the sharp break in the curves near the middle.

An Engineer's Thought on the Economic Scene

To the Editor:

The following refers to the addresses on "What Place the Engineer in the Changing Economic Scene?" by Dr. Virgil Jordan and Col. W. T. Chevalier, published in ELECTRICAL ENGINEERING for November 1934, page 1546–51:

Doctor Jordan, if I understand him correctly, offers no explanation and suggests no remedy for our present economic chaos. He confuses the economic with the financial aspects in a quite orthodox fashion. Colonel Chevalier at least ventures to express the pious hope that our next generation will learn to put a premium on creation of wealth rather than acquisition of wealth. Just why we should wait for the next generation is not quite clear.

At present there is an analogy going around, which I have not seen in print so far. A private water company was formed. It employed laborers on the condition that for every gallon of water they put into the company's storage tank, they, the laborers, received one gallon. The laborers sold their surplus water or traded it for goods they needed and all was well. But suddenly the company found their tank full and naturally enough laid off all their help. The laborers were told that when they had bought enough water from the company, they would be put back to work again and prosperity would return. The laborers told the company that they had nothing and could buy no water until they got back to work.

A 2 weeks' intermission followed, while the company officials cogitated and ruminated. Finally it was decreed that an advertising specialist should be called in. After making a careful detailed analysis of the situation, he concluded that advertising was the remedy. Tell the folks about your wonderful water. And the tank stayed full, except of course for the fee of this specialist. Etc., ad libitum.

In other words, the public works programs, the housing plans, etc., can accomplish nothing as long as they are to be self-liquidating, which means that the consumers (the workers) are to foot the bill. When the federal government gets ready to start extensive projects to be paid for out of income and inheritance taxes on the higher and highest brackets, i. e., to be taken from the water storage tank, then things will begin to move and will stay moving. That will be fine for business, but not so good for the financiers. This is production for use and it is the only way out. To fit this into the existing order so as to produce the least dislocation of essential functions is the real problem. Electrical engineers interested in transient phenomena may well try their hands at this and let us hear from them. Engineers ought to be interested in social-economic problems and ELECTRICAL ENGINEERING ought to be a proper forum.

Very truly yours,
B. F. JAKOBSEN (A'09, M'13)
(Consulting Engineer, Central Building, Los Angeles, Calif.)

Reignition of an Arc at Low Pressures

To the Editor:

In a recent "Letter to the Editor" (ELECTRICAL ENGINEERING for December 1934, pages 1679–80) R. C. Mason criticizes the theory of the transition from a glow discharge to an arc proposed by us in a paper "Reignition of an Arc at Low Pressures" (ELECTRICAL ENGINEERING, volume 53, July 1934, pages 1081–5).

Mr. Mason claims that the data show that it is impossible for a sufficiently high electric field to be produced in the abnormal glow discharge to produce "field currents" from the cathode. He assumes that a field of 2×10^7 volts per centimeter is necessary to produce such field currents. This figure is correct for tungsten which has been very carefully outgassed in a very high vacuum. However if tungsten or any other metal is used which has not been outgassed, then field currents will appear at about 10^4 volts per centimeter. Obviously the latter condition obtains in a glow discharge.

Mason further assumes that the length of the cathode drop remains constant as the current is increased, so that an abnormal cathode drop is produced. This is not true. The field increases at the cathode primarily because the region of the cathode drop diminishes and thus produces a greater field at the cathode.

Only a very small amount of impurity on the cathode is necessary to act as a trigger action in the transition from a glow to an arc. This small amount can produce an excess of electrons from the cathode at that spot and these electrons due to ionization produce the high field necessary. Since this effect is cumulative, only some kind of a trigger action is necessary to start it. The theory is presented more in detail in "Cathode Drop in Arc Discharges" by S. S. Mackeown (ELECTRICAL ENGINEERING, volume 51, June 1932, page 386–8).

While it is true that there is not sufficient experimental data to give a good quantitative check of this theory, nevertheless the theory is consistent with all quantitative data that are available.

Simple energy considerations show that, if a high field does exist in the cathode drop of an arc, then that field must be produced during the transition from a glow discharge to an arc. It is only during a transition from a high to a low cathode drop that the high energy density in the cathode drop of an arc can be established. If for any reason this energy is dissipated, it is necessary for the arc to change to a glow discharge before this high energy density at the cathode can be reestablished.

Very truly yours,
S. S. MACKEOWN (A'27, M'34)
(Asst. Prof. of Elec. Engg., Calif. Inst. of Tech., Pasadena)
J. D. COBINE (Enrolled Student)
(Instructor in Elec. Engg., Harvard Univ., Cambridge, Mass.)

Why Use Vectors and Complex Notation?

To the Editor:

Quite recently an important electrical periodical has published a discussion of a-c vectors and the use of complex quantities. Many such presentations of the use of complex notation in a-c studies are confusing to students and it appears that this is partly due to authors failing to mention explicitly the fundamental ideas that form the foundation of the engineering use.

A development of the subject that is simplified to an extreme may be suggested as follows. It is only the sketchiest sort of outline that is offered here and the reader must complete the story. In fact, an effort has been made to give in this outline only those basic principles that are in general most neglected.

Alternating voltages and currents are of sinusoidal form, and so a voltage (for instance) whose maximum value is E_m may be written as a function of time

$$e = E_m \cos \omega t \qquad (1)$$

Such a sinusoidal voltage, and *only* one that is sinusoidal, may be represented by a vector in the following manner: A vector of length E_m rotates with an angular velocity ω and its projection on a fixed axis—with which it always makes an angle ωt—is equal to $E_m \cos \omega t$. See figure 1. With this understanding a vector may represent the voltage at all times, for at any particular instant its projection on the axis is equal to the instantaneous value of the voltage e. The voltage is not the vector, but only the projection of the vector, and vectors are used because it is easier to speak of the vector voltage E than to write equation 1.

It is mathematically expedient to use complex notation, and to measure "real" numbers along the reference axis of figure 1, and to measure "imaginary" numbers along an axis at right angles to it. The vector of voltage is then revolving in the "complex plane" as in figure 2 and at any instant its "real" component is the instantaneous value of voltage e as in equation 1. Hence it is only the "real" component of the vector that has an electrical meaning.

Complex notation is introduced for convenience only, because it is useful mathematically. We wish to add vector quantities (as 2 voltages, or 2 currents) and to divide (as a voltage by a current), because it is expedient to add and to divide vectors instead of computing with the instantaneous values given by equation 1. It happens that the addition of voltage vectors, according to the rule for addition set forth in algebra of complex quantities, gives a resultant vector which represents a voltage that is the sum of the 2 component voltages. That is to say, if e_1 be added to e_2 where

$$e_1 = E_{1m} \cos \omega t$$
$$e_2 = E_{2m} \cos (\omega t + \theta)$$

the actual resultant voltage is

$$e_3 = e_1 + e_2 = E_{1m} \cos \omega t + E_{2m} \cos (\omega t + \theta) \tag{2}$$

The rule for adding complex quantities is, by definition,

$$(a + jb) + (c + jd) = (a + c) + j(b + d)$$

and if the voltage vectors are added according to this rule the complex sum is a vector E_3 which properly represents the voltage e_3 because its real part is always equal to the

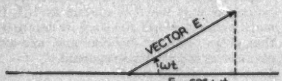

Fig. 1

sum of the real parts of its components and it therefore satisfies equation 2. The addition may be done graphically.

In an ordinary electric circuit a voltage $e = E_m \cos \omega t$ will produce a current $i = I_m \cos (\omega t - \phi)$. This is established experimentally. There is no simple relationship between these quantities, but there is a very simple one, called impedance, between their vectors. For if we represent the voltage by a vector E, and the current by a vector I, those vectors will be rotating at the same velocity ω, and a constant angle ϕ will always separate them. When the vectors are represented by complex quantities one may express this relationship by saying that the voltage "divided" by the current is a constant, and the division is performed according to the rule of complex algebra which says

$$\frac{E}{I} = \frac{E_m \underline{/j\omega}}{I_m \underline{/j\omega - \phi}} = \frac{E_m}{I_m} \underline{/(j\omega - (j\omega - \phi)}$$
$$= \frac{E_m}{I_m} \underline{/\phi} = Z \tag{3}$$

This constant ratio is then called "impedance." It is worthy of note that the usual concept of impedance has meaning only in terms of vectors. This is the chief justification of the use of complex quantities in electrical engineering, for without such a system the job of finding the current which would result from a given voltage would not be the simple computation that it is.

Another approach which is available for more mathematically minded students would begin by writing the instantaneous voltage as

$$e = E_m \cos \omega t = E_m \frac{\epsilon^{j\omega t} + \epsilon^{-j\omega t}}{2}$$
$$= \frac{1}{2} (E_m \epsilon^{j\omega t} + E_m \epsilon^{-j\omega t}) \tag{4}$$

The voltage is therefore half the sum of 2 quantities which may be identified as vectors rotating in the complex plane, and since the quantities are conjugate the vectors are of equal magnitude but rotate in opposite directions. In the same way, current is

$$i = \frac{1}{2} (I_m \epsilon^{j(\omega t - \phi)} + I_m \epsilon^{-j(\omega t - \phi)}) \tag{5}$$

The ratio of the vectors with angular velocity $+\omega$ is

$$\frac{E_m \epsilon^{j\omega t}}{I_m \epsilon^{j(\omega t - \phi)}} = \frac{E_m}{I_m} \epsilon^{j\phi} = Z \tag{6}$$

and this is identical with the impedance of equation 3. The ratio of the vectors with angular velocity $-\omega$ is similarly

$$\frac{E_m}{I_m} \epsilon^{-j\phi} \tag{7}$$

and this is the conjugate of impedance as defined above. To handle a-c problems in a simple manner, then, proceed as follows: Discard the conjugate vectors of equations 4 and 5 and write

$$\left.\begin{aligned} E &= E_m \epsilon^{j\omega t} \\ I &= I_m \epsilon^{j(\omega t - \phi)} \end{aligned}\right\} \tag{8}$$

with the convention that the voltage and current are the *real parts only* of the vectors. The usual concept of impedance is the result, as in equation 6, and it is unnecessary to carry through the conjugate impedance of equation 7. But when the answer is obtained it must be interpreted in accord with the convention specified.

Many other presentations will doubtless be found equally good or better (for a good engineering treatment see "Differential Equations for Electrical Engineers," by P. Franklin; John Wiley and Sons, 1933) but there is one matter which is seen so often in print that it may deserve special mention. It has to do with the definition of j. The symbol j, we often read, is defined as an operator that rotates a vector through 90 degrees, and $j \cdot j \cdot E$ leads E by 180 degrees and since the magnitude is unchanged it equals $-E$. These operations are by definition of j and are irreproachable. But j in such a case is not a number; it is a symbol of operation, for it has been so defined, and one cannot take the square root of a symbol of operation. While it is perfectly true that

$$j \cdot j \cdot E = j^2 E = -E$$

it is too naïve to say therefore

$$j^2 = -1 \text{ and } j = \sqrt{-1} \tag{9}$$

A similar disregard for definition could lead one to say that

$$\frac{d}{dx} \frac{d}{dx} \sin x = \frac{d^2}{dx^2} \sin x = -\sin x$$

and it therefore follows that

$$\frac{d^2}{dx^2} = -1 \text{ and } \frac{d}{dx} = \sqrt{-1} \tag{10}$$

Of course the difference between equations 9 and 10 is that by universally accepted definition and notation the former is true

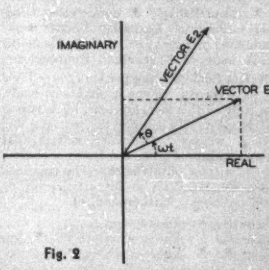

Fig. 2

and the latter is not. But the methods of derivation of the 2 equations are equally erroneous, for in each case a symbol of operation has been treated as if it were a number. To derive equation 9 properly, adopt the following *definition* of multiplication of complex quantities:

$$(a + jb)(c + jd) = (ac - bd) + j(ad + bc) \tag{11}$$

Then let $a = c = 0$ and $b = d = 1$, and one finds $j1 \cdot j1 = -1$. If by convention the symbol j is written to mean the number $j1$, one may now proceed to equation 9 with complete rigor by application of the definition of square root. It is essential to note that j (apart from the agreement to designate $j1$ by this symbol) is not itself a number and does not equal $\sqrt{-1}$. Thus the use of the symbol j in $(a + jb)$ may be said to be a useful shorthand notation for "the ordered pair of real numbers a and b." In fact, a careful approach to the study of complex quantities is by way of ordered number pairs. (An excellent discussion of complex quantities appears in "Pure Mathematics," by G. H. Hardy; Cambridge University Press, 1925.)

This is not the hair-splitting quibble that it may seem, for in the absence of a definition of multiplication such as is supplied by equation 11 there is no way provided by mathematics to multiply together complex quantities. Should this not be clear it will become so if one will start with the formulation of the number system and review the

definitions of multiplication. It is perhaps unreasonable to expect a student of elementary engineering to comprehend the "foundations of arithmetic," but his lack of familiarity with mathematical modes of thought does not justify confusing him with loose statements for the sake of a specious simplicity.

Very truly yours,

HUGH SKILLING (A'28, M'34)
(Dept. of Elec. Engg., Stanford University, Calif.)

H. M. BACON (Nonmember)
(Dept. of Mathematics, Stanford University, Calif.)

Loading a Bank of Dissimilar Transformers

To the Editor:

In the article by J. A. Bock on the "Loading a Bank of Dissimilar Transformers" published on pages 1597–8 of the December 1934 issue of ELECTRICAL ENGINEERING, the first fundamental equation $I_a = -j\sqrt{3}\, I_A$ is incorrect for the assumptions made. In spite of this fact, however, his equation 11 is right. To correct this mistake and clarify whatever misleading notions that may be derived from the faulty equation, is the purpose of this letter. The notations used by Mr. Bock in his article will be adopted here. Furthermore, let

$\dot{Z}_A = R_A + j\,X_A$
$\dot{Z}_B = R_B + j\,X_B$
$\dot{Z}_C = R_C + j\,X_C$

$\dot{I}_d$ be the direct sequence current in the windings of the transformers
$\dot{I}_0$, the zero sequence current in the windings of the transformers
Under the assumption that $I_a = I_b = I_c$ (see figure 1) we get

$\dot{I}_A = \dot{I}_d + \dot{I}_0$
$\dot{I}_B = a^2\dot{I}_d + \dot{I}_0$
$\dot{I}_C = a\dot{I}_d + \dot{I}_0$

The line currents

$\dot{I}_a = \dot{I}_B - \dot{I}_C = -j\sqrt{3}\,\dot{I}_d$
$\dot{I}_b = a^2\,\dot{I}_a$
$\dot{I}_c = a\,\dot{I}_a$

Therefore

$$0 = N_A\dot{E}_A' + N_B\dot{E}_B' + N_C\dot{E}_C' - [(\dot{I}_d + \dot{I}_0)\,\dot{Z}_A + (a^2\dot{I}_d + \dot{I}_0)\dot{Z}_B + (a\dot{I}_d + \dot{I}_0)\,\dot{Z}_C]$$

Hence If $E_A' = E_B' = E_C'$ we get

$$\dot{I}_0 = \frac{\dot{E}_A'(N_A + a^2N_B + aN_C)}{\dot{Z}_A + \dot{Z}_B + \dot{Z}_C} - \dot{I}_d\,\frac{\dot{Z}_A + a^2\dot{Z}_B + a\dot{Z}_C}{\dot{Z}_A + \dot{Z}_B + \dot{Z}_C}$$

Under the 2 assumptions made it could clearly be seen that the unbalance in the current of the transformers is due to

(a). The difference in the ratios of transformations and to
(b). The difference in the impedances of the transformers

The total current in the secondary winding of transformer A is

$$I_A = I_0 + I_d = \frac{\dot{E}_A'(N_A + a^2N_B + aN_C)}{\dot{Z}_A + \dot{Z}_B + \dot{Z}_C} + \frac{\dot{I}_a(a\dot{Z}_B - a^2\dot{Z}_C)}{\dot{Z}_A + \dot{Z}_B + \dot{Z}_C}$$

$$I_B = \dot{I}_0 + a^2\dot{I}_d = \frac{\dot{E}_A'(N_A + a^2N_B + aN_C)}{\dot{Z}_A + \dot{Z}_B + \dot{Z}_C} + \frac{\dot{I}_a\dot{Z}_c - a\,\dot{I}_a\dot{Z}_A}{\dot{Z}_A + \dot{Z}_B + \dot{Z}_C}$$

and

$$I_C = I_0 + aI_d = \frac{\dot{E}_A'(N_A + a^2N_B + aN_C)}{\dot{Z}_A + \dot{Z}_B + \dot{Z}_C} + \frac{\dot{I}_a(a^2\dot{Z}_A - \dot{Z}_B)}{\dot{Z}_A + \dot{Z}_B + \dot{Z}_C}$$

If we assume that the ratios of transformations of the 3 transformers are equal then

$$\dot{I}_0 = -\,\dot{I}_d\,\frac{\dot{Z}_A + a^2\dot{Z}_B + a\dot{Z}_C}{\dot{Z}_A + \dot{Z}_B + \dot{Z}_C}$$

and

$$I_A = \frac{\dot{I}_a(a\dot{Z}_B - a^2\dot{Z}_C)}{\dot{Z}_A + \dot{Z}_B + \dot{Z}_C}$$

$$\dot{I}_B = \frac{\dot{I}_a(\dot{Z}_c - a\dot{Z}_A)}{\dot{Z}_A + \dot{Z}_B + \dot{Z}_C}$$

and finally

$$\dot{I}_C = \frac{\dot{I}_a(a^2\dot{Z}_A - \dot{Z}_B)}{\dot{Z}_A + \dot{Z}_B + \dot{Z}_C}$$

If on the other hand the ratios of transformations are unequal but the impedances are equal in both moduli and arguments then

$$\dot{I}_0 = \frac{\dot{E}_A'(N_A + a^2N_B + aN_C)}{\dot{Z}_A + {}_B\dot{Z} + \dot{Z}_C}$$

and

$$\dot{I}_A = \frac{\dot{E}_A'(N_A + a^2N_B + aN_C)}{\dot{Z}_A + \dot{Z}_B + \dot{Z}_C} + j\,\frac{\dot{I}_a}{\sqrt{3}}$$

$$\dot{I}_B = \frac{\dot{E}_A'(N_A + a^2N_B + aN_C)}{\dot{Z}_A + \dot{Z}_B + \dot{Z}_C} + \frac{\dot{I}_a}{\sqrt{3}}\,e^{-j\,90}$$

and

$$\dot{I}_C = \frac{\dot{E}_A'(N_A + a^2N_B + aN_C)}{\dot{Z}_A + \dot{Z}_B + \dot{Z}_C} + \frac{\dot{I}_a}{\sqrt{3}}\,e^{j\,210}$$

In all the preceding it should be kept in mind that I_a is the circulating current in the transformers due to the unbalance.

Yours very truly,

E. M. SABBAGH (A'28)
(Instructor in Elec. Engg., Purdue University, Lafayette, Ind.)

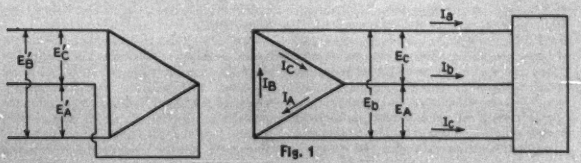

Fig. 1

Operational Calculus

To the Editor:

In my commentary appearing as a "Letter to the Editor" in the December 1934 issue of ELECTRICAL ENGINEERING, p. 1681, 2 D operational theorems are given. The first and so-called "transfer" operator is Lagrange's (Oeuvres, volume 3, 1772, page 450) symbolic form of Taylor's theorem ("Methodus Incrementorum," 1717, 1715? page 23). The second theorem (functional derivative of a product) is my own, and I append herewith a crisp derivation of same.

Within the scope of Teixeira's theorem (1900; *q. v.*, "Modern Analysis," Whittaker and Watson, 4th edition, page 131) it is possible to expand one function in terms of another:

$$\phi(t) = \sum_{n=-\infty}^{n=+\infty} A_n[F(t)]^n$$

Consider now the functions $\phi_1(t)$ and $\phi_2(t)$, and the functional operator $\phi_3(D)$. Let:

$\phi_3(D) = \Sigma A_n e^{nD}$
$\phi_1(t) = \Sigma B_m e^{mt}$

and with D_t operating on $\phi_t(\ )$ only,

$$\phi_3(D)\{\phi_1(t)\phi_2(t)\} =$$

$$= \sum_{m=-\infty}^{m=+\infty} B_m \sum_{n=-\infty}^{n=+\infty} A_n e^{m(t+n)}\phi_2(t+n)$$

$$= \sum_{m=-\infty}^{m=+\infty} B_m e^{mt} \sum_{n=-\infty}^{n=+\infty} A_n e^{n(m+D_t)}\phi_2(t)$$

$$= \sum_{m=-\infty}^{m=+\infty} B_m e^{mt}\phi_3(m + D_t)\phi_2(t)$$

$$= \sum_{m=-\infty}^{m=+\infty} B_m e^{m(t+D_t)}\phi_3(D_t)\phi_2(t)$$

$$= \phi_1(t + D_t)\phi_3(D_t)\phi_2(t)$$

From this result, other interesting and useful theorems are easily derivable.

While in my above referred to communication the unit function appears as $1(_t)$, I much prefer the form $1(t)$ since its nature is that of an ordinary function and not an operator as is sometimes supposed.

Thus:

$$p^{-1}\ \{\phi\ (t)\ 1(t)\} \equiv \lim_{n \gtrsim 0} \int_n^t \phi(t)1(t)dt$$

For a diversity of mathematical and dynamical reasons, I believe my equivalent form:

$$p^{-1}\{\phi(t)1(t)\} \equiv \int_\epsilon^t \phi(t)1(t)dt$$

where ϵ is a positive infinitesimal of arbitrarily high order, superior to the above. Also, $t\ 0 \lesssim$ should be corrected to $t \lesssim 0$, and my street number is 52 and not 32.

Very truly yours,

I. H. BARKEY (A'29)
(Technical Consultant, 2020 52nd St., Brooklyn, N. Y.)

Personal Items

W. F. Wells (A'99, F'12) first vice president and general manager, and a director, of the Brooklyn Edison Company, Inc., Brooklyn, N. Y., retired March 1, 1935, after more than 42 years of service. Mr. Wells studied at Rutgers College, and in 1892 entered the employ of the Edison Electric Illuminating Company of Brooklyn, predecessor of the Brooklyn Edison Company. Several years later he became connected with other companies, which later merged to form The New York Edsion Company, and was associated in the construction of the Waterside generating station, being placed in charge of its operation upon completion in 1901. In 1905 he returned to the Brooklyn company as general superintendent, and in 1913 was elected vice president and general manager and a director of this company and of the Kings County Electric Light and Power Company, these companies forming the Brooklyn Edison Company in 1919. Mr. Wells was a member of the Institute's committee on power stations (now power generation) 1917–19, and took an active part in the work of other societies and organizations.

T. R. Langan (A'13, M'30) since 1931 northeastern district manager, Westinghouse Electric and Manufacturing Company, New York, N. Y., has been appointed traffic manager of the company with headquarters at East Pittsburgh, Pa. Mr. Langan studied at Pratt Institute and at Carnegie Institute of Technology, and was employed by the Westinghouse company in 1904. He engaged principally in electric railway engineering, and in 1919 was transferred to the sales department, becoming manager of the Syracuse, N. Y., office in 1922. Two years later he became transportation manager of the northeastern district, and more recently district manager. Among the important operations with which he has been associated may be mentioned the electrification of the New York, New Haven and Hartford Railroad, and subway and elevated rapid transit train service in New York, N. Y., and Brooklyn, N. Y.

H. P. Charlesworth (M'22, F'28, and junior past-president) assistant chief engineer, American Telephone and Telegraph Company, New York, N. Y., has been reelected as chairman of the board of the Engineering Foundation. He was elected chairman recently to fill an unexpired term as announced in Electrical Engineering for January 1935. Mr. Charlesworth is the Institute's representative on the board. He is also serving the Institute at present as chairman of the committee on Institute policy and a member of the Edison medal and code of principles of professional conduct committees, as well as representative of the Institute on the John Fritz medal board of award. He has also served on other Institute committees, and was a manager 1923–27, a vice president 1930–32, and president 1932–33.

G. H. Bucher (M'24) president and general manager, Westinghouse Electric International Company, New York, N. Y., has been elected a vice president of the Westinghouse Electric and Manufacturing Company. Mr. Bucher is a graduate of Pratt Institute, Brooklyn, N. Y., and has been with the Westinghouse organization since 1909. In 1911 he was transferred to the export department at New York and in 1920 was appointed assistant to the general manager of the Westinghouse Electric International Company. In this company he advanced to the successive positions of assistant general manager in 1921, vice president and general manager in 1932, and president and general manager in 1934.

F. D. Newbury (A'07, F'21) general manager, machinery engineering, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been reelected as a member of the executive committee of the electrical standards committee of the American Standards Association. Mr. Newbury has been a member of the Institute's standards committee since 1919, and was its chairman 1928–31. He also has been Institute representative on the United States national committee of the International Electrotechnical Commission since 1923, and representative on the electrical standards committee of the American Standards Association since 1931. Mr. Newbury has served on several other Institute committees, and was chairman of the committee on electrical machinery for the year 1927–28. He has presented several Institute papers.

C. R. Harte (A'10, M'32) engineer, The Connecticut Company, New Haven, Conn., has been unanimously reelected chairman of the electrical standards committee of the American Standards Association. This committee, representing 12 trade and technical associations and government departments, is responsible to the standards council of the association for the orderly development of the associations electrical standardization work. Mr. Harte has been a member of the Institute's standards committee since 1923, and was a representative of the Institute on the United States national committee of the International Electrotechnical Commission, 1929–32.

S. L. Nicholson (A'00, F'13) assistant to vice president and general manager, Westinghouse Electric and Manufacturing Company, New York, N. Y., has been reelected as a member of the executive committee of the electrical standards committee of the American Standards Association.

R. H. Tapscott (A'18, F'29, and vice president) vice president, The New York Edison Company, New York, N. Y., has been reelected as a member of the executive committee of the electrical standards committee of the American Standards Association. Mr. Tapscott was a director of the Institute, 1930–34, and has served on a number of the Institute's committees, and is now chairman of the finance committee, of which he has been a member since 1931. He is also a member of the Institute's executive committee and of the committee on coordination of Institute activities, and since 1928 of the headquarters committee, during 1929–33 as chairman.

Sidney Withington (M'20, F'24) electrical engineer, New York, New Haven and Hartford Railroad, New Haven, Conn., has been unanimously reelected vice chairman of the electrical standards committee of the American Standards Association. Mr. Withington has been a member of the Institute's transportation committee since 1927, serving as its chairman 1929–31, and was a member of the meetings and papers (now technical program) committee 1929–31.

V. E. Bird (A'13) executive vice president, Hartford Electric Light Company, Hartford, Conn., and president, Connecticut Power Company, has been elected president of the former company. He had been its executive vice president since 1929, and has been president of the Connecticut Power Company since 1933. He was formerly with the Stone and Webster organization, and since 1913 has been with the Connecticut Power Company, which was acquired by the Hartford Electric Light Company in 1922.

C. N. Simpson (M'34) since 1929 chief engineer of the Gatineau Power Company, Ottawa, Ont., Can., has been appointed general manager of the utility. Mr. Simpson is a graduate of the University of Toronto and was with the Northern Canada Power Company and the Abitibi Power and Paper Company before coming to the Gatineau company in 1926. He is a member of the executive committee of the Canadian Electrical Association and of the Professional Engineers of Quebec.

Samuel Ferguson (A'02) president, Hartford Electric Light Company, Hartford, Conn., has been elected chairman of the board of directors of the company. Mr. Ferguson came to the Hartford company as vice president in 1912 after 12 years with the General Electric Company, and became president in 1924. He is a past-president of the Association of Edison Illuminating Companies and a trustee of the Edison Electric Institute.

G. L. Knight (A'11, F'17) vice president, Brooklyn Edison Company, Inc., Brooklyn, N. Y., has been reelected as first vice president of United Engineering Trustees, Inc., serving until October 1935. Mr. Knight has been Institute representative on the

board of United Engineering Trustees, Inc., since 1933, and served a previous term 1926–31. He has also served on a number of the Institute's general committees.

C. F. Hood (A'20) since 1933 manager of the Worcester, Mass., district of the American Steel and Wire Company, has been appointed vice president in charge of operations. Mr. Hood is a graduate of Purdue University, and has been with the company since 1917.

C. H. Lydall (A'20) Chicago, Ill., North American representative of Merz and McLellan and associated firm of Merz and Partners, London, England, is not a member of the staff of Sargent and Lundy, Inc., Chicago, as stated in the February 1935 issue of Electrical Engineering, page 258, but may be addressed in care of Sargent and Lundy, Chicago.

Gano Dunn (A'91, F'12, Life Member, and past-president) president, J. G. White Engineering Corporation, New York, N. Y., has been elected president of the board of trustees of Cooper Union, New York. Mr. Dunn is well known for his activities in the Institute, having served on many committees as well as 2 terms as a manager, 2 terms as a vice president, and as president, 1911–12.

T. S. Bills (A'31) motion picture sound engineer, formerly with Fox Movietone News, Inc., New York, N. Y., is now in the employ of the Hearst Metrotone News, New York, and is at present in Washington, D. C.

W. L. Knauss (A'31) who has been a student engineer in the testing department of the General Electric Company at Schenectady, N. Y., is now in the refrigeration engineering department at Fort Wayne, Ind.

J. H. Gill (A'12) former president and general manager, Florida Power and Light Company, Miami, is now chairman of the board of the Memphis Electric Company and vice president of the National Power and Light Company.

C. H. Anderson (M'34) former assistant superintendent, Cattaraugus division, Niagara, Lockport and Ontario Power Company, Olean, N. Y., is now superintendent of the Bradford Electric Company, Bradford, Pa.

J. S. Overstreet (A'31) formerly quotation engineer, General Electric Company, Schenectady, N. Y., is now in the cable sales department of the company at Bridgeport, Conn.

J. L. Tudbury (A'28) manager, Salem Electric Lighting Company, Salem, Mass., has been named general manager of the Gloucester Gas Light Company.

J. O. Turner (A'33) is now an assistant engineer in the national park service, U.S. Department of the Interior, with field headquarters at San Francisco, Calif.

F. B. Conlon (A'31) of Philadelphia, Pa., has recently become an engineering draftsman in the office of the electrical engineer, Pennsylvania Railroad, New York, N. Y.

G. W. Mikuls (A'30) formerly with the Pacific Gas and Electric Company, Oakland, Calif., is now with the Shell Oil Company at Long Beach, Calif.

T. O. Zittel (A'34) is now a student engineer with the Bethlehem Steel Corporation, Lackawanna, N. Y.

C. J. Dunn (A'33) is now a valuation engineer with the Westchester Lighting Company, Mt. Vernon, N. Y.

Obituary

Michael Idvorsky Pupin (A'90, F'15, HM'28, past-president and member for life) professor emeritus in active residence, Columbia University, New York, N. Y., died March 12, 1935. One of the leading scientists at the time of his death, he came to the United States in 1874 as a penniless boy intent on securing a higher education, but whose first job was driving mules for a Delaware farmer. Doctor Pupin was born at Idvor, Banat, Hungary (now in Yugoslavia) October 4, 1858. In 1879 he entered Columbia University, and was graduated with the degree of bachelor of arts in 1883. He afterward studied mathematics at the University of Cambridge, England, and physics at the University of Berlin, Germany, holding while in Berlin the John Tyndall fellowship of Columbia University. After receiving the degree of doctor of philosophy at Berlin in 1889 he became instructor of mathematical physics at Columbia University, and adjunct professor of mechanics in 1892. In 1901 he was appointed professor of electromechanics, and 2 years later director of the Phoenix Research Laboratory of Columbia University, a position which he held until he retired from active service in 1929. Doctor Pupin made important contributions to knowledge in a-c theory, the passage of electricity through gases, long distance communication, and other subjcts. In a paper published in 1896 he first described the nature of secondary X ray radiation, and in 1902 he sold patents covering his inventions in electrical tuning, so important in radio broadcasting, to the Marconi Company. Previous to this he had accomplished the rectification of high frequency electrical waves, the description being published in 1899. Rapid X ray photography by the use of a fluorescent screen was invented and described by Doctor Pupin in 1896. The chief invention credited to him is the principle of loading telephone or telegraph lines by lumped inductance, his "loading coils" compensating by their inductance for the capacitance between the 2 wires of the circuit. Doctor Pupin also proposed a rule for the placement of these inductances along the line. In this way transmission over long open wire or cable lines was greatly improved. Doctor Pupin received numerous honors for his work, and was awarded some 18 honorary degrees. Among the medals he received are the Cresson medal of the Franklin Institute, 1902; the Prix Herbert of the French Academy, 1916; the medal of the Institute of Radio Engineers, 1924; the Edison medal of the Institute, 1925; and the John Fritz medal, 1932. Doctor Pupin was a past-president of the Institute of Radio Engineers, a past-chairman of the Engineering Foundation, and a member of many other societies. He was a manager of the Institute, 1892–95, a vice president, 1895–97 and 1901–03, and president, 1925–26, in addition serving on a number of Institute committees. Several books and numerous papers have been written by him, many of his papers having been presented before the Institute.

John C. Barclay (A'03, M'04, and member for life) Montclair, N. J., died August 24, 1934, according to word just received at Institute headquarters. For many years he was in the service of the Western Union Telegraph Company, and was assistant general manager when he left the company in 1910. Born at Greensburg, Pa., April 17, 1856, he became a messenger boy for the Pennsylvania Railroad in 1868. Two years later he became a telegraph operator, working for various railroads until he was engaged in 1875 as an inspector for the Automatic Fire Alarm Company, New York, N. Y. The following year he was employed by the Western Union Telegraph Company at Baltimore, Md., and in 1878 was sent to Chicago, Ill. In 1888, while night manager, he completed a course in dental surgery, but continued in the telegraph company and was appointed electrician of the western division in 1898. Four years later Mr. Barclay was appointed electrical engineer of the entire Western Union system, with headquarters in New York, and in 1903 he was appointed assistant general manager. Mr. Barclay secured several patents covering improvements on telegraph instruments and a type printing system.

William Rawson Collier (F'20) manager, Southern Natural Gas Corporation, Birmingham, Ala., died late in January 1935. He was a graduate of Massachusetts Institute of Technology, class of 1900. For the following 4 years he was senior partner of the firm of Collier and Brown, consulting engineers of Atlanta, Ga., and had charge of the design and construction of a number of power and industrial plants. In 1904 he joined the Georgia Railway and Electric Company, where he was in charge of designing and later of sales. In 1912 the Georgia Railway and Power Company was formed and he became its sales manager, subsequently taking similar duties in subsidiary companies. In 1922 he resigned to

accept a position with the Central Hudson Gas and Electric Corporation, Poughkeepsie, N. Y., and in more recent years he was connected with Dwight P. Robinson and Company, United Gas Improvement Contracting Company, Hall Electric Heating Company, Alabama National Gas Corporation, and Mississippi Public Service Company.

JEROME G. VANZANDT (A'31) San Pedro, Calif., died recently following an automobile accident. He was born at Chicago, Ill., July 22, 1883, and received the degrees of bachelor of science, Purdue University, 1904, and master of science, University of Wisconsin, 1908. He then became an associate professor in the engineering college of the University of Southern California for 2 years, following which he was project engineer for the Southern Sierras Power Company on various projects in California. In 1918 he went to France with the A.E.F. engineers, and engaged in private practice upon his return, being in Chile 1922–27 as a consulting engineer to the Republic of Chile and as a designing engineer with the Braden Copper Company at Rancaugua. In 1927 Mr. VanZandt was employed by the U.S. War Department, engineers office, and was located at Pittsburgh, Pa., and more recently at San Pedro.

FREDERICK W. MCKOWN (A'19) member of the technical staff, Bell Telephone Laboratories, Inc., New York, N. Y., died February 27, 1935. He was born at Ironduquoit, N. Y., March 1, 1893. In 1914 he received the degree of bachelor of arts from Williams College, and in 1916 the degree of bachelor of science in electrical engineering from Massachusetts Institute of Technology. Mr. McKown then entered the engineering department of the Western Electric Company, New York, transferring to the development and research department of the American Telephone and Telegraph Company in 1921. Since March 1934 he had been a member of the laboratories. Mr. McKown had been in charge of the transmission rating and quality group of the local transmission development department of the laboratories, where he was concerned with fundamental studies on matters effecting transmission, making important contributions in this field.

HENRY EDISON PHELPS (A'17) member of the technical staff, Bell Telephone Laboratories, New York, N. Y., died on February 21, 1935. He was born at Oxford, Mass., March 15, 1893, and received the degree of bachelor of science from Worcester Polytechnic Institute in 1914. He then went to Purdue University as an assistant and received the degree of electrical engineer in 1916. After another year of teaching electrical machinery design at the university he entered the American Telephone and Telegraph Company at New York as a member of the general engineering department, later entering the development and research department. His work was in connection with the development of toll switchboards and switching systems. In March 1934, Mr. Phelps was transferred to the laboratories.

HARRY HANSON DANSBOE (A'30) electrical superintendent, Atlantic Oil Producing Company, Dallas, Tex., died January 19, 1935. He was born at Dallas October 28, 1889, and was employed at the age of 12 as a messenger boy by the Western Union Telegraph Company. He worked his way through successive steps as operator and lineman, and in 1910 became night manager. In that year he went to California with the Producers Transportation Company, and later was a foreman on the Los Angeles aqueduct construction. After a number of other positions in Oklahoma and Texas, he came to the Atlantic Oil Producing Company as electrical superintendent in 1924.

CHARLES KEWLEY KNEALE (A'23) sound engineer, Warner Brothers Circuit Management Corporation, Philadelphia, Pa., died August 26, 1934, according to word just received at Institute headquarters. He was born at Baltimore, Md., December 27, 1897, and attended Marconi Wireless School, Cleveland, Ohio, and Drexel Institute, Philadelphia. In 1920 he entered the testing department of the Philadelphia Electric Company, and was with this company until 1929 when he was employed by Electrical Research Products, Inc.

JOSEPH C. POTTS (A'32) sales engineer, The Electric Storage Battery Company, Washington, D. C., died February 17, 1935. He was born at New York, N. Y., February 1, 1893, and entered the employ of the company in 1912, becoming superintendent of the assembling plant in 1915 and sales engineer in 1931.

WILLIAM EDWARD AHRENS (A'22) western district plant manager, Pacific Telephone and Telegraph Company, Seattle, Wash., died on January 26, 1935. He was born at Elberfeld, Ind., July 15, 1881, and graduated from the electrical engineering course at Purdue University in 1908. Following graduation he entered the construction department of the telephone company at Seattle, and advanced through the department to the position of plant engineer, which he held until he became plant manager in 1929.

CARLETON MURRAY BROWN (A'15) sales engineer, Westinghouse Electric and Manufacturing Company, Washington, D. C., died February 12, 1935. He was born at Lenox, Mass., October 5, 1889, and studied at Worcester Polytechnic Institute. He then entered the apprentice course of the Westinghouse company, and later the general engineering division, engaging in power house and railway high voltage overhead work for a short time, after which he entered sales engineering.

WILL G. COLE (A'24) construction engineer, Natoma, Calif., died recently according to word received at Institute headquarters. He was born in Allegheny County, Pa., April 4, 1882, and began the study of electricity while working in the electrical departments of coal mines in Pennsylvania and West Virginia. He was employed in plant maintenance by a number of companies throughout the west.

CLAUDE KING (A'30) building superintendent, Memphis Tenn., died February 22, 1935. He was born at Owensboro, Ky., May 9, 1892, and studied electrical engineering through extension courses of the University of Tennessee. For a number of years he was chief engineer of the American Finishing Company, Memphis, and had been superintendent of the Falls Building for the past year and a half.

LEON BASIL BOULAVIN (A'32) meter tester, Brooklyn Edison Company, Inc., Brooklyn, N. Y., died June 12, 1934, according to word just received at Institute headquarters. Mr. Boulavin was born in Russia June 30, 1892, and studied in Russia and at Pratt Institute, Brooklyn, N. Y. He had been employed by the Brooklyn Edison Company since 1930.

Membership

Recommended for Transfer

The board of examiners, at its meeting held on March 21, 1935, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Beach, Robin, prof. of E.E., head of dept., Poly. Inst. of Bklyn., N. Y.
Brackett, Byron B., director of radiophone broadcasting, Univ. of S. D., Vermillion.
Horle, Lawrence C. F., consg. engr., 90 West St., N. Y. City.

3 to Grade of Fellow

To Grade of Member

Calvert, John F., E.E., Westinghouse E. & M. Co., E. Pittsburgh, Pa.
Eberman, Joseph W., chief electrician, Cerro de Pasco Copper Corp., Morococho, Peru, S. A.
Groves, Wm. M., Jr., plant extension engr., Okla. Southwestern Bell Tel. Co., Okla. City.
Hansson, Edwin, transmission engr., Pa. Water & Pwr. Co., Baltimore, Md.
Kelso, Newton T., fractional hp motor engr., Gen. Elec. Co., Fort Wayne, Ind.
Kimbark, Edward W., asst. in E.E., Mass. Inst. of Tech., Cambridge.
Kramer, Andrew W., Jr., application engr., Gen. Elec. Co., Fort Wayne, Ind.
McFarlan, James P., asst. engr., Union Gas & Elec. Co., Cincinnati, O.
Morrill, Wayne J., engr. in charge of design engg., Gen. Elec. Co., Fort Wayne, Ind.
Moulton-Redwood, W. J., cons. and appraisal engr, 20 Eastdale Ave., Toronto, Ont.
Rifenburg, R. C., division engr., Bklyn. Edison Co. Inc., N. Y.
Schaefer, Edward J., design engr., Gen. Elec. Co., Fort Wayne, Ind.
Skinner, Thomas V. S., special field representative, Westinghouse Elec. Intl. Co., Shanghai, China

Spruce, Allan M., switchgear dept., Gen. Elec. Co., Witton, Birmingham, Eng.
Stansel, Numan R., industrial engg. dept., Gen. Elec. Co., Schenectady, N. Y.
Towner, Orrin W., broadcast engr., Bell Tel. Lab., Inc., N. Y. City.
Tuites, Clarence E., instructor in elec. layout design, Mechanics Inst., Rochester, N. Y.
Vedder, Edwin H., E.E., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Warner, Wilbur W., E.E., Gen. Elec. Co., Fort Wayne, Ind.
Webb, Robert T., instructor in E.E., Wash. Univ., St. Louis, Mo.

20 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before Apr. 30, 1935, or June 30, 1935, if the applicant resides outside of the United States or Canada.

Adair, W. G., Southern Bell Tel. & Tel. Co., Louisville, Ky.
Amatneek, W., 792 E. 175th St., N. Y. City.
Ankrom, W. R., Ohio Pwr. Co., Bellaire.
Appleman, W. R. (Member), Marathon Elec. Mfg. Corp., Wausau, Wis.
Baessler, K. H., Calif. Wire Cloth Co., Oakland.
Bagwell, L. R., Caywood Elec. Co., Houston, Tex.
Ballenger, W. R., Texas Oil Co., Fillmore, Calif.
Baluta, R. E., Bklyn. Union Gas Co., N. Y.
Barger, G. K., U. S. Bureau of Fisheries, Seattle, Wash.
Bentley, C., Valley Radio & Elec., Mission City, B. C., Can.
Bergson, S. J., Bklyn. Engg. Inst., N. Y.
Birch, J. E., Endura Mfg. Co., Quakertown, Pa.
Blade, Mary F., N. Y. State Employment Serv., Bklyn., N. Y.
Bleuth, F. S., United Engrs. & Constructors, Inc., Phila., Pa.
Blum, A. R., 10 Rawson St., Albany, N. Y.
Blum, L. E., Barium Products Ltd., Modesto, Calif.
Bohne, W. M., Wells Gardner & Co., Inc., Chicago, Ill.
Bondurant, J. E., U. S. Coast & Geodetic Survey, Washington, D. C.
rakel, O. W., Puget Sound Pwr. & Lt. Co., Seattle, Wash.
Bridgers, J. F., 920 E. 2nd St., Washington, N. C.
Brother Bernard (J. F. Ryan) (Member), Manhattan Col., N. Y. City.
Brown, J. C., Ga. Pwr. Co., Atlanta.
Brown, J. D., 2806 Jefferson St., Baltimore, Md.
Brownell, A. B., G. P. Goode Lamp Co., Cincinnati, Ohio.
Buie, J. M., 2505 Willing Ave., Fort Worth, Tex.
Buttner, C. M., Hunter Fan & Motor Co., Fulton, N. Y.
Callaghan, T. J., Waite & Bartlett X-Ray Co., Cleveland, O.
Carlson, R. T. (Member), Trumbull Elec. Mfg. Co., Ludlow, Ky.
Carlson, W. H., 2124 Vineyard Ave., Los Angeles, Calif.
Carter, J. K., Allen Bradley Co., Milwaukee, Wis.
Caspar, R. B., with M. R. Scharff, Mt. Vernon, N. Y.
Cayce, D. F., James & Co., St. Louis, Mo.
Clemens, H. L., Cleveland Elec. Illum. Co., Cleveland, O.
Cleveland, A. W., Gen. Radio Co., Cambridge, Mass.
Clough, F. P., U. S. North Eastern Penitentiary, Lewisburg, Pa.
Coffman, G. M., c/o George W. Taylor Co., Williamson, W. Va.
Collins, H. L., Hoover Co., N. Canton, Ohio.
Colville, D. A., Wash. Water Pwr. Co., Spokane.
Cook, D. E., Citizens Bank Bldg., Rm. 200, Pasadena, Calif.
Cooper, J. H., with M. R. Scharff, Dobbs Ferry, N. Y.
Cotner, W. W., Cornell Univ., Ithaca, N. Y.
Cox, H. O., 1408 N. Garey Ave., Pomona, Calif.
Craig, R. B., Standard Milk Machy. Co., Louisville, Ky.
Crichton, A. L., Wayne Co., Relief Administration, Wooster, Ohio.
Czyzewski, J. B., Consolidated Film Industries, Palisades Park, N. J.
Danesi, C. M., Brown Univ., Providence, R. I.
D'Aniello, J. P., Postal Tel. Cable Co., N. Y. City.
Davis, R. W., Jr., New Brunswick Public Night Schools, N. J.
Deane, B. T., Essex, Conn.
Deane, J., Donshaven Devpmnt. Co., Riondel, B. C., Can.
Deardorff, E. R., Bingham Pump Co., Portland, Ore.
Decker, W. C., Du Pont Rayon Co., Richmond, Va.
Dellamonica, L., Box 237, Yerington, Nev.
Deming, H. P., Indianapolis Rys., Ind.
Dieffenbach, P. E., 16 Colony St., West Hempstead, N. Y.
Dix, W. H., Potomac Elec. Pwr. Co., Washington, D. C.
Dixon, H. S., Reclamation Dist. No. 108, Knights Landing, Calif.
Dodge, W. R., Federal Shipbldg. Co., Kearny, N. J.
Doonan, R. E., Elec., Water & Sewage Systems, Winterset, Ia.
Eichhorn, C. W., Am. Transformer Co., Newark, N. J.
Fahton, H. H., 364 Jefferson Ave., Sharon, Pa.
Few, E. L. (Member), Carborundum Co., Niagara Falls, N. Y.
Fischer, A. J., Union Wire Die Co., N. Y. City.
Fortin, J. J., Duke Price Pwr. Co., Arvida, Que., Can.
Fulton, R. W., Factory Ins. Assn., Hartford, Conn.
Gaffney, C. J., 2531 W. Wisconsin Ave., Milwaukee, Wis.
Gallmeier, R. A., Gen. Elec. Co., Fort Wayne, Ind.
Galloway, J. H., Jr., A. B. Staley Mfg. Co., Decatur, Ill.
Geiger, W. C., Jr., Penn. R. R. Co., Phila., Pa.
Gerz, G. H., Lincoln Tel. & Tel. Co., Nebr.
Gieringer, C. K., Liebel-Flarsheim Co., Cincinnati, Ohio.
Gilly, H. A., Gen. Elec. Co., Bridgeport, Conn.
Gohn, C. T., Westinghouse E. & M. Co., Phila., Pa.
Goldberg, H., Univ. of Wis., Madison.
Gow, R. B., Mass. Inst. of Tech., Cambridge.
Griffith, J. O., Nassau Collegiate Center, Garden City, N. Y.
Guilford, E. S., Rockefeller Center, N. Y. City.
Guttmann, R., 330 Madison Ave., Albany, N. Y.
Halle, C. B., 1234 N. Prospect Ave., Milwaukee, Wis.
Hammarstrom, B. P., 44 Whitmarsh Ave., Worcester, Mass.
Hanks, G. P., Federal Shipbldg. & Dry Dock Co., Kearny, N. J.
Hardy, R. F., First Boston Corp., N. Y. City.
Harshberger, J. D., El Paso Elec. Co., Texas.
Hartsell, B. E., Columbus Ry., Pwr. & Lt. Co., Ohio.
Hayhurst, G. F., 17 Fairmount Ave., Hamilton, Ont., Can.
Hesden, H. V., Dunwoody Industrial Inst., Minneapolis, Minn.
Hearst, B. E., Univ. of Colo., Boulder.
Hedler, C. A., Ponemah Mills, Taftville, Conn.
Henderson, M. N., N. Y. Tel. Co., N. Y. City.
Hilbert, E. E., Wagner Elec. Corp., St. Louis, Mo.
Hill, J. S., Radio Air Serv., Inc., Cleveland, Ohio.
Hilton, R. R., 2033–37th Ave. West, Vancouver, B. C., Can.
Hoehn, W. G., Am. Transformer Co., Newark, N. J.
Hood, J. T., Gen. Elec. Co., Schenectady, N. Y.
Hoover, A. J., Underwood Elliott Fisher Co., Kansas City, Mo.
Horsfall, R. E., Salem Elec. Ltg. Co., Mass.
Hough, W. R., Reliance Elec. & Engg. Co., Cleveland, Ohio.
Hoye, J. P., 20 Orchard Ave., Auburndale, Mass.
Hunt, D. W., Clyde, N. Y.
Itkin, K., 8753–26th Ave., Bklyn., N. Y.
Jacobs, D., 1730 Ocean Ave., Bklyn., N. Y.
Johnson, A. L., Jr., 2224 Prince St., Berkeley, Calif.
Johnston, O. B., U. S. Govt., Fort Peck, Mont.
Jones, T. B., Jr., Carbide & Carbon Chemicals Corp., W. Gelling, Ind.
Jung, C. L., Hoover Co., Milwaukee, Wis.
Kaufman, R. B., Gen. Elec. Co., Schenectady, N. Y.
Kenline, W. J., Southern Sierras Pwr. Co., El Centro, Calif.
Klein, K. M., Ore. State Highway Commission, Waldoort.
Koellein, C. L., Jr., Conite Engg. & Sales Co., Nashville, Tenn.
Krack, E. J., 2113 Liberty St., Erie, Pa.
LaBelle, R. P. (Member), British Columbia Tel. Co., Vancouver, B. C., Can.
Lamb, A. H., Weston Elec. Instrument Corp., Newark, N. J.
Lastovicka, L. J., 5618 W. 24th St., Cicero, Ill.
Laubenthal, G. J., Todd Shipbldg. & Dry Docks Co., Mobile, Ala.
Lawson, F. C., Hydro-Elec. Pwr. Comm. of Ont., Fraserdale via Cochrane, Ont., Can.
Lees, A. M., Jr., 227 Clinton St., Boone, Ia.
Lehmann, S. G., Ill. Bell Tel. Co., Chicago.
Lipson, M. H., Jandous Elec. Equip. Co., Inc., N. Y. City.
Lockwood, M. D., Gen. Elec. Co., Schenectady, N. Y.
Loeschner, R. C., Salem Depot, N. H.
Louargand, A., Western Pipe & Steel Co., So. San Francisco, Calif.
Luckingham, A. L., Colts Fire Arms Mfg. Co., Hartford, Conn.
Manoukian, K. M., W. H. Binty Co., Salt Lake City, Utah.
Manthe, R. H., 307 N. Frances St., Madison, Wis.
Markham, T. C., Jr., Durham Tel. Co., N. C.
Marshment, B. C., Marshment Coal & Ice Co., Detroit, Mich.
Martin, S. A., Columbus Ry., Pwr. & Lt. Co., Ohio.
Martin, T. J., Goodman Mfg. Co., Chicago, Ill.
McCallum, R. R., 1300 No. 46th St., Lincoln, Nebr.
McCalman, J. R., Sparks Grammar School, Sparks, Ga.
McCord, C. M. (Member), Memphis Water Dept., Tenn.
McDonald, D. J., Bell Tel. Co. of Can., Montreal, Que., Can.
McGee, F. A. (Member), Reading Co., Phila., Pa.
McIlvaine, W. D., Jr., Minneapolis-St. Paul Sanitary Dist., St. Paul, Minn.
McKinney, L. H., Detroit Edison Co., Mich.
Mischke, C. A. C., 1508A S. 7th St., Milwaukee, Wis.
Moe, O. B., Commonwealth Edison Co., Chicago, Ill.
Montgomery, W. R., So. Calif. Edison Co., La Canada.
Moore, W. M., Am. Zinc Oxide Co., Columbus, Ohio.
Morris, R. R., R-B-M- Mfg. Co., Logansport, Ind.
Murphy, E. K., Panama Canal, Gatun, C. Z.
Nielsen, A. H., Milwaukee Elec. Ry. & Lt. Co., Wis.
Noecker, T. C., Drifted Coal & Supply Co., Shoemakersville, Pa.
Nolen, M. S., Mo. Relief & Reconstruction Comm., Jefferson City.
O'Fiel, J. C. D., Jr., Independent Exploration Co., Houston, Tex.
Oliver, D. F., Reading Elec. Co., N. Y. City.
Oorthuys, H. J., U. S. Bureau of Fisheries, Corvallis, Ore.
O'Sullivan, G. H., Waterbury Cable Serv. Inc., Bronx, N. Y.
Packard, D., Gen. Elec. Co., Schenectady, N. Y.
Patterson, G. R. (Member), Carnegie Inst. of Tech., Pittsburgh, Pa.
Payne, E., Pub. Serv. Co. of Okla., Weleetka.
Pearson, S. I., Gen. Elec. Co., Schenectady, N. Y.
Pedersen, J. H., Box 231, Gilbert, Ia.
Petscavage, M. J., 152 State St., Kingston, Pa.
Pignolet, L. W., Weston Elec. Instrument Co., Newark, N. J.
Pilten, A., Radio Mfg. Co., Bklyn., N. Y.
Pollastro, J. B., Milwaukee Sch. of Engg., Wis.
Prince, M. A., 60 West St., Bloomfield, N. J.
Quinn, J. A., 250 S. Main St., Pittston, Pa.
Raffill, A. W., Pub. Serv. Comm., Madison, Wis.
Rankin, M. B., Ohio Edison Co., Akron.
Rappel, U. J. (Member), Univ. of Dayton, Ohio.
Reece, J. S., U. S. Navy, New London, Conn.
Reed, C. M., VI, Phila. Elec. Co., Pa.
Ribreau, G., Owner & Tenants Elec. Co., N. Y. City.
Ridenhour, W. L., Univ. of N. C., Chapel Hill.
Ringer, R. L., Jr., Wilson Welder & Metals Co., North Bergen, N. J.
Ritter, H. D., Detroit Edison Co., Mich.
Roberts, J. H., Quality Radio Co., San Diego, Calif.
Robinson, R. A., Carborundum Co., Niagara Falls, N. Y.
Rollman, M. E., Cincinnati Milling Machine Co., Ohio.
Root, C. S., Corp. Dept., State of N. Y., Albany.
Rosebrock, F. H., Jr., with M. Scharff, Mt. Vernon, N. Y.
Rotten, I., G. Boulitte & Co., N. Y. City.
Rumpanos, G., Tampary Constr. Co., Mobile, Ala.
Russo, P., 380 Congress Ave., Waterbury, Conn.
Rutter, A. R., Westinghouse E. & M. Co., Newark, N. J.
Schell, D. H., Cass City, Mich.
Schumacher, W. C., Gen. Motors Export Co., N. Y. City.
Scott, H. U., with L. W. Driscoll, Durham, N. C.
Seppa, G. E., Box 147, Route 1, Wakefield, Mich.
Seuffert, G. C., RCA Mfg. Co., Inc., Phila., Pa.
Shaver, L. C. (Member), Federal Pwr. Commission, Washington, D. C.
Sherer, H. P., Route No. 2, Waynesburg, Ohio.
Sheridan, J. J., 4389 Martha Ave., N. Y. City.
Shimer, A. J., H. N. Crowder, Jr., Co., Allentown, Pa.
Shore, A. G., 244 E. 20th St., N. Y. City.
Shuster, J. D., Bethlehem Shipbldg. Corp., Quincy, Mass.
Richard, J. D., 206 College Ave., Ithaca, N. Y.
Sidway, C. L. (Member), Westinghouse E. & M. Co., San Francisco, Calif.
Simons, W. D., U. S. Geological Survey, Tacoma, Wash.
Simpson, C. E., TERA Bradley-Polk Counties, Cleveland, Tenn.
Richards, S. R., Zenith Products Co., Salt Lake City, Utah.
Singler, E. L., Ingersoll Steel & Disk Co., Chicago, Ill.
Sizelove, O. J., Jr., Diehl Mfg. Co., Elizabethport, N. J.
Smith, J. K., 2955 Grand Concourse, N. Y. City.
Smith, L. M., Los Angeles Bureau of Pwr. & Lt., Calif.
Smith, R. M., Westinghouse E. & M. Co., Newark, N. J.
Snipes, M. A., Western Union Tel. Co., Denver, Colo.
Sogge, R. C. (Member), Gen. Elec. Co., Schenectady, N. Y.
Speck, R. J., Bureau of Pwr. & Lt., City of Los Angeles, Saugus, Calif.
Sreb, J. H., with M. R. Scharff, N. Y. City.
Stewart, A. C., Central Pwr. Co., Grand Island, Nebr.
Stratton, B., Jr., 1226 No. Marshall St., Milwaukee, Wis.
Stryker, N. U., Jr., Ill. Tool Works, Chicago.
Suprenant, H. A., New Eng. Pwr. Assoc., Shelburne Falls, Mass.
Sutton, E. L., Darwind White Coal Mining Co., Windber, Pa.
Tabler, M. C., Penn. R. R. Co., Baltimore, Md.
Tevlin, H. F., Detroit Edison Co., Mich.
Thorne, B. W., Jr., 1946 W. 22nd St., Los Angeles, Calif.
Trainer, S. W., 1209 N. Jefferson St., Milwaukee, Wis.
Trieste, C. W., Fla. Pwr. & Lt. Co., Miami.
Todd, J. R., Arkville, N. Y.
Tolivar, C. A., Am. Dist. Tel. Co., N. Y. City.
Tucker, M., Chandeysson Elec. Co., St. Louis, Mo.
Turner, J. L., F.E.R.A. Research, Houghton, Mich.

Urquhart, M. D., Broad River Pwr. Co., Columbia, S. C.
Valois, R. F., Consolidated Film Industries, Inc., Fort Lee, N. J.
Vertryla, R. J., 194 Drayer Ave., Waterbury, Conn.
Verdier, W. H., 624 Parkwood St., Grand Rapids, Mich.
Votava, G. E., 1563 Jarvis Ave., N. Y. City.
Wacker, K., Crosley Radio Corp., Cincinnati, Ohio.
Wahlers, F. A., Bklyn. Edison Co., N. Y.
Wall, R. E., Teleweld, Inc., Chicago, Ill.
Walsh, W. J., 1980 Gates Ave., Bklyn., N. Y.
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237 Domestic

Foreign

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Farnhill, E. S., British Thomson Houston Co., Ltd., Coventry, Eng.
Lansdown, L. P., Victoria Falls & Transvaal Pwr. Co., Germiston, So. Africa.
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17 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

A.S.T.M. STANDARDS on ELECTRICAL INSULATING MATERIALS, prepared by Committee D-9 on Electrical Insulating Materials. Oct. 1934, Phila., American Society for Testing Materials. 281 p., illus., 9x6 in., paper, $1.75. This volume brings together all the specifications and test methods for electrical insulating materials which the society has adopted, in their latest approved form. It also contains the latest report of the committee in charge of this subject, discussing the developments of interest during the past year.

AUTOMATIC PROTECTIVE GEAR for A-C Supply systems. By J. Henderson. Lond., Sir Isaac Pitman & Sons; N. Y., Pitman Publishing Corp., 1934. 201 p., illus., 8x5 in., cloth, $2.50. The schemes for transmission line protection which have been used in Great Britain and which have been successful in practice are described briefly but with sufficient fullness to present their principles clearly and to show the details of the various methods of connection.

Course in ELECTRICAL ENGINEERING. Vol. 2, Alternating Currents. By C. L. Dawes. 3 ed. N. Y. & Lond., McGraw-Hill Book Co., 1934. 705 p., illus., 8x6 in., cloth, $4.00. This is an introductory text for students who have some knowledge of direct currents but are unfamiliar with alternating currents. Two chapters are devoted to the fundamental laws of alternating currents and alternating-current circuits, after which the applications of these laws to measurements, polyphase circuits, machinery, and power transmission are discussed. New developments have been included, the chapter on vacuum tubes has been expanded, and a chapter on gaseous rectifiers added.

ELECTRIC POWER METERING, a Textbook of Practical Fundamentals. By A. B. Knowlton. N. Y. and Lond., McGraw-Hill Book Co., 1934. 340 p., illus., 9x6 in., cloth, $4.00. Practical methods of watt hour, reactive, and demand metering, and of telemetering and totalizing, are described and the basic principles that underly them and determine their accuracy and reliability are explained.

FROM GALILEO to COSMIC RAYS, a New Look at Physics. By H. B. Lemon. Univ. of Chicago Press, 1934. 450 p., illus., 9x7⅝ in., cloth, $5.00. This textbook of physics, intended for the use of undergraduate students at the University of Chicago, is designed to stress the source material and phenomena, and to interpret them in nontechnical style.

HANDBOOK of CHEMISTRY. By N. A. Lange, assisted by G. M. Forker and R. S. Burington. Sandusky, Ohio, Handbook Publishers, Inc., 1934. Illus., 8x5 in., lea., $6.00. Nearly 1,800 pages of chemical and physical tables are included, selected for the needs of engineers and industrial and research chemists. Appended to the main work are 247 pages of mathematical tables.

MACHINERY'S HANDBOOK for Machine Shop and Drafting Room. 9 ed. N. Y., Industrial Press, 1934. 1592 p., illus., 7x5 in., lea., $6.00. This handbook aims to provide data frequently wanted by machine designers and builders. Much practical information upon the strength of materials, gearing, bolts and screws, speeds and feeds, fits, screw threads, heat treatment, pipe fittings, etc., is presented.

Les MACHINES ASYNCHRONES à Champs Tournants, à Bagues et à Collecteur. By R. Langlois-Berthelot. 2 ed. Paris, Dunod, 1934. 274 p., illus., 9x6 in., cloth, 63.50 frs.; paper, 53.50 frs. This volume represents the course given at the École Supérieure de l'Électricité, Paris, and constitutes essentially a general method for studying asynchronous machines. An introductory chapter describes the industrial properties of these machines, after which a general theory is developed. A final section on design illustrates the application of the theory.

MODERN ACOUSTICS. By A. H. Davis. N. Y. Macmillan Co., 1934. 345 p., illus., 9x6 in., cloth, $6.00. Sources of sound and their theoretical relations, audiofrequency electrical apparatus, the measurement of sound intensity and frequency, sound analysis, acoustical impedance and sound transmission, sound dissipation and absorption, hearing, noise measurement and suppression, acoustics of buildings, sound recording and reproduction are among the subjects discussed.

PRINCIPLES of MATHEMATICAL PHYSICS. By W. V. Houston. N. Y. and Lond., McGraw-Hill Book Co., 1934. 265 p., illus., 9x6 in., cloth, $3.50. This text is intended to give students who have a thorough knowledge of elementary physics, analytical geometry and calculus, a working knowledge of the fundamental methods of mathematical physics which will enable them to use the more advanced treatises on special subjects.

WHO GETS the MONEY? How the People's Income is Distributed. By W. Rautenstrauch. New York and London, Harper & Brothers, 1934. 99 p., charts, tables, 8x5 in., cardboard, $1.00. This contribution to the discussion of the economic crisis is concerned with the costs of producing the national income and with its distribution. The author ascribes most of our present economic troubles to undue overhead costs in the national industrial plant.

SYMPOSIUM on the OUTDOOR WEATHERING of METALS and METALLIC COATINGS. Washington Regional Meeting, American Society for Testing Materials, March 7, 1934. Phila., A.S.T.M. 118 p., illus., 9x6 in., cloth, $1.50. The material that appears in this volume was presented at a symposium held in Washington in 1934. Five papers, with discussions, are given: outdoor test results on bare and metal-coated ferrous specimens; the harmony of outdoor weathering tests; influence of rainfall and smoke on the corrosion of iron and steel; early interpretation of test results in the atmospheric corrosion of non-ferrous metals and alloys; and galvanic corrosion by contact of dissimilar metals.

CONCISE OXFORD FRENCH DICTIONARY. Compiled by A. Chevalley and M. Chevalley. Oxford (Eng.), Clarendon Press; N. Y., Oxford Univ. Press, 1934. 895 p., diagrs., 8x5 in., cloth, $3.00. This new dictionary presents a vocabulary of nearly 40,000 words covering modern literary and commercial idiom with reasonable completeness and including many technical and industrial terms.

TECHNIQUE of EXECUTIVE CONTROL. E. H. Schell. 4 ed. N. Y. and Lond., McGraw-Hill Book Co., 1934. 231 p., 8x5 in., cloth, $2.00. This book discusses the problems of the executive in his relations with his subordinates and superiors. Methods for securing effective coöperation are considered in detail.

TEILCHENSTRAHLEN (Korpuskularstrahlen). Sammlung Göschen 1083. By H. Mark. Berlin and Leipzig, Walter de Gruyter & Co., 1934. 152 p., illus., 6x4 in., cloth, 1.62 rm. This book aims to provide a simple, yet comprehensive account of present knowledge of corpuscular rays. The experimental methods by which they are produced, the behavior of these forms of radiation, and their importance to the physicist, are set forth.

Engineering Societies Library

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MAINTAINED as a public reference library of engineering and the allied sciences, this library is a coöperative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

Industrial Notes

General Electric Operations Increased in 1934.—At the March meeting of the board of directors of the General Electric Company, the preliminary results for 1934 were presented, showing orders received amounting to $184,000,000, compared with $143,000,000 in 1933, an increase of 29%, and sales billed of $164,797,000 compared with $136,637,000 in 1933, an increase of 21%. The average number of employees was 49,642 compared with 41,560 in 1933. The total earnings of these employees amounted to $75,227,000 as against $55,287,000 for 1933. The average annual earning increased 14% over 1933. Between March 1, 1933 (the approximate low), and December 31, 1934 (the high), the number of employees on the payroll increased almost 37%, and the total annual payroll rate increased from $47,604,000 to $81,300,000, or 70%. At the end of 1934 there were 196,248 stockholders compared with 188,316 a year earlier.

Westinghouse Business Improved During 1934.—The annual report of the Westinghouse Electric & Mfg. Co. for 1934, recently released, shows a net income earned of $189,562, compared with a net loss of over $8,000,000 during the preceding year. Sales billed for 1934 totaled $92,158,893, compared with $66,431,591 for 1933. Orders received totaled $106,473,226 as against $72,473,117 in 1933, an increase of 47%. Better business was reported by all principal divisions of the company and billings for the year were substantially above 1933. The total, however, was still only approximately 50% of the average in the years preceding the depression. Plants of the company that produce the heavier equipment normally used by the electric utilities have operated throughout the year at a load much lower than the 50% average. While Westinghouse has suffered in common with the entire industry from the severe recession in business activity, according to the report it has been able to maintain and in some directions improve its relative position in the electrical field. The volume of the company's foreign business, obtained through the Westinghouse Electrical International Company showed a substantial increase over 1933, and the profits have been greater than for a number of years. The increase in foreign business has not been confined to any single country, but has been world wide. The consolidated companies disbursed $47,321,400 in payroll payments, and gave employment to an average of 35,281 persons during the year. In 1933 the total payroll was $36,047,031, with an average of 29,980 persons employed. It is believed that unless there is a marked change for the worse, the operations of the company for the year 1935 will show a substantial profit.

U.S. Rubber Appoints C. P. Boone. C. W. Bigbie, sales manager of United States Rubber Products, Inc., wire division, recently announced the appointment of C. P. Boone, at San Francisco, as manager of the company's wire sales on the Pacific Coast.

A New Line Connector.—A new semi-automatic mechanical line splice has been introduced by Connect-O-Line, Inc., 7607 Vincennes Ave., Chicago. Simplicity of construction is a marked feature of the new connector, and the positive grip on the wire is claimed to prevent either solid or stranded cable from turning or slipping. The hexagonal body of the connector is pure copper; the gripping lugs and tightening nuts are made of Everdur. Splices for all sizes of both solid and stranded wire are available.

Trade Literature

Wood Preservation.—Bulletin, 16 pp., "Preservation with Eastman NO-D-K." Outlines various methods of wood preservation and recommendations for different types of construction. Tennessee Eastman Corporation, Kingsport, Tenn.

Mechanical Rubber Goods.—Bulletin, 24 pp. Describes transmission, conveyor belting, rubber hose and other mechanical goods for industrial service; more than 200 items and illustrated with 100 diagrams and photographs. The B. F. Goodrich Co., Mechanical Div., Akron, O.

Electronic Rectifiers.—Bulletin, 4 pp. Describes B-L dry metallic electronic rectifiers and lists many standard applications where conversion of alternating to direct current is involved. Commercial sizes and types available, as well as prices, are included. B-L Electric Mfg. Co., 19th & Washington Ave., St. Louis.

Air Circuit Breakers. Bulletin GEA-1662A, 4 pp. Describes trip-free air circuit breakers for buildings, industrial plants and power stations; 600 volts, 1600–6000 amperes, alternating current; 750 volts, 1600-10,000 amperes, direct current, manually or electrically operated. General Electric Co., Schenectady, N. Y.

Air Filters.—Bulletin F-320-3. Describes the Coppus unit type filter for motor and generator intakes and general commercial and industrial ventilation. Bulletin F-310-2 describes filters for air compressors, internal combustion engines, etc. Coppus Engineering Corp., Worcester, Mass.

X-Rays for Industry.—Bulletin, 42 pp., "Instruments of Precision." Describes X-Ray apparatus for use in industrial and educational laboratories and applications in analysis and structure of materials. Testing machines of various types for fatigue tests of metals are also described. J. B. Hayes, Inc., Urbana, Ill.

Fusion Furnace.—Bulletin, 4 pp. Describes the Barrett fusion furnace for determining the fusing temperature of coal ash. Other uses include such operations as the determination of pyrometric cone equivalents of refractory materials, the study of test pieces of ceramic bodies, heat treating and other laboratory work requiring a high temperature gas furnace for producing heat up to 3000°F. Burrell Technical Supply Co., 1936 Fifth Ave., Pittsburgh.

Industrial Condensers.—Catalog, 28 pp. Includes general engineering data on electrolytic and oil-filled industrial condensers as well as their application to motor-starting, power-factor correction and other industrial uses. Lists a large line of industrial units in which the company has pioneered for many years, and facilitates the selection of proper equipment for any given purpose. Aerovox Corporation, 82 Washington St., Brooklyn, N. Y.

Generator Car Axle Drive.—Bulletin, 6 pp. Describes a compensating car axle drive for motivating lighting generators, air conditioning generators, etc. This drive, available in any capacity, uses endless V-belts and, it is claimed, successfully overcomes truck misalignment while producing a constant flow of power without noise. Installation is possible without jacking up wheels and it is readily accessible for maintenance. The Medart Co., 3500 DeKalb St., St. Louis.

Chain Belts.—Catalog K-1, 54 pp., pocket size. Describes chains and sprockets for power transmission, conveying and elevating. A feature of the publication is a section devoted to practical engineering data, and containing rules and formulas for determining chain size, length, pitch, sprocket diameter and ratios; rules for installation, alignment and operation, lubrication methods, etc. A series of charts and tables illustrate the correct type of chain to use, the horsepower to be transmitted, etc. Baldwin-Duckworth Chain Corp., Springfield, Mass.

Insulation Testers.—Catalog 1400, 32 pp. Describes "Megger" insulation testing instruments—self-contained, portable devices for measuring electrical resistance, especially insulation resistance, having various ranges to as high as 10,000 megohms. Modified types, such as "Bridge-Megger" and "Bridge-Meg" sets, have facilities also for measuring conductor resistance to as low as 0.01 ohm. The catalog describes in detail the principle of operation of seven types of instrument now available. James G. Biddle Co., 1211 Arch St., Philadelphia.

Condensers.—Catalog 127. For manufacturers and engineers. On the use of condensers for power factor correction, motor starting, high voltage circuits, etc. Catalog 128, 16 pp. For service men, distributors, dealers. Lists a wide variety of mica, paper and electrolytic condensers in many capacities, voltage ratings and sizes for general radio applications. Catalog 129 includes a comprehensive listing of standard types of replacement condensers of both paper, dielectric and electrolytic construction. Cornell-Dubilier Corp., 4377 Bronx Blvd., New York.

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Front Cover

At Boulder Dam. A lengthwise view of the interior of one wing of the power house, at the turbine level. Water from the turbines to be installed here will discharge through the openings at the right. Note top of dam

Photo by D. M. Simmons (F'28)

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The Great Fall of Taughannock

This gorge, in Taughannock State Park, is about 11 miles from Cornell University, Ithaca, N. Y. The top of the fall is 215 feet above the man shown standing on the rocks at the right. The Institute's 51st annual summer convention will be held on the campus of Cornell University, June 24–28, 1935.

WITH a dam reaching more than 1/4 mile above the natural water level of the river and more than 1/4 mile long at the crest, the combination flood control, water conservation, and power development on the Colorado River known as the Boulder Canyon Project represents one of the outstanding engineering achievements of its kind. The reservoir will be 115 miles long and will have a capacity of 30,500,000 acre-feet. The power plant, half of which is in Arizona and half in Nevada, ultimately will contain 17 main generating units with a total capacity of 1,317,500 kva; initially 5 units will be installed with a total capacity of 370,000 kva. Power will be transmitted to several municipal and privately owned power systems over specially built lines. A brief review of historical facts leading up to the project appeared in the April 1935 issue (*pages 361–5*). Engineering features of the 2 275 kv lines that will transmit power to the City of Los Angeles, Calif., are discussed in this issue (*pages 494–512*); circuit breakers of the impulse type developed especially for this line were described in the April issue (*pages 366–72*). A paper on the engineering features of the dam and power house is scheduled for publication in the June issue, and one outlining the method by which sag and tension calculations were carried out in designing the several steep transmission line spans between the plant and the canyon rim is scheduled for early publication. A group of pictures depicting various phases of the project during the constructional period is included in this issue (*page 567*).

ECONOMY is one of the features stressed in making arrangements for the Institute's 51st annual summer convention to be held on the campus of Cornell University, Ithaca, N. Y., June 24–28, 1935. In addition to the low priced college dormitories and cafeteria, the customary hotel accommodations are available to those who wish them. It has been termed "a summer convention for the entire Institute." The technical program is extensive; discussion conferences, a new feature, have been scheduled; and attractive entertainment features are made possible by the location chosen. *pages 560–4*

INDUCTION motors come in for their share of attention in this issue, one of the papers presenting a general method of mathematic analysis of induction motor phenomena, giving special attention to short-circuit problems (*pages 526–9*); and the other considers d-c braking of induction motors, outlining the fundamental principles involves in this method, and presenting a simple means of calculating the current and wattage necessary *pages 488–93*

IN calculations on synchronous machines, various types of reactances are used. Magnetic saturation in the machine is shown to have an effect on the values which should be used for these reactances, and saturation factors for the more important constants used in transient and unbalanced load conditions, based upon actual short-circuit tests on a large number of machines, have been made available in curve form. *pages 545–50*

DURING the last 30 years, the use of electric power equipment in steel plants has increased rapidly. Extensive installations of power generation and distribution equipment have been made in steel plants, and many large sized generating units are used. Electric motors were applied first to auxiliaries, but are now used also for main mill drives; synchronous motors and d-c motors largely have superseded induction motors for this purpose. *pages 481–5*

THE satisfactory charging of storage batteries requires a knowledge of the proper rate at which to charge a battery, and the determination of the proper point at which to stop the charge. Observation of gas evolution, acid concentration, heating, and "local action" may be used to determine proper methods of charging. Automatic as well as manual control may be used in several different charging schemes. *pages 516–25*

TIME - TEMPERATURE tests frequently provide a convenient method of measuring losses in electrical machines. The method, although most frequently used in connection with turbine generators, can be applied to practically all types of electrical apparatus. These losses are determined from the initial slope of the time-temperature curve immediately after a load is thrown off. *pages 512–5*

WITH cheaper capacitors available, an induction generator with capacitive excitation, which has load-voltage characteristics similar to those of a d-c shunt wound machine, offers attractive possibilities. Recent tests show that such a machine may be operated independently at a predetermined voltage and frequency with good wave form. *pages 540–5*

THERMAL expansion of a liquid in a closed system actuates the mechanism in an improved electrothermic instrument for measuring various electrical quantities. It is not subject to the errors inherent in bimetallic strip instruments, and it has a linear input-deflection characteristic. *pages 474–81*

BY means of stroboscopic light of great instantaneous intensity and a moving-film camera the power angle of a synchronous machine can be recorded directly. This method was developed particularly for studying the transient performance of machines during system disturbances. *pages 485–8*

THE Engineers' Council for Professional Development recently published its second annual report, outlining past accomplishments and plans for the future with regard to student guidance, accrediting of schools, professional training, and improvement in professional status of the engineer. *pages 568–9*

TRANSMISSION engineers may find useful a set of hyperbolic function charts covering line lengths from 0 to 290 miles (for 60 cycle lines). *pages 550–4*

Engineering Education Needs a "Second Mile"

By WILLIAM E. WICKENDEN, Member A.I.E.E.
Case School of Applied Science, Cleveland, Ohio

The demand for strictly professional engineering service will diminish in volume but will rise sharply in its qualitative standards, while the demand for quasi-professional services will increase markedly. This is one of the opinions voiced by Doctor Wickenden in a recent address,* full text of which is presented herewith. In order to prepare men to furnish these services most effectively, he concludes that their education should consist of a common matrix of 3 years, with a terminal year for men who purpose to enter the general service field, and a longer period of more profound and generalized scientific studies for those who aspire to the professional field—not a separate route for the purely professional engineer, but a "second mile."

HOW can industry be supplied with trained man power adequate for its producing, distributing, and service functions, and the engineering profession advance to a properly restricted and selective status? Can the same machinery of recruitment and education serve both ends? The occasion for a discussion of these questions arises from an increasingly urgent campaign not only to restrict by law the practice of engineering, but also to reduce the number of future applicants for this privilege by limiting admissions to engineering colleges. The avowed aim of this campaign is wholly praiseworthy—to safeguard the professional and economic position of the engineer and to advance his claim to the esteem and confidence of the public. The licensing of engineers is already an accomplished fact in a majority of states and presumably soon will prevail in all. For the present, at least, this issue has passed out of the realm of argument. The campaign for restriction of college enrollments is only beginning.

Appealing to the law of supply and demand, as the key to social and economic status, the advocates of restriction clearly imply that the open doors of the colleges are a direct menace to the profession. The argument is supported by assuming a close parallel between engineering and certain other professions. In my opinion the parallel is not valid, and a policy of purely numerical restriction applied at college doors is short-sighted, narrow in perspective, and likely to injure the engineering profession in the long run, whatever the immediate benefits to a minority.

In the present emergency every profession is seeking to make its status more secure. The threat or reality of unemployment, the stress of competition, the spur of ambition, the advance of knowledge, the growth of specialization, the universal sense of social insecurity—all contribute to this concern. Teachers, librarians, social workers, personnel executives, and secretaries of welfare organizations, whose place in the professional hierarchy never has been too secure, exhibit this concern in fairly acute degree, and older and more traditional groups but little less so. The medical profession, firmly entrenched in its legal privileges, secure in its restriction of numbers, and high in prestige as a result of brilliant technical progress, has become the standard by which every other group measures its position. The strict limitation of admissions, applied at the doors of medical schools has contributed so conspicuously to the welfare of the medical profession that now many engineers are tempted to pay the tribute of imitation. We are reminded that in 1906 there were 162 approved medical colleges in the United States, while in 1930 there were only 76; that in 1905, there were 26,147 medical students, while in 1920 there were but 13,798; that in 1905, the medical schools turned out 5,606 graduates, but that by 1919 this number had been reduced by more than half, to 2,656; and that in 1904, 4,700 physicians were added to the profession, while in 1918 the new admissions had fallen to 2,975. I do not question these figures, they are presumably accurate; I do not question the benefits conferred upon both the medical profession and the public. What I question is the intimation that the engineering profession should have done likewise.

The contrasts in status and function between the engineer and the physician are so great that the supposed parallel is without validity. Medicine, as everyone knows, is one of a group of professions that serves individuals in personal emergencies. The incidence of these emergencies in a population living on a given social level is quite well known and determines the number of persons a single physician can serve effectively. Inevitable inequalities in distribution and service must be allowed for, but an optimum quota, or ratio of physicians to population is easy to establish. An increase in physicians beyond this quota does not insure superior service nor does it contribute to medical progress; on the contrary, it merely multiplies the temptations to exploit human ignorance and frailty, on the plea that surplus practitioners must live, somehow. Competition may be the life of trade, but it is the death of good medical care. Furthermore, medicine is a sharply bounded calling from which few men are called by choice or circumstance to other careers; nor are there any easy gradations of authority to keep a career open to talents. Every French private, according to Napoleon, carried a marshall's baton in his knapsack, but no hospital orderly is permitted the illusion that he may somehow rise to rank of chief surgeon.

* One of 4 addresses delivered at a forum on "Scientific Education—What Is Wrong With It?" held by the New York Electrical Society, New York, N. Y., March 29, 1935.

Merely to state these facts suffices to make clear the contrast between medicine and engineering. Engineers seldom serve individuals, nor is their concern the relief of personal emergencies; instead they serve society through its corporate agencies and in its constructive enterprises. No statistician can state the incidence of these constructive needs; their number is not limited inherently, nor does engineering progress tend to restrict or eliminate them, as medical progress aims to banish disease. Rather, all engineering progress tends to widen the domain of engineering. No one can set an optimum quota of engineers for a given population nor prove that a sharp restriction of their numbers is necessary for public welfare and safety. To have fewer engineers does not necessarily imply better engineers, so long as their work lies principally in areas of competitive enterprise.

Technical progress in engineering apparently is little affected by over-crowding, except as the "horse sense" of one generation is unable to compete successfully with the science of the next. This condition was easily observable during the past decade in Germany, where a surplus of nearly 200,000 in the technical professions is reported to have been built up, as young men fresh from the universities rapidly were absorbed at the bottom and older men who had not kept abreast of their professions gradually were crowded out. To create and protect a partial monopoly for these men would have been in their personal interest, but not in the interest of scientific advance.

Engineering Not a Caste

The relation a profession bears to associated groups is especially pertinent to this matter of restriction. The profession of medicine is by law and tradition a caste; sharp, closed boundaries separate it from all other groups that touch on its functions. The profession of engineering is not a caste, but a vaguely bounded nucleus within a large body of technical workers. No wall separates them as a membrane divides the yolk from the white of an egg. The gradations of function are imperceptible. The professional nucleus continuously is drawing into itself much of the superior talent in the outer mass, on the one hand, and on the other continuously sending out men into almost purely executive functions. Close these free paths of interchange between professional, executive, commercial, and producing groups, and in my opinion, the engineering profession quickly will sterilize itself.

Technical education, in its broader sense, conceivably might be overdone, but actually it never has been. Who is competent to fix an arbitrary limit to those who should be trained to use Stephen Van Rensselaer's historic phrase, "in the application of science to the common purposes of life"? In America, at least, we certainly have not overdone education in applied science. At the highest estimate, less than $^1/_3$ of the posts in industry that could be filled with gain to society by persons who had completed a substantial scientific or technological education, have been so filled under normal business conditions. If we were to go one step further down in the scale of organization and include in our estimate the higher levels of foremanship as well as the general planning and supervisory forces, the potential outlet in industry for technical education would be doubled or trebled.

This brings us to the heart of our problem. What relations should exist between these general service needs of industry and the selection and training of the inner nucleus of professional engineers? Should separate provision be made for each, or should one be an outgrowth and extension of the other? All engineers desire to see the inner professional body advance in public esteem and influence, and to see it enjoy sufficient security and compensation to attract men of high talent and character. This inner body, we recognize, is not coexistent with any existing organization. Probably some more exact and advanced code of educational qualifications should be its chief distinguishing feature, since the gradations from professional to executive and commercial functions are so imperceptible. Merely to distinguish between publicly licensed engineers and others is not enough—a true profession is still too much a thing of the spirit.

Two Types of Technological Education?

Returning now to ways and means of education, why not separate higher technological education into 2 quite distinct compartments? In one, train men for purely professional work as engineers; in the other, provide training of a more elastic character for the general service needs of industry? Whatever the abstract merits of the idea, the practical difficulties of converting the existing educational machinery to this dual function are fairly forbidding. The experience of such engineering colleges as have sought to become professional schools in this strictest sense is not reassuring. Enrollments have fallen, costs have risen, and the problem of maintaining a sufficient scope and volume of work to support an adequate specialized faculty has become acute. However, is the idea of segregation sound in principle? How is a young man to determine in advance whether he belongs in the professional nucleus of engineering or in its general service functions? Will he find it out by prolonging his preliminary education in an arts college? Can any vocational counselor or tester make the choice for him? Would employers of engineers respect it? I doubt it.

Supposing the segregation could be made, however, would it be beneficial to future professional engineers to train them as a caste apart? Is not the presence in industry of a great body of scientifically intelligent and technically competent men an essential condition on which the purest of professional engineers must rely for the execution of his plans and schedules? Must not these 2 groups speak the same language, or understand each other sympathetically? Would a caste system of education work to that end? Can the division of functions come through any other process than natural selection at a mature age?

I suspect that those who are intent on restriction and exclusion as means of raising the professional status of engineering are tempted by narrow self-

interest to forget what the nation has at stake in maintaining the numerical strength of the great quasi-professional body of those who now call themselves engineers. In the struggle for industrial supremacy, as in war, victory is likely to be on the side of the heaviest battalions. A lack in the professional nucleus can be compensated for in large part, as we have done in America, by importing highly trained men from abroad and by drafting men from the realm of pure science; but a deficit in the quasi-professional group in service functions cannot be met by improvisation, as Russia has learned to her regret. Each year sees American engineering grow more self-sufficient. With present standards of advanced training we are virtually free from the need of importing talent. Fortunately, we remain free from the fetters of caste. We still are able to assimilate the research scientist, to upgrade men from the ranks, and to match ingenuity in invention, adaptation, and production with refinement in design.

Doctor Wickenden

The best evidence available seems to indicate that the total demands on technological schools of all levels will continue to increase, though possibly the rate of increase will diminish. More young people will want this type of education and industry will continue the process of upgrading its general service forces by recruits from engineering colleges. In predicting future demands from past, 3 controlling influences that have been dominant in the last half century deserve critical attention: (1) the building up from rudimentary levels of a vast system of mineral production, manufacturing, transportation, and communication; (2) the rapid growth of urban population and the resulting development of public works; and (3) the progressive replacement of an older generation of self-trained engineers by younger men of better scientific education. The coincidence of these forces in recent decades is reflected in the age distribution of our present body of engineers, with a concentration above normal between the ages of 25 and 45.

The pace of sheer expansion in industry, urban development, and population almost certainly is diminishing. Replacement demand, pure and simple, is likely to be relatively small for 2 decades to come. We appear to have passed for a time beyond the era of original plant construction and to have entered upon a stage of progressive refinement. When all the controlling factors are considered, it seems safe to estimate that the demand for strictly professional engineering service will diminish in volume, but will rise sharply in its qualitative standards. However, the demand for quasi-professional business activity in producing, distributing, and adapting technical goods and services may be expected to increase markedly.

While an actual division of the field of engineering education between 2 types of colleges is seemingly impossible, it must be admitted that we are actually at the limit of our ability to accommodate a single educational program to both our professional and our general service objectives. A 4 year undergraduate course rapidly is becoming totally inadequate as preparation for engineering service of a high professional type, yet it remains for the present a reasonably adequate basis for the great body of service activities for which young engineers are in active demand. It is, in fact, as advanced a type of education as industry and business in general are now able to capitalize. Furthermore, it approaches close to the saturation point for the great body of engineering students. A 5 or 6 year course for all students seems not only unwarranted and unwise, but highly desirable for a considerable minority, and virtually imperative for a selected few.

What the American engineering college offers its undergraduate students is more properly called functional rather than professional education. Judged by this standard it probably is not surpassed in its effectiveness by any other undergraduate program. Its inadequacy as a professional discipline is scarcely open to question. In the present state of training and guidance, it seems inevitable that much of the process of selection between professional and general service objectives must fall within the college period rather than precede it. A common matrix of 3 years, as broadly humanistic and scientific as possible and only moderately differentiated between the major branches of engineering, should suffice for this phase of preliminary selection. For men who purpose to enter the general service field, a terminal year, about equally divided between business subjects and some major technical division of engineering may be provided, while those who aspire to the professional field may pass at this point into a longer period of more profound and generalized scientific studies, with adequate attention to the techniques and problems of research, design, and application and with due consideration of professional relations and ethics.

In a word, my ideal of professional education for engineers is not a separate route, but a second mile. In setting qualifying standards for the latter stage, all socially needful restrictions may be applied. The profession may sit as judge of standards and objectives without putting the colleges into a straight jacket. The Engineers' Council for Professional Development is adapted admirably to this function. In time, the standards of attainment it may set for full professional recognition may make public licensure of relatively nominal significance. Meanwhile the solidarity of the greater engineering fraternity may be preserved for the ideals of democracy and the larger service to our common life.

An Improved Electrothermic Instrument

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An improved electrothermic instrument for measuring watts, amperes, or volt-amperes, actuated by the thermal expansion of a liquid in a closed system which includes a Bourdon tube, is described in this paper. The new instrument is not subject to the errors inherent in the bimetallic strip type of electrothermic instrument, it has a linear input-deflection characteristic, and its time period may be adjusted readily to any desired value up to at least 60 minutes.

IN 1915 the writer contributed a paper[1] to the A.I.E.E. describing a method of measuring watts, amperes, and volt-amperes by electrothermic methods. In 1918, a second paper[2] was contributed setting forth in some detail the characteristics of a wattmeter built according to the principles set forth in the 1915 paper. The electrothermic demand meter described in the writer's 1918 paper was introduced into Canada a year later, where it now is widely used. It was not introduced into the United States until 1928. In 1929 a third paper[3] was contributed describing how the principles enunciated in 1915 could be applied to the totalizing of system loads so that load measurements at widely separated points on an electric system might be added automatically and indicated or recorded at one central point. It is the object of this paper to describe still further developments of the principles enunciated in the 1915 paper. These developments have led to an improvement in the electrothermic instrument, based primarily upon securing a first-power law for the heat loss that necessarily takes place in any instrument of this type. This first-power law for heat loss is responsible for an accuracy of measurement that is utterly unattainable with the present construction.

Shortcomings of Bimetallic Strip Instrument

The electrothermic instrument as now built is described fully in the writer's 1918 paper already referred to, and no further description is incorporated in this paper. There are certain shortcomings in the device as now built of which the writer long has been aware. There are 4 deficiencies in the present construction which the writer has been endeavoring to eliminate for many years and which the construction described later in this paper does eliminate. These are: temperature error, power factor error, lack of scale uniformity, and lack of torque in the moving element.

While the temperature error of the existing bimetallic strip instrument is within the meter code requirements, there is nevertheless an appreciable temperature error. Means for correcting the temperature error in the existing construction are now available. This correcting means, however, is aimed at the symptom and not the cause. The new construction described in this paper eliminates the cause.

The reason for this temperature error is not hard to find. As is well known, a hot body may lose its heat in 3 ways: by radiation, by convection, and by conduction. Each of these methods of heat dissipation follows a different law. Radiation follows the well-known Stefan-Boltzman law. In figure 1 may be found the mathematical expression for this law and a graphical presentation of the losses per square centimeter for the 3 ambient temperatures, −40, 0, and +40 degrees centigrade. The differences in the radiation loss at different ambient temperatures account for most of the temperature error in the existing bimetallic strip type of instrument.

Loss by radiation is defined by the Stefan-Boltzman law:

$$J = 3.00 \times 10^{-12} (T_1^4 - T_2^4)$$

in which

J = watts loss per square centimeter

T_1 = absolute temperature of hot body

T_2 = absolute ambient temperature

Watts loss by convection is defined by the theoretical Rice formula:

$$W_c = 0.00066 \frac{(\Delta t)^{1.25}}{T_{ave}^{0.193}}$$

in which

W_c = watts loss per square centimeter

Δt = temperature rise of hot body

T_{ave} = absolute temperature (average) of hot body and ambient air

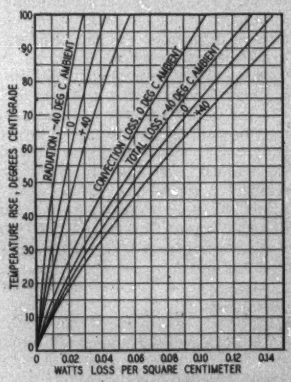

Fig. 1. Watts loss by radiation and convection per unit area of a body

When the instrument was first manufactured, it was hoped that this variation in radiation loss with

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1. For all numbered references see list at end of paper.

ambient temperature could be made negligible by using polished surfaces for the parts where heat was dissipated, but it was found that the permanence of a polished surface could not be depended upon. For "black body" radiation the constant in the Stefan-Boltzman law given in figure 1 is 5.75×10^{-12} (not 3×10^{-12} as there given), and it was found that permanence could not be depended upon for values of this constant less than about 3×10^{-12}. Permanence for radiation losses cannot be assured with a smaller value of this constant.

In the matter of heat loss by convection, the best data available at the time of the preparation of the writer's 1915 paper indicated that this loss was directly proportional to the temperature rise of the hot body above the ambient air. Since that time much new light has been shed on convection losses. Probably the most authoritative information now available is the work of Chester W. Rice reported[4] in 1924. According to his findings, convection loss varies *not* with the first power of the temperature rise of the hot body, but with the 1.25 power; it also varies very gradually with the ambient temperature (see theoretical Rice formula in the subcaption of figure 1). Figure 1 gives a curve showing the convection loss per square centimeter from a small cylinder calculated from the data given in the Rice paper. This curve is calculated for an ambient temperature of 0 degrees centigrade; the ambient temperature may depart from this assumed value by some 40 or 50 degrees in either direction without changing the resultant convection losses by more than 2 or 3 per cent. Figure 1 shows also the total losses

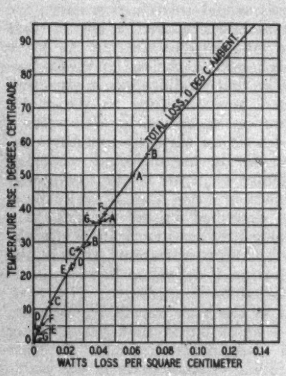

Fig. 2. Total-loss curve for ambient temperature of zero degrees centigrade of figure 1, points A to G indicate differential wattages corresponding to data in table I

Curve	Per Cent Full Load	Power Factor
A	50	0.25
B	100	0.50
C	50	0.50
D	50	0.75
E	50	1.00
F	100	0.75
G	100	1.00

of heat from a hot body resulting from convection and radiation combined; that is, to the convection loss values are added the corresponding values of the radiation loss giving 3 resultant total loss curves for the 3 ambient temperatures, −40, 0, and +40 degrees centigrade.

In the matter of heat loss by conduction, this follows strictly a first-power law. If the heat flow takes place through copper, as it does in an electric meter, there is the advantage of a very low temperature coefficient for thermal conductivity (−0.013 per cent per degree centigrade).

In the writer's 1915 paper it was proved that the instantaneous temperature difference between 2 similar bodies A and B when heated electrically by the methods described in that paper is given by the expression:

$$\theta_1 - \theta_2 = \frac{H_1 - H_2}{SE + 2Q}\left(1 - \epsilon^{\frac{-(SE+2Q)t}{M}}\right) \tag{1}$$

where

θ_1 = instantaneous temperaure of A above ambient temperature
θ_2 = instantaneous temperature of B above ambient temperature
H_1 = rate in gram-calories per second at which heat is applied to A
H_2 = rate in gram-calories per second at which heat is applied to B
Q = thermal conductivity of thermal shunt in gram-calories per second per degree centigrade temperature difference
E = heat emissivity of A or B in gram-calories per second per degrees centigrade per square centimeter of surface (similar)
S = surface area in square centimeters of A or B (similar)
M = amount of heat in gram-calories stored in A or B per degree centigrade of temperature rise (similar)
t = time after beginning heat application, in seconds
ϵ = base of Napierian logarithms = 2.718+

It might be pointed out further that equation 1 was derived on the assumption that all heat losses were first-power functions of temperature. It was proved further that with the arrangement of circuit as shown in that paper, the quantity $H_1 - H_2$ is always proportional to watts, independent of power factor and wave form. It was recognized at the time of presentation of the 1915 paper that if radiation were permitted to become an appreciable factor, some error would result; but it was believed that radiation could be made negligible by proper treatment of the surfaces of the heat radiating parts of the instrument. This hope was not realized. It was further believed in 1915 that convection loss from a hot body was a first-power function and it was not until Rice presented his classical paper in 1924 that this belief also was dissipated. In this connection, it is interesting to note that Rice himself in a preliminary paper presented in 1923 still held at that time to the first-power law for convection loss.

Causes of Temperature and Power Factor Errors

In the light of this new information, the results of which are presented graphically in the curves of figure 1, a very casual analysis shows the reasons for both the temperature and power factor errors of the electrothermic instruments as previously built. It is obvious at once from an inspection of the curves of figure 1 that a given differential wattage application to the 2 elements of the instrument will not cause the same differential temperature, but that this differential temperature itself will vary with ambient temperature. For instance (see figure 1) 0.05 watts per square centimeter will cause a 39.5 degree temperature rise when the environment temperature is +40 degrees and a 47.0 degree temperature rise when the ambient temperature is −40 degrees. This is a difference of approximately 16.0 per cent

Table I—Watts Applied to the 2 Elements of an Electrothermic Wattmeter for 2 Values of Circulating Current

Circulating Current	Per Cent Load	1.00 Power Factor			0.75 Power Factor			0.50 Power Factor			0.25 Power Factor		
		$\frac{I}{2}$	a^2	b^2	$\frac{I}{2}$	a^2	b^2	$\frac{I}{2}$	a^2	b^2	$\frac{I}{2}$	a^2	b^2
50% of unity power factor full load current = 0.5 amp	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	50	0.25	0.5625	0.0625	0.3333	0.5833	0.0833	0.5	0.7500	0.2500	1.0	1.5000	1.0000
	100	0.50	1.0000	0.0	0.6667	1.1667	0.1667	1.0	1.7500	0.7500	2.0	4.7500	3.7500
125% of unity power factor full load current = 0.795 amp	0	0.0	0.625	0.625	0.0	0.625	0.625	0.0	0.625	0.625	0.0	0.625	0.625
	50	0.1580	0.900	0.400	0.2110	0.919	0.419	0.3160	0.975	0.475	0.632	1.275	0.775
	100	0.3160	1.225	0.225	0.4220	1.303	0.303	0.6320	1.525	0.525	1.264	2.725	1.725

Watts loss in meter element A proportional to a^2; in element B, b^2.

for an 80 degree temperature change or approximately 0.2 per cent per degree centigrade. The temperature error thus calculated agrees closely with that observed. The method proposed for eliminating this radiation error is indicated by the construction shown in figures 4 and 6 and is discussed further later in this paper.

The source of the power factor error also is obvious from the foregoing analysis. The reason for this error is that the watts loss versus temperature rise relation is not linear. It might be pointed out further that the observed power factor error is essentially a temperature error. By reference to table I, it may be noted that while the *differential* watts applied to the 2 heaters of the electrothermic instrument is always proportional to watts and independent of voltage, frequency, wave form, and power factor, the actual watts applied to each heater increases as the power factor departs from unity whether lagging or leading.

In order to determine the order of the power factor error in the electrothermic instrument, the total-loss curve for an ambient temperature of 0 degrees centigrade of figure 1 is reproduced in figure 2. On this curve are indicated the positions of the differential wattages corresponding to various loads and power factors. These differential watts are taken from table I on the assumption that the differential watts per square centimeter at 50 per cent load are 0.02 and at 100 per cent load 0.04. From this analysis it is obvious that the power factor error is well within the meter code limits at the loads and power factors specified in the code. However, as heavier loads are applied at lower power factors, the error rapidly becomes greater. For instance, the theoretical error, as determined by the foregoing method of analysis, at full load and 0.5 power factor (double full load current at unity power factor) is of the order of 20 per cent. The actual error under test is only about 4 per cent. Most of this theoretical error is eliminated by properly proportioning the meter scale, that is, by contracting it at the upper end. It is evident therefore from the foregoing analysis that the power factor error in the electrothermic instrument is caused by the departure of the watts versus temperature rise curve from a straight line.

A comparatively large circulating current in the electrothermic instrument is desirable. Table I shows the watts that will be applied (and therefore the approximate temperature rise) to the 2 elements of an electrothermic wattmeter when the circulating current is 50 per cent of the unity power-factor full-load current, and also when the circulating current is 125 per cent of the unity power-factor full-load current. It is obvious that the "spread" between the maximum and minimum temperatures attained by the elements of the instrument under conditions of load and power factor met in practice is lower when using the larger circulating current.

Early Experiments to Eliminate Errors

Once having determined the cause of an error, means for its elimination begin to suggest themselves. It may be of interest to describe a few of the earlier attempts to eliminate the errors observed in the electrothermic instrument and thereby to show how continued investigation and experiment finally led to the complete solution described in this paper.

As soon as it was realized that radiation losses could not be made negligible in an instrument in which permanence is essential, it was realized also that radiation losses would introduce a curvature into the watts versus temperature rise curve; that is, that there is an inherent curvature in the curve representing the relationship as defined by the Stefan-Boltzmann law. The first modification in structure that was considered was a return to the metal diaphragm construction described in the writer's 1915 paper. The reason for this was that this construction would permit the use of liquid expansion for the heat responding elements of the instrument instead of the bimetallic strips that actually have been used and as described in the writer's 1918 paper. The bimetallic strip has practically a straight line response to temperature variation; that is, the deflection (or the torque, if deflection be restrained) is directly proportional to temperature. However, if a liquid be used as the heat responding element, it is possible to select a liquid that has a rising characteristic and thereby compensate, at least partially, for the falling characteristic in the watts versus temperature rise curve. By careful selection of the liquid it was hoped to obtain complete compensation. Hundreds of liquids are available, and, by considering mixtures of 2 or more liquids, the possibilities in matter of adjustment of the expansion characteristic of a liquid become literally infinite. Later in this paper appears a table (table II) giving the expansion characteristics of a few liquids; this table, of course, contains only an exceedingly small proportion of the liquids that might have been considered.

Experiments with metal diaphragms were unsatisfactory. The principal reason for this was the impossibility, so far at least, of obtaining a sufficiently large motion with temperature variations. The only metal diaphragms available that would give the desired motion were of relatively large diameter; this in turn, meant a relatively large volume of liquid to be heated, a comparatively large watt input, and long time period. If metal diaphragm stacks of sufficiently small diameter and sufficiently great flexibility could be secured, the metal diaphragm construction might be a quite satisfactory solution. However, the difficulties of securing a solution by this method seemed to be greater than those offered by other possible constructions, and attention accordingly was turned to these other possibilities.

Experiments With Bourdon Tubes

After experimenting with many other various schemes, all of which proved abortive, attention was turned to the Bourdon tube. The use of the Bourdon tube was suggested in the writer's 1915 paper, but at that time consideration was given only to a tube in which the liquid being heated was contained within the curved portion of the tube itself. The method, now widely used, employing a bulb containing a liquid connected to a Bourdon tube through a capillary tube seemed to offer promise. This structure as manufactured by several companies was studied. The temperature of the bulb, as used in this structure, is registered by the Bourdon tube. The pressure changes developed in the bulb by temperature changes and registered by the Bourdon tube may be those of a completely filled system or those of a partially filled system. In the completely filled system, the expansion of the filling liquid develops the pressure; in the partially filled system, the vapor pressure of the filling liquid is registered. The liquid expansion principle is utilized in the thermal meter now proposed.

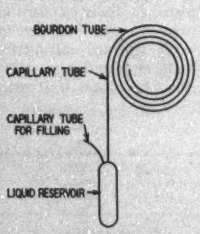

Fig. 3. A Bourdon tube with liquid reservoir for use in electrothermic instruments

The first Bourdon tubes with separate reservoirs were made by the writer in 1930, and experimentation has proceeded continuously ever since. It might be added that technical literature contains very little information concerning Bourdon tubes and it was necessary to determine by the method of trial and error the limitations of such tubes. Tubes of various materials, lengths, dimensions, wall thicknesses, reservoir volumes, spiral dimensions, etc., were tried before finally arriving at a satisfactory solution. One of the things that early became obvious was that the amount of liquid in the Bourdon tube itself should be reduced to a minimum in order that the temperature of the liquid-containing reservoir and not the temperature of the Bourdon tube itself would control the pressure within the tube.

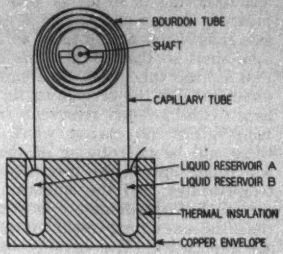

Fig. 4. Diagram of instrument mechanism using 2 Bourdon tubes with liquid reservoirs

This meant making the volume within the tube a minimum. Minimum internal volume is secured when the tube is rolled flat and this was the construction adopted. A Bourdon tube is essentially a spring, and steel is well-known to be the best available spring material. Consequently, after some preliminary experiments with other materials, steel has been used in all the writer's experimental work. Steel has the further advantage of having minimum hysteresis, being so nearly zero in the final product as to be entirely negligible. Proper heat treatment is of course important; steel is amenable to heat treatment while most other metals are not. Tubes of a material other than metal were considered, but seemed to offer no advantages.

Figure 3 shows a Bourdon tube with bulb as now proposed for use in electrothermic instruments. The Bourdon tube consists of 20 inches of $^3/_{16}$ inch steel tubing with a 0.010 inch wall. This tubing is rolled or pressed flat before being coiled into the shape shown in figure 3. After coiling, the tube is heat-treated. The liquid reservoir consists of a short length of steel tubing and is provided with hemispherical ends; its over-all inside length is approximately 1.324 inches. The capillary tube joining the reservoir to the Bourdon tube is of copper and has an outside diameter of approximately 0.06 inch; its length may be anything desired, but 4 to 5 inches have been used in the experimental models. All joints are either brazed, welded, or soldered to insure permanent freedom from leakage.

Use of 2 Bourdon Tubes

With a structure of the dimensions described, the angular motion of the Bourdon tube for a one degree centigrade change in reservoir temperature is approximately 0.8 angular degree when the tube is free, or $^1/_2$ of this value when 2 identical tubes are used opposing each other as shown in figures 4 and

6. This value is, of course, governable by the size of reservoir, type of liquid, conformation of Bourdon tubes, length of supporting arm, and many other factors. The method of using these tubes in the structure of an instrument is exactly the same as that for the bimetallic spring construction described in the writer's previously mentioned 1918 paper. The Bourdon tubes are used in pairs, these pairs being selected carefully so that they have identical characteristics in so far as their response to temperature change and torque is concerned. The inside ends of this pair of tubes are attached to a common shaft so that the 2 tubes oppose each other; that is, one tube tends to rotate the shaft in one direction and the second in the other. Thus, so long as the 2 liquid reservoirs remain at the same temperature, no matter what that temperature, there will be no rotating of the shaft; the shaft will rotate only if the 2 reservoirs are at different temperatures, and the amount of rotation is proportional to the difference in pressure developed in the 2 tubes resulting from a given difference in wattage application. If a circuit connection such as described in the writer's 1915 paper be used, a differential wattage strictly proportional to the watts of the circuit under measurement can be applied to the 2 liquid reservoirs. The problem therefore reduces to the finding of a construction that, for a given differential wattage, will cause a strictly proportional differential pressure between the 2 liquid reservoirs.

Experiments with the construction shown in figure 4 were carried out. It is obvious that this construction eliminates the errors of the earlier construction which were caused by variations in radiation losses caused in turn by variations in ambient temperature. With this construction, the exchange of heat between the liquid-containing reservoirs A and B is dependent entirely upon the rate of heat conduction through the thermal insulation, through whatever metallic connections may be installed between elements A and B, and through the lead wires and the capillary tubes. A considerable part of the heat will escape through the thermal insulation to the copper envelope and thence by radiation and convection to the ambient air. However, *differential temperature* does *not* depend in any degree upon the rate of escape of heat from the envelope except in so far as the escaping heat affects the temperature, and therefore the thermal conductivity, of the thermal insulation. It therefore becomes important to determine the temperature coefficient of thermal conductivity for this thermal insulation. All available data on this point were studied. Thermal insulators invariably were found to have a positive temperature coefficient for thermal conduction, that is, thermal conduction for a given temperature difference always increases as temperature rises. Thus, the compensation sought can be obtained if a liquid can be found with an expansion coefficient that increases at the same rate as does the temperature coefficient of the thermal conductivity in the thermal insulation. For this purpose a study was made of the characteristics of various expansible liquids.

Expansion Characteristics of Liquids

Table II contains data on the expansion characteristics of a few of the liquids considered. The data for expansion is taken from the International Critical Tables (vol. III, page 28). Many other liquids might have been considered. The last column in this table headed "excess" is a value that has been calculated on the basis of the effect of the β and γ components of the expansion curves. This value is, therefore, a measure of the amount of curvature in the expansion curve of the liquid in question. This calculation, of course, assumed that the expansion curves (see table II) may be extrapolated to 100 degrees centigrade—an assumption that may or may not always be justified.

From tests made on structures similar to that shown in figure 4 the writer has found that complete compensation can be secured. There is great latitude in the choice of available liquids, with a wide range of upward curvature in their expansion curves, and there is also a wide range of choice in heat insulating materials, with upward curvature in their temperature-thermal conductivity relations. Many combinations may be found that give

Table II—Characteristics of Some Expansible Liquids

Liquid	Expansion Coefficients (See Appendix) $\alpha\times10^{-6}$	$\beta\times10^{-6}$	$\gamma\times10^{-9}$	Temperature Range, Deg C Minimum	Maximum	Boiling Point, Deg C	Melting Point, Deg C	Excess (See Text)
Methyl alcohol	+1.0041	+1.802	+16.57	− 94.5	+ 15	+ 66	− 97.1	+34.4
Ethyl alcohol	+0.8461	+0.160	+ 8.5	0.0	80	+ 78.4	−114	+11.9
Carbon tetrachloride	+1.911	+0.69		0.0	40	+ 76	− 23	+ 3.6
Chloroform	+1.8563	+0.6300	+ 8.81	− 53	+ 55	+ 61.2	− 70	+ 7.62
Acetone	+1.1142	+0.315		− 83	+ 25	+ 56.5	− 94.0	+ 2.83
Methyl ethyl ketone	+1.022	+0.46		0.0	+ 50	+ 80.6	− 86.0	+ 4.1
Ether	+1.1044	+0.4772		−120	0	+ 35	−116.2	+ 4.32
Ethyl lactate	+1.126			+ 7	+108	+154.5	?	0.0
Benzene	+1.0636	+0.0376	−2.213	+ 11	+ 72	+ 80.36	+ 5.4	− 1.725
Hexane	+0.8486	+1.084	−0.164	0.0	+100	+ 69	− 94	+ 1.38
Toluene	+0.9159	−0.368		− 95	+ 18	+111	− 95	− 4.02
Xylene	+0.8515	+0.109	+ 1.73	0.0	+100	+139	− 53	+ 3.31
Cyclohexane	+0.8879	+0.972	− 1.55	0.0	+ 65	+ 80.8	+ 6.4	+ 9.2
Bromotoluene	+1.25			+ 30	+100	+181	− 26	0.0
Pinene	+0.83			+ 20	+293	+156	?	0.0
Tetrachloroethylene	+1.62			0.0	+ 90	+121	− 22	0.0
Hydrocyanic acid	+1.45			0.0	+ 15	+ 25.2	− 12	0.0
Ethane	+1.307			−108	− 74	− 86	−172	0.0
Allylene	+1.245			− 55	− 13	− 23.5	−110	0.0

complete compensation (see mathematical analysis in appendix).

The ideal to be attained is that a given differential wattage applied to the 2 liquid reservoirs A and B in figure 4 always shall give the same angular deflection independent of ambient temperature, power factor, wave form, voltage, frequency or any other variable that may be applied to the meter. The writer's 1915 paper proved that the differential watts, using the circuit arrangement therein described, is always proportional to watts, independent of power factor and wave form, and, within reasonable limits dictated by design, can be made independent of voltage and frequency. However, a given differential wattage does not necessarily mean the same deflection at all temperatures and power factors with the instrument as built up to the present time for reasons that have been set forth. With the modifications of structure shown in figure 4, it is obvious that the temperature error in the bimetallic strip type of meter caused by radiation is eliminated since there is no radiation from each element separately. The error in the bimetallic strip type of instrument caused by the departure of the watts versus temperature curve from a straight line is eliminated not by making this curve a straight line, but by making the temperature differential versus deflection curve bend in one direction by exactly the same amount as the watts versus temperature curve bends in the other direction. Thus the watts versus deflection curve becomes a straight line and, so long as this is true, a given differential watt will cause exactly the same deflection at one part of the curve as it does at any other. Thus the error in the bimetallic strip type of instrument attributable to both temperature and power factor variations is avoided. The appendix indicates how this result may be obtained.

In addition to adjusting the temperature coefficient of the expanding liquid and of the thermal insulation, still another method of adjustment for temperature and power factor errors is available, and this lies in the selection of the thermal shunt between A and B, figure 4. A thermal shunt may be used to adjust the instrument for the desired time period. This thermal shunt, of course, should be made of metal and preferably of high thermal conductivity to curtail the amount of material used. The thermal conductivity of metals varies over a wide range; some metals have a positive and others a negative coefficient. In this respect, the metals differ from thermal insulators since the latter, as pointed out in an earlier paragraph, all have positive coefficients. Therefore, the wattage differential versus deflection relation is capable of adjustment by 3 separate methods or by a combination of all 3 of them: (1) by the selection of the expanding liquid; (2) by the selection of the thermal insulation; and (3) by the selection of the thermal shunt.

Vacuum Containers Used for Heat Insulation

As experiments were continued on the structure shown in figure 4, a still further modification seemed to offer still further advantages. This modification consisted simply of substituting for the thermal insulation of the usual type shown in figure 4, thermal insulation of the vacuum type. Heat insulation by vacuum has been known for many years. It was used first by Dewar in 1892 in connection with his classical work on liquid air. The popular thermos bottle is based upon this principle.

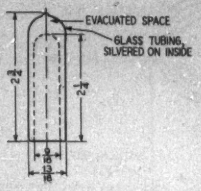

Fig. 5. Vacuum container for providing heat insulation for liquid reservoirs of electrothermic instrument

All dimensions are in inches

If, therefore, vacuum bottles be substituted for the heat insulation shown in figure 4, a structure such as shown in figure 6 will be obtained wherein the loss of heat from the liquid reservoirs A and B by convection and radiation is reduced to practically zero. This, in turn, means that the value of E (emissivity) that appears in equation 1 in the early part of this paper becomes so small in comparison to Q that E may be neglected. The ultimate temperature differential for a given wattage differential and also the time required to reach that temperature differential is then dictated almost entirely by the value of Q (thermal shunt).

Actual tests demonstrated that the time to attain a given percentage of final temperature could be varied from 10 minutes to 75 minutes simply by varying the size of leads conducting current into the heaters. Still wider range could be secured if desired.

The writer's experimental work finally led to the structure shown diagrammatically in figure 6. In this structure the heat set free in resistances A and B escapes almost entirely by thermal conduction, and the rate of escape is therefore a first-power function. The rate of heat escape is governed by the length and cross section of the thermal shunts $S1$ and $S2$, of the leads l_1, l_2, l_3, and l_4, and of the capillary tubes t_1 and t_2. The vacuum bottles are silvered on the inside and are consequently very effective heat insulators, practically free from radiation and convection losses. As would be expected, manufacturers' tests have shown the insulating properties of these bottles to be of a permanent character.

Thermal shunts S_1 and S_2 are necessary only when very short time period is required. For most purposes, the desired characteristics may be secured by adjustment of the leads l_1, l_2, l_3, and l_4. These leads serve the double purpose of electrical and thermal conductors. It may be of interest to point out that copper has not only a high thermal conductivity (3.84 watts per cubic centimeter per degree centigrade at 0 degrees), but also a low temperature coefficient for thermal conductivity (-0.013 per cent per degree centigrade).

It is this substitution of thermal conduction, a strictly first-power function, for radiation and convection, which are *not* first-power functions, that is responsible for the elimination of the curvature in the response of the Bourdon tube type of instrument to heat applications, and is therefore

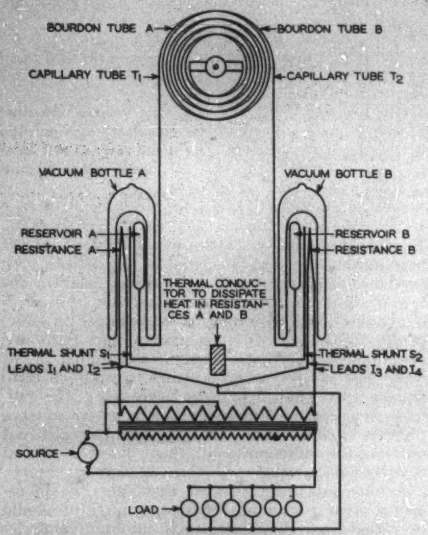

Fig. 6. Diagram showing final form of electrothermic instrument proposed in this paper, with connections to load

responsible for the elimination of the errors in the electrothermic instrument as heretofore built. The writer wishes again to emphasize particularly the importance of this first-power law for heat loss in any thermal meter.

Characteristics of New Instrument

Some of the characteristics of this new electrothermic instrument may be of interest. In the matter of torque, it has many times the torque of any previous instrument ever built so far as the writer's knowledge extends. Tests on several 500 watt instruments show a torque in excess of 300 millimeter-grams per degree of deflection of the Bourdon tubes. This means a full scale torque of 6,000 to 7,000 millimeter-grams, which is some 12 times the torque available in the bimetallic strip type of instrument.

In the matter of overloads, sample instruments have been tested at loads 4 to 6 times full load continuously without signs of distress other than charring of fibrous insulations.

In the matter of losses, tests on experimental instruments show total losses at no load of less than 2 watts including transformer losses. At full scale deflection these losses rise to somewhat less than 3 watts. Thus it may be noted that the watt losses in this new type of electrothermic instrument are of the same order of magnitude as those of the usual type of induction watt-hour meter. It should be noted particularly, however, that these losses are pure resistance losses; that is, the volt-ampere losses are the same as the watt losses. Thus, the volt-ampere losses in this new instrument are a rather small fraction of those in the usual type of watt-hour meter, and consequently its burden on potential and current transformers is correspondingly less.

In the matter of temperature rise, the new electrothermic instrument is adjusted to have approximately a 20 degree centigrade rise above the ambient air in both liquid-containing reservoirs at no load. At unity power factor, full scale (the maximum load the meter is expected to carry continuously), the temperature rise of the hotter reservoir above the ambient air is approximately 50 degrees centigrade. The differential temperature between the 2 reservoirs is strictly proportional to watts, independent of power factor and wave form. At power factors other than unity, the temperature rise of the hot reservoir is less than with the same current at unity power factor.

In the matter of voltage, power factor, and temperature variations, their effect on the indications of this new instrument is negligibly small.

In the matter of time period, this may be adjusted readily to any value desired, up to at least 60 minutes. The time period on rising loads and falling loads is the same in this new instrument. This is not strictly true with the bimetallic strip instrument. The reason for this difference is obvious; in the Bourdon tube instrument the relation between temperature and deflection is strictly a linear function, while in the bimetallic strip instrument it is not.

In this new instrument, since heat loss is strictly a first-power function, scale deflection is uniform throughout the entire range. In this respect it differs materially from the bimetallic strip instrument where the upper end of the scale is contracted approximately 12 per cent as compared with the lower end. The first-power law for heat loss further insures that this new type of instrument always will follow a true exponential law for watt applications. These features may be utilized to extend the usefulness of the meter.

Appendix—Expansion Characteristics of Liquids

The expansion characteristic of a liquid may be represented by the expression

$$V_t = V_0(1 + \alpha t + \beta t^2 + \gamma t^3)$$

where

V_0 = the volume of the liquid at 0 degrees centigrade
V_t = the volume of the liquid at t degrees centigrade
t = temperature of the liquid in degrees centigrade
α, β, and γ = constants

Similarly, the thermal conductivity of a thermal insulator may be expressed by

$$K_t = K_0(1 + \alpha' t + \beta' t^2 + \gamma' t^3)$$

Differentiating this expression for V_t and K_t with respect to t,

$$dV_t = V_0(\alpha dt + 2\beta t dt + 3\gamma t^2 dt) \quad (2)$$

$$dK_t = K_0(\alpha' dt + 2\beta' t dt + 3\gamma' t^2 dt) \quad (3)$$

Dividing equation 2 by equation 3,

$$\frac{dV_t}{dK_t} = \frac{V_0}{K_0} \frac{\alpha + 2\beta + 3\gamma t^2}{\alpha' + 2\beta' t + 3\gamma' t^2} \quad (4)$$

From an inspection of equation 4 it is obvious that $\frac{dV_t}{dK_t}$ becomes a constant when $\alpha + \beta + \gamma = c(\alpha' + \beta' + \gamma')$ where c may have any value whatever.

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Electric Power Equipment for Steel Plants

The rapid increase in the use of electric power equipment in steel plants in the United States during the last 3 decades is outlined briefly in this paper, and the principal types of apparatus now in use are discussed. Power generation and distribution equipment is considered briefly and the types of electric motors used in different kinds of main mill drives are outlined. Synchronous motors and d-c motors are shown to have largely superseded the use of induction motors.

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THE history of the electrification of the steel industry in America covers a period of little more than 30 years. Between 1905 and the present, American manufacturers have furnished main drive motors for steel plants having a total continuous capacity of 2,850,000 horsepower. Of this capacity, 85 per cent has been supplied since 1915. Because of the rapidity of this development and the wide variety of electrical equipment used, the story of the electrification of the steel industry forms an interesting chapter in the history of American industry.

Years before the use of electricity in industrial operations, the iron and steel industry was a large user of high capacity power units. When wrought iron was giving way to steel, power requirements increased and the low capacity, unflexible water wheel was abandoned in favor of steam power. The reciprocating steam engine and the rolling mill rapidly grew up together, each successive installation pointing the way to the use of heavier mills and more powerful engines. By 1890 the manufacture and servicing of rolling mill engines had become a flourishing business. One builder alone supplied 294 engines to the iron and steel industry.

The most spectacular units produced by the engine builders were the large reversing engines for driving reversing blooming, slabbing, and plate mills. The most advanced types were 4-cylinder, twin, tandem-compound units, some of which were capable of exerting 15,000 peak horsepower. When operated condensing, the steam consumption of these units alone was not excessive for conditions existing at that time. Their simplicity and large size and the smoothness and apparent ease with which they worked inspired confidence in the hearts of rolling mill men. At first these men were loath to place the same confidence in the smaller and less spectacular, but more powerful, reversing motor.

Gradual Adoption of Electricity

During the development of the reciprocating engine for main roll drive, the mill auxiliaries were driven by small non-condensing engines or by hydraulic mechanisms. These drives were inherently inefficient and their excess steam consumption, together with the losses in the complex system of steam lines necessary for their operation, seriously affected the over-all economy of the power system. Therefore, the first major step in the electrification of iron and steel plants was to replace steam and hydraulic drives on cranes, hoists, roll tables and other auxiliaries. By the beginning of the present century, the advantages of electric drive for all auxiliaries were well established and the changeover was proceeding rapidly. Even operators who continued to purchase engines for main power units used electric auxiliaries.

As it became necessary to analyze operating costs more closely it grew increasingly evident that the

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operating cost of large engine drives was usually excessive for the service rendered. This was not due so much to excessive steam consumption of the engines themselves as it was to the inherent disadvantages of the steam power system. Rolling mills are usually scattered over a considerable area. This

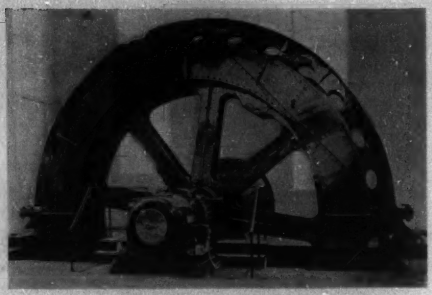

Fig. 1. Typical slow speed induction motor drive. Synchronous motors are now used for this application

made it necessary either to have a separate boiler plant for each mill or long steam lines to a central boiler plant. Where there were a number of reversing drives, either arrangement was unsatisfactory because of the enormous momentary demands for steam. Because of the standby and transmission losses, the engines seldom utilized more than 65 per cent of the total steam generated and usually the figure was much lower. Steam system maintenance costs were also excessive.

The successful and economical operation of electrically driven auxiliaries caused steel plant engineers to become interested in using electricity for main roll drive. Test data on existing engine drives were being compiled in such a way that they could be used in selecting motor drives for new mills.

The first installation of motors for main roll drive was made in 1905 at the Edgar Thomson Works of the Carnegie Steel Company, near Pittsburgh, Pa. This installation consisted of 2 1,500-horsepower 100/125-rpm 220-volt d-c motors driving a light rail mill. At about the same time the first electric reversing mill drive was purchased to drive a universal plate mill at the South Chicago plant of the U.S. Steel Corporation. This installation was followed in 1910 by a reversing blooming mill drive at the Algoma Steel Company, Sault Ste. Marie, Ontario. The Gary (Ind.) plant of the U.S. Steel Corporation, on which construction work was begun in 1906, was laid out for electric drive for both main rolls and auxiliaries, as far as was practicable with equipment then available. This was the first steel plant to be designed to use electric power for practically all operations. It is interesting to note that every one of the pioneer electrical installations mentioned above is still in service and operating at the original efficiency.

Power Generation and Distribution

By 1910 it became evident that steel plants eventually would be operated almost entirely by electric power and that suitable electric power systems would have to be installed. At that time the steam turbine and steam generating equipment were not highly developed, especially in small units of 5,000 kw or less, which was about the maximum capacity that steel makers were then willing to tie up in one unit.

Gas engines which could operate on available blast furnace gas could be had in capacities of 2,000 to 3,500 kw and would generate a kilowatthour on 15,000 to 18,000 Btu. A great many gas engine generating units were installed, a large part of which is still in use. The speed regulation of the older engines is poor, because of variations in the quality of the gas and on account of the slow speed (83 rpm). The variations in system frequency which occur as a result of poor engine regulation often have an undesirable effect on plant operations, so it was common practice to operate turbogenerators in parallel with gas engine units to give stability. Gas engines were improved and units as large as 6,000 kw installed, but the need for large generating units and the improvement of the steam turbine and boiler plants have made it desirable to use steam turbine units for power plant extensions.

In a modern steel plant, blast furnace gas is used to generate superheated steam at 250 to 300 pounds pressure. Steam generators are also equipped to burn coke breeze or coal. Part of this steam is utilized in steam turbocompressors to produce the air blast for the blast furnaces. The remaining steam is utilized in turbogenerators of 15,000 to 30,000 kw capacity. Waste heat from open hearth furnaces also provides a source of power which is being utilized to an increasing extent. A battery of 14 150-ton furnaces installed a few years ago was

Fig. 2. A 1,800-horsepower 150-rpm 6,600-volt synchronous motor driving tube piercing mill. Loads are heavy and of such duration that flywheels are undesirable for load equalization

Fig. 3. 7,000 horsepower and 2,000 horsepower reversing motors operating in parallel. The 7,000 horsepower motor in the background drives the main horizontal rolls of a universal mill. The 2,000 horsepower motor drives a pair of vertical rolls in synchronism with the main rolls

equipped with waste heat boilers, 2 10,000 kw turbo-generators, and an evaporator to generate steam at moderate pressure for general mill use. Each 150 ton furnace produces an average of about 750 boiler horsepower. Under normal operating conditions it is possible to obtain from waste heat practically all the electric power required for a steel plant. Dry quenching of coke promises to provide another source of waste heat.

Steel plants necessarily occupy a great deal of space and points where power is used are seldom near to the place where it is convenient to install generating equipment. Present power requirements make it necessary to generate and distribute at 6,600 or 13,200 volts. The former voltage is practically standard for large motors. For small finishing plants operating on purchased power, 2,200 volts is satisfactory. Widely scattered plants operating under the same management are usually interconnected by transmission lines operating at 22 kv or 44 kv. One such 44 kv system has a total connected generating capacity of 120,000 kw. Thus, every large steel plant is confronted with the same problems of power generation and distribution as the utilities.

Electric Motor Well Suited for Main Drive

In the early stages of the electrification of the industry, the performance of the steam engine on main roll drives was the standard by which motor drive was judged. Mill design and rolling processes had been worked out to suit the characteristics of the engine. Except for reversing service, in which the speed was regulated manually, the reciprocating engine was essentially a constant speed power unit. Early rolling mills, except reversing type, therefore, were designed to operate at practically constant speed. It was then necessary to have a number of mills, each with a limited range of product. As experience was gained in applying motors, it became evident that by careful co-ordination of mill design and motor design to take advantage of the greater flexibility of the electric motor, mill performance could be improved. So, modern mills may use several types of electric drive in a single installation and a wide range of product can be rolled. In one recent instance, 7 old mills were replaced by a single mill with modern electric drive.

Recently great advances have been made in rolling mill processes. For example, all plate formerly was rolled in mills having not more than 2 independently driven stands of rolls and in most cases only a single stand. In such mills, plate can be rolled only in short lengths and coarse gauges. The modern mill has as many as 10 independently driven roll stands arranged in tandem and with finishing stands closely spaced. The total connected motor capacity is usually between 30,000 and 40,000 horsepower. Such mills, known as wide strip mills, may have rolls up to 100 inches long and can roll long plates in heavier gauges, or long coils of wide thin material known to the trade as strip.

Wide strip mills have been made possible through advances in mechanical design of mills and by the development of the adjustable speed d-c motor. The first 4 roll stands, which are spaced so the steel is in only one stand at a time, are usually driven by synchronous motors or induction motors of about 2,500 horsepower rating. The finishing stands are closely spaced and are each driven by a 600-volt d-c adjustable speed motor with a 2 to 1 speed range by field control. These motors vary in capacity from 2,000 horsepower to 3,500 horsepower in existing installations.

Likewise, the methods of producing sheet and tinplate have undergone a tremendous change. Formerly all sheet and tinplate was produced by a slow and laborious process. Small bars were heated, rolled to light plate, reheated in packs of 2 or more and the packs rolled, doubled, reheated and rerolled as often as was necessary to obtain the desired gauge. The modern method of rolling such material is to start with a coil of strip weighing several tons and cold roll it directly to the desired gauge in one operation. Mills for this process may be either multi-stand tandem mills or single stand reversing mills. D-c adjustable speed motors are used for either type of mill with special control equipment to keep the steel under tension during rolling.

And so, through the entire list of finished steel products, it will be found that present day processes all depend heavily on drive characteristics which can be obtained only with the electric motor. A review of the various types of motors and their application to main roll drives will serve to illustrate this point.

Fig. 4. Typical installation of d-c adjustable speed motors for high speed tandem mill drive

Induction Motors

The induction motor has been widely used in the past for 2 main types of drives: (1) constant speed drives which were subjected to heavy peak loads of short duration, and which required high starting torques; and (2) constant speed drives for continuous type mills in which a number of stands were driven from a common shaft. For the first type of drive, wound rotor motors and flywheels and fixed or adjustable slip resistance are used. This arrangement was especially popular when power systems were small and it was necessary to protect generating equipment against short, heavy peaks. Induction motors up to 7,000 horsepower capacity have been used for this type of drive. Changes in mill design and increase in power system capacity have greatly reduced the demand for induction motor drives with flywheels for equalizing load peaks. Induction motors were used for the second type of drive largely because suitable synchronous motors were not available. A typical slow speed induction motor drive is illustrated in figure 1.

A number of systems have been developed for speed regulation of wound rotor induction motors, and 145 equipments ranging in capacity up to 7,500 horsepower have been installed. Due to changes in mill design and the demand for maximum simplicity of electrical equipment there is little application for a-c adjustable speed motors.

Synchronous Motors

Improvement in synchronous motor design and increase in capacity of power systems now make it possible to use synchronous drive for many constant speed applications for which induction motors were used previously. The synchronous motor is the ideal drive for certain types of multi-stand mills in which one motor drives a number of roll stands and the load is steady. Paradoxically, the synchronous motor may also be superior to other types for operations which impose heavy peak loads. In a seamless tube plant, for example, a large piercing mill requires 10 to 20 seconds to pierce a billet and the motor load will be several thousand horsepower. In the interval between billets the load is negligible. Because of the relatively long load period, an excessively heavy flywheel would be required to equalize such a load if induction motor drive were used and a definite period would have to be allowed between operations to permit recovery to no-load speed. An installation of this type is shown in figure 2. Between the comparatively steady load and the load which consists of a succession of long, heavy peaks there also are a number of constant speed loads for which the synchronous motor is suitable.

Small and medium capacity synchronous motors are started at full voltage. Larger motors are usually wound with 6 primary leads so that a starting reactor can be connected permanently in the neutral. This reactor is short-circuited by a 2 pole circuit breaker as the motor approaches synchronous speed. By proper design of the rotor cage winding, the starting torque can be made to suit a wide range of conditions. Synchronous motors up to 9,000 horsepower are in successful operation.

D-C Reversing Equipments

Reversing motors are used principally to drive heavy primary reduction mills such as blooming and slabbing mills which reduce the original ingots to sections which can be used in finishing mills. Reversing stands are used also for making roughing passes in rail, structural, and plate mills. Over 100 reversing equipments varying in continuous capacity from 500 horsepower to 12,500 horsepower have been built in the United States. These drives usually consist of a specially designed reversing motor having a speed range of at least 2 to 1 by field control; a motor generator consisting of one or more variable voltage generators, a wound rotor induction motor and a flywheel; a slip regulator to equalize the input to the motor generator; and a variable voltage control. In special cases a synchronous motor-generator can be used. The speed and direction of rotation are controlled by a small foot master switch. A special form of reversing drive in which 2 motors drive separate pairs of rolls in the same mill housing is shown in figure 3.

Reversing drives are usually direct connected to the mill rolls, so the motors are designed for slow speeds and heavy torques. The most powerful equipment built to date has 2 5,000-horsepower, 40/80-rpm motors, one connected to each of the main horizontal rolls of the mill, and a third motor of 2,500 horsepower capacity for driving a pair of vertical edging rolls. The combined maximum

torque capacity of the 5,000 horsepower main motors is 3,950,000 pound-feet. The use of the twin-motor arrangement makes it possible to apply extremely high capacity slow speed drives to a single pair of rolls.

D-C Adjustable Speed Motors

The tendency to design modern finishing mills for a wide range of product frequently makes it necessary to drive each stand of rolls with an individual adjustable speed motor. Mill stands usually are arranged in tandem on close centers so that it is necessary for the mill operator to have close control of the speed of every motor in the roll train. The d-c motor is peculiarly adapted to this class of service. (A typical installation is shown in figure 4.) The d-c motor is indispensable for cold roll mills, in which both the speed of the mill and the tension on the metal must be regulated closely.

A brief explanation of the operation of a single stand reversing cold roll mill will serve to show the flexibility of the d-c motor and its control. Such a mill consists of a roll stand with 2 working rolls and a driving motor and 2 motor driven reels; one on either side of the roll stand. A long coil of hot rolled strip weighing several thousand pounds is placed in the reel on the entry side of the mill and the end of the strip is threaded through the rolls at slow speed and into the jaws of the reel on the delivery side. Electrical adjustments are made which place the strip under tension on both sides of the mill and the mill and reels are brought up to speed by variable voltage control. Due to the decreasing diameter of the coil on the entry side, the speed of the reel must increase as rolling progresses. The motor acts as a generator while maintaining the desired back tension. On the delivery side, the diameter of the coil increases so the delivery reel drive, acting as a motor, must continually decrease its speed while maintaining the strip under constant tension. Successive passes are made in opposite directions so the functions of the reel drives are reversed for each pass.

A Stroboscopic Power Angle Recorder

An automatic stroboscopic power angle recorder developed to study directly the transient performance of synchronous machines during load disturbances is described in this paper. A portion of the machine under observation is illuminated by stroboscopic light, and its oscillations are recorded directly by a moving-film camera. The operation of the device is made automatic by connecting a suitable relay in its circuit. A typical installation on a hydroelectric generator is described.

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THE automatic stroboscopic power-angle recorder described in this paper, an instrument that might be called the "strobograph," makes possible the direct recording of the power angle of synchronous machines—a measurement otherwise very difficult to obtain especially during disturbances. The present strobograph is an improvement of an earlier model described in Electrical Engineering, May 1931, pages 327–9.

The electromagnetic oscillograph has been used for the study of transient conditions in power networks, and has produced commendable results. Several types of oscillographic instruments capable of great flexibility and usefulness have been developed, particularly for obtaining records showing what happens during disturbances. A serious limitation of the oscillograph, however, is that it cannot measure the power angle directly in the way that it records voltage or current, since the power angle cannot be measured electrically at the terminals. The power angle is one of the most important variables to measure, since stability is a function of this angle. Auxiliary apparatus such as a pilot a-c generator (having the same number of poles as the machine under test and rigidly connected to it) or a special commutator can be used in conjunction with the oscillograph to record the power angle, but these methods seldom are employed because they are difficult to arrange, especially upon large machines.

A stroboscope permits the direct measurement of the power angle. Stroboscopic light, flashed in constant phase relationship with the stator voltage, shows the field poles in a stationary position in space when the machine is running in synchronism at constant load. As the load changes, the poles can be seen to move to their new equilibrium position and oscillate about it. The oscillation is over in a few

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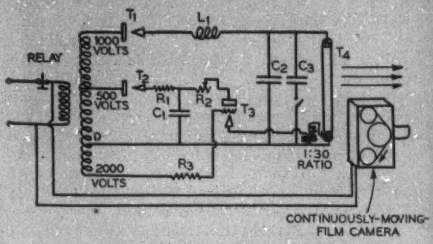


Fig. 1. Wiring diagram of a stroboscope for producing one flash of light each cycle in accurate phase relationship with the voltage

R_1 20,000 ohms
R_2 100 ohms
R_3 20,000 ohms
T_1 Type 866 rectifier tube
T_2 Type 280 rectifier tube
T_3 Type FG-17 grid-controlled mercury-vapor tube
T_4 Mercury arc stroboscope tube
L_1 1 henry or 300 ohms resistance
C_1 0.25 microfarad
C_2 1 microfarad
C_3 3 microfarads

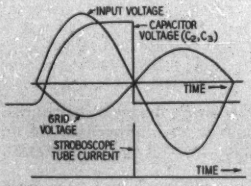


Fig. 2. Voltage and current variations in circuit of figure 1

seconds—in fact, so quickly that it is impossible to measure with the eye the angle time curve—but with a camera a series of readings may be exposed on the film. The stroboscope for this purpose must produce light having several properties which will be discussed in detail later.

This paper describes a method of measuring the power angle during disturbances by photographing the field structure with stroboscopic light. An application of the method was made in the Bellows Falls, Vt., plant of the New England Power Association during the summer of 1933, and some of the results are shown.

Stroboscopic Method of Measuring Power Angle

Speed and angle measurement with stroboscopic light have long been in use in the operation of synchronous machines, and the principles involved are well understood by engineers and operators of power systems. The method is not in general use at the present time because there has been a lack of a suitable convenient high-power source of stroboscopic light. The stroboscopes described in this paper overcome this objection. The method was developed in the electrical engineering department at the Massachusetts Institute of Technology in order to measure the transient performance of synchronous machines during load disturbances.

Fig. 3. A stroboscope in the laboratory of the Massachusetts Institute of Technology for measuring the angular displacement of a synchronous motor

The requirements of a suitable stroboscope for making photographic records of power angle transients are:

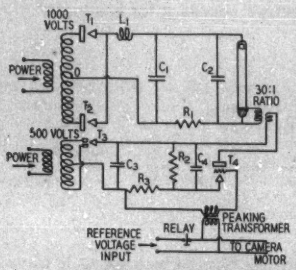
1. An accurate *phase relationship* between the time of flash and the terminal voltage.
2. A brief flash of light (less than 10^{-4} second). A short flash is necessary in order to produce a clear unblurred image of the moving scale or pointer.
3. A great instantaneous intensity of illumination. This is important when pictures are needed for obtaining records.

One circuit arrangement that is very satisfactory is shown in figure 1. A short flash of light is produced each cycle from the mercury arc tube at a time corresponding approximately to the time when the supply voltage is zero. The magnitude of the input voltage can be varied without any appreciable change in phase shift between the flashes and the voltage. Experiment shows that the error in angle measurement is less than $^1/_2$ an electrical degree for a voltage change from -10 per cent to $+10$ per cent. Limitations to the allowable variations of voltage depend primarily upon the filaments of the rectifier tubes, T_1 and T_2 and the vapor tube T_3. Should the voltage drop too low, the electron emission becomes insufficient and the oxide surfaces of the cathodes are damaged. The filaments, however, have appreciable thermal time constants that permit them to operate for brief intervals without difficulty following a sudden drop of voltage. Where violent voltage variations are expected, the filaments should be heated separately from an auxiliary circuit the voltage of which is known to be reasonably constant.

A flash of light from the mercury arc stroboscope lamp results when a capacitor that is connected directly across it discharges violently through the tube. For the conditions shown in figure 1 the capacitor is 4 microfarads and it is charged to about 1,200 volts for each flash. In normal operation the mercury tube does not break down with this voltage across it until a high suddenly applied potential is impressed on the starting band at the junction of the mercury and glass. A cathode spot quickly forms

on the edge of the liquid mercury when the high voltage surge arrives, and it furnishes ample electron emission to discharge the capacitor at a rapid rate. Naturally the current through the tube reaches a large value, since there is very little impedance in the discharge path. This sudden pulse of current as it passes through the mercury tube excites the mercury vapor and causes it to produce the brief intense flash of light that is used for stroboscopic observation and for instantaneous photography.

The high voltage pulse for starting the mercury tube is obtained in this circuit from the secondary of a step-up transformer when a small capacitor ($^1/_4$-microfarad charged to about 600 volts) is discharged into the primary. The vapor tube T_3 in figure 1 acts as a switch to connect the small capacitor to the primary of the external-grid exciting transformer at a time when the grid of T_3 is at about zero potential. Before this time the grid voltage on tube T_3 has been negative, which prevents it from conducting during the time that the small capacitor is being charged from the power transformer through the rectifier tube T_2. The large capacitor (C_2, C_3) across the mercury lamp is charged at the same time through the rectifier T_1. The a-c grid voltage has a value of several hundred volts so that the starting of conduction in tube T_3 will be nearly independent of the magnitude of the grid voltage or the temperature of the tube, this conduction starting when the grid voltage swings from a negative to a positive value. During the half-cycle that the grid of tube T_3 is positive the plate voltage on both rectifier tubes is negative, and so no current flows through them. The current to the grid of T_3 is limited by a resistor. Various voltage and current relations in the circuit are shown in figure 2.



C_1 10 microfarads
C_2 4 Microfarads
C_3 10 microfarads
C_4 0.25 microfarad
R_1 2,000 ohms
R_2 100,000 ohms
R_3 10,000 ohms
L_1 5 henrys
T_1,T_2 Type 866 rectifier tubes
T_3 Type 83 rectifier tube
T_4 Type FG-17 grid-controlled mercury-vapor tube

Fig. 4. Wiring diagram of a stroboscope for producing one flash of light each cycle

The circuit for tripping the light is not required to supply power to the stroboscope tube, as in the circuit of figure 1

Operation of the stroboscope is made automatic by connecting a relay (tripped by line or neutral current) in series with the primary of the power transformer, as shown in figure 1. The stroboscope starts to flash within one cycle after the transformer is energized and will run until disconnected, for instance by a definite-time relay arranged to open the circuit in about 10 seconds, which is long enough to cover the duration of most power angle transients. In this automatic use, the tube filaments need to be heated continuously so that they will be ready to operate immediately.

For intermittent duty such as the 10 second service just mentioned, the power to operate the stroboscope is between 100 and 200 watts, depending upon the exact arrangement used. Continuous operation will overheat the mercury lamp and it will begin to miss and "stutter" unless cooled or unless the power into the lamp is reduced by lowering the voltage or capacitance. A switch is shown in figure 1 for disconnecting capacitor C_3 from the circuit for continuous operation. The useful life of the mercury tubes depends upon their treatment in the circuit; like all other electronic devices, the harder they are worked the shorter is their life. In automatic service the stroboscope lamps should be tested occasionally and replaced after 10 or 20 operations. The lamps become dark on the inside after use, which reduces light output. At the Bellows Falls application it was necessary to wipe the dust off the tube and reflector at least once a week.

A second type of stroboscope, the circuit of which is shown as figure 4, has one advantage over that of figure 1, in that it requires less power from the reference voltage circuit. Power to operate the vapor tube control circuit and the mercury arc lamp for this circuit is obtained from a source of power that

Fig. 5. Looking up in wheel pit at Bellows Falls (Vt.) plant showing location of platform supporting stroboscope and camera

Fig. 6 (right). View showing reference marks (one for each pole) on inside rim of rotor, stationary scale, stroboscope, and camera

may be independent of the a-c source used as a reference voltage. A peaking transformer is connected in the vapor tube grid circuit to give a peaked wave form on the secondary and thereby cause the tube to be "tripped" suddenly at the same angle, even if the magnitude of the reference voltage may vary over a considerable range.

Values of circuit constants that have been used in the laboratory are indicated on the circuit diagrams, figures 1 and 4. Because of the fact that the mercury stroboscope lamp is operative over a large range of voltage, the circuits are not critical to changes of the circuit constants.

Power Angle Recorder at Bellows Falls

During the summer of 1933 a stroboscope of the type shown in figure 4 was installed in the wheel pit of generator 1 at the Bellows Falls plant of the New England Power Association. The stroboscope and the camera were held underneath the rotor by a platform fastened to the concrete walls. One white reference mark was accurately located by means of a scriber on the inside rim of the rotor for each of the 48 poles of the machine. Below this rim with the index marks was placed a stationary scale reading directly in electrical degrees. Photographs of this installation are reproduced in figures 5 and 6. The mercury-arc stroboscope tube is in a protecting fiber tube and is located just below the scale (figure 6).

The camera for recording the angle was a rebuilt 16-millimeter hand-cranked motion-picture camera in which the intermittent motion had been removed so that the film moved continuously. A $^1/_{20}$ horsepower synchronous motor was geared to the drive and arranged to pull the film past the gate at the rate of exactly 60 frames per second. The removal of the intermittent motion greatly reduced the torque required to drive the camera. With this arrangement the film came up to speed within less than $^1/_{10}$ second after the motor was connected.

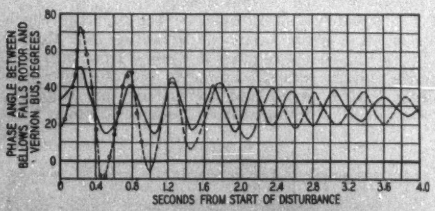


Fig. 7. Two angle-time curves recorded automatically at Bellows Falls during the 1933 lightning season

—Single phase fault --- 2 phase fault

During the 10 seconds that the definite-time relay permits the camera to run, about 14 feet of film is exposed. Thus with 100 foot supply on rolls of film, about 7 disturbances are recorded without reloading the camera. Two typical records obtained from films taken at the Bellows Falls plant are plotted in figure 7.

D-C Braking of Induction Motors

The rapid deceleration of induction motors from relatively high speeds to standstill by the application of constant potential to the terminals is considered in this paper. Applications in which d-c braking of induction motors is desirable are mentioned, and the fundamental principles involved in this method of braking are considered. The characteristics of the speed-torque curve are derived from these principles. The practical application of d-c braking is demonstrated by the results of extensive tests, and a simple means of calculating the approximate values of current and wattage necessary for braking is included.

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THESE days of high speeds in transportation and in industrial processes have given rise to new problems incident to acceleration to and deceleration from these increased speeds. Whereas acceleration frequently comes in for a major share of the consideration in connection with high speed problems, this paper deals entirely with deceleration—or more specifically with the deceleration of loads powered by a-c induction motors.

The evolution of that portion of the steel industry having to do with the production of steel strips and sheets has brought into existence the modern so-called continuous strip mill. In this mill, all the steps in the process of reducing a slab to strips or sheets are made part of a continuous and progressive sequence of operation, and entirely new problems of deceleration are presented.

The increase in mill speeds when handling hot steel shapes from 300 feet per minute up to actual present operations at 1,600 feet per minute and

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higher, requires the complete control of the entire mill with much greater facility than was previously occasioned. Particularly is this true of the so-called finishing end of a mill where the higher linear speeds are attained, and where the material already has sufficient value as represented by its successive processing as to require the most complete flexibility of handling means in order to dispatch the finished product successfully.

The application of a constant potential to the terminals of very large induction motors has not been unknown for accomplishing an economical and practicable braking effect. It remained, however,

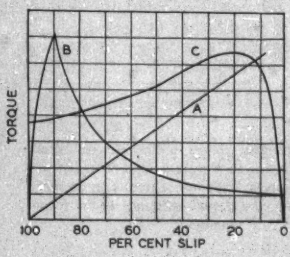


Fig. 1. Characteristic torque curves showing: original and present conception of d-c braking (curves A and B, respectively) and standard induction motor torque curve (curve C)

for the necessities arising from the operation of modern continuous mills to bring this old principle of d-c braking of induction motors—both singly and in groups—into further prominence.

It was the problem of successfully handling the necessary deceleration of strip steel on the conveying rollers and coilers of continuous mills, which in turn

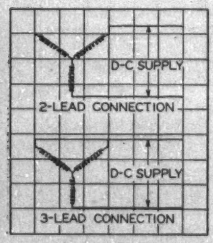


Fig. 2. Schematic wiring diagram showing 2 methods of applying direct current to 3-phase stator terminals

were powered by individual induction motors, that prompted further investigation of d-c braking for such a purpose.

As it has been proved many times in the past, some well-known phenomenon when brought into the limelight and investigated, proves to have somewhat different characteristics and behavior than generally ascribed to it. So it is with d-c braking of induction motors.

It has been generally considered that the characteristic d-c braking curve of an induction motor was from a maximum at top speed down to zero at standstill, as illustrated by figure 1, curve *A*. While this is a possible curve for a very high resistance wound rotor induction motor, the most representative curve of the family for induction motors or more particularly squirrel cage motors, is that shown in figure 1,

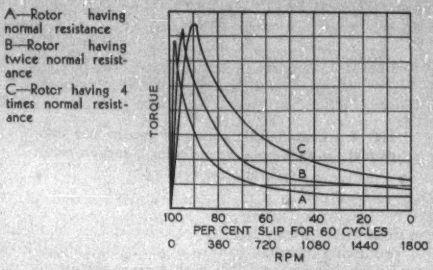


Fig. 3. Characteristic torque curve of 4-pole squirrel-cage motor during d-c braking. Three types of rotors, normal torque (A), semi-high torque (B), high torque (C)

curve *B*. It may be of interest at this point to observe that the general shape of the d-c braking curve is the opposite of the typical squirrel cage speed curve which might be illustrated by curve *C*, figure 1.

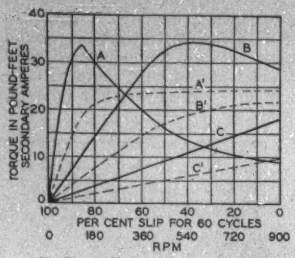
Throughout this paper curves will be presented in which d-c braking torque in pound-feet is plotted against speed in revolutions per minute. In every case the speed scale will be limited to that speed which would be attained if the motor were to be connected to a 60 cycle supply since that frequency represents the present limits of commercial frequency.

Principles Involved in D-C Braking

It would be well to review just how this braking effect is secured. An induction motor which is rotating at synchronous speed less a small slip and driving a load, upon removal of the a-c supply tends to continue rotating at its original speed, except as the friction and windage of the connected load, plus that of its own rotor, retard it.

D-c braking may be accomplished by applying the potential to either 2 or 3 terminals of a 3-phase induction motor, as illustrated in figure 2. This direct current produces a number of fixed poles of constant polarity and intensity in the stator or primary, equal in number to the poles for which the machine is wound. In this field the rotor in motion resembles a short-circuited armature of as many parallel circuits as there are rotor bars, the short-circuiting rings forming the end connections. There is produced at each rotor bar an alternating potential giving rise to a circulating current such as to oppose rotation.

To carry this review a step farther, consideration will be given to the speed-torque curves of d-c braking on a 4-pole squirrel-cage induction motor when disconnected from a 60 cycle supply with,



Torque curves solid lines; secondary current curves dotted lines
Curves A, A' without external resistance
Curves B, B' with 5 ohms external resistance
Curves C, C' with 20 ohms external resistance

Fig. 4. Characteristic curves of torque and rotor current for an 8-pole wound-rotor induction motor during d-c braking

successively, rotors having characteristics incident to producing normal torque and normal slip, then semi-high torque, and full high torque rotors; or in other words, rotors all having the same reactance as determined by the shape and positions of the slots and end rings, but differing in resistance value as determined by the material in the bars and rings. These curves are shown in figure 3, where curve A is that for a normal resistance rotor, curve B is that for a rotor having twice normal resistance, and curve C that for a rotor having 4 times normal resistance. The curves are all taken with the same value of d-c amperes flowing continuously between stator terminals.

They serve to illustrate several important details of d-c braking. At first consideration it seems illogical that the maximum braking effort should come at other than maximum speed where maximum voltage is produced. However, it must be borne in mind that at any speed with direct current impressed on the stator terminals, the voltage produced in the rotor has an instantaneous frequency indicated by the well-known formula

$$f = \frac{p}{2} \times \frac{\text{rpm}}{60} \qquad (1)$$

where p is the number of poles.

Thus, at the instant a 4 pole motor (1,800 rpm) should be disconnected from a 60 cycle line and have direct current impressed on its primary terminals, the frequency in the secondary would be approximately 60 cycles, decreasing directly with the speed to zero frequency at standstill. During deceleration the secondary voltage is a direct function of the speed, as would be expected and as verified by oscillograph charts taken on a wound rotor motor.

The secondary current will then decrease with the speed at a rate determined by the proportion between the resistance and reactance comprising the rotor impedance. This is verified by an oscillographic study of the secondary current in a wound rotor motor of known constants during d-c braking.

The increasing torque, then, in the face of a decreasing current be explained by the phase relation between the secondary voltage and current. As the rotor comes down in speed, the power factor of the secondary approaches unity, bringing the peak current into the most effective position to produce maximum braking effect.

This is illustrated by the curves in figure 4 representing the braking speed-torque curves and the accompanying secondary curves for an 8-pole wound-rotor induction motor operated from a 60 cycle supply. Curves A and A' are torque and current

Torque curves solid lines; secondary current curves dotted lines
Curves A, A' without external resistance
Curves B, B' with 5 ohms external resistance
Curves C, C' with 20 ohms external resistance

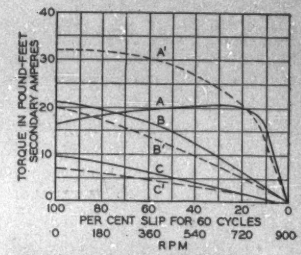


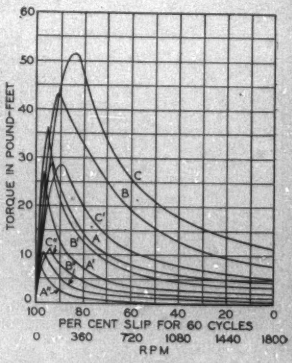
Fig. 5. Characteristic curves of torque and rotor current versus slip for an 8-pole wound-rotor induction motor. Curves with no external resistance and with 2 values of external resistance in the rotor circuit

respectively taken without external resistance in the rotor circuit. Curves B and B' are taken with an external resistance of 5 ohms, while curves C and C' are taken with 20 ohms external resistance. These are all taken with the same d-c excitation.

It is simply an item of interest to note the similarity of character of the torque and current curves

Fig. 6. Four-pole squirrel-cage motor torque versus slip curves for d-c braking illustrating variation of torque for changes of rotor resistance up to 4:1 and changes in d-c amperes supplied to the stator up to 3:1

See text for meaning of curves



for d-c braking in figure 4, with their corresponding speed-torque curves and current curves taken on the same motor with the same external resistances, and as powered from a 60 cycle source of supply, all as shown in figure 5. Aside from their similarity and the fact that secondary resistance and reactance have similar effects on both a-c motor and d-c

braking torque curves because of like rotor frequency in both cases, there is no comparison of area under the curves applicable to the problem of stopping. The a-c motor when plug-stopped by alternating current has not the curve shown in figure 5, but an extension of these curves for values of slip from 100 per cent to 200 per cent, and, of course, the d-c excitation of the stator cannot produce rotation for acceleration.

It is also obvious that the entire speed-torque curve for a given motor—i. e., stator winding and rotor winding of given design—can be raised and lowered along the Y axis by adjusting the d-c potential applied to the stator terminals. This relation is one of the second power representing the product of volts and amperes. Thus, a given motor producing say 10 pound-feet braking torque at a speed of 600 rpm with 5 amperes d-c excitation, should produce 40 pound-feet at the same speed with 10 amperes direct current.

This change in torque is, of course, subject to the limitation of saturation of the core, but for the range of stopping time apt to be required in stopping induction motors, this relation safely can be assumed to apply.

Illustration of These Principles

Figures 6, 7, and 8 serve to illustrate the foregoing statements with regard to d-c braking characteristics for 4, 8, and 12 pole motors, respectively. Figure 6 shows in curves A, B, and C, the braking curve of rotors with normal resistance, twice normal resistance, and 4 times normal resistance, respectively, all taken with the same value of d-c excitation on the stator terminals of a 4 pole motor. Curves A', B', and C' are for the same rotors but with a d-c excitation value approximately 67 per cent of that for the curves A, B, and C. Curves A'', B'', and C'' are for the same rotors but with a d-c excitation value approximately 33 per cent of that for curves A, B, C.

With particular reference to figure 6 where there are shown 3 separate sets of curves, each with different current values, it will be noted that the maximum torque point occurs at a higher speed at each successive increase in d-c excitation. This is to be expected due to the effect of saturation of the leakage paths in the rotor and the increased rotor resistance incident to the increase in heating occasioned by the securing of such curves.

Curves A, B, and C in figure 7, as in figure 6, illustrate 3 different rotor resistances with a fixed value of d-c braking current in an 8 pole motor, with curves A', B', and C' representative of the similar results but with approximately 50 per cent of the d-c excitation value.

In the same way figure 8 illustrates exactly the same results for 3 rotor resistances and 2 values of d-c excitation, curves A', B' and, C' being taken with approximately 50 per cent of the d-c value used for securing curves A, B, and C.

All of the foregoing curves in figures 6, 7, and 8 may be secured by driving an induction motor through a dynamometer over a wide range of speed and measuring torque at incremental steps over this entire range, repeating the process for different values of d-c excitation.

Characteristics of D-C Braking

With the evidence thus far disclosed, certain general characteristics are fairly well established:

1. It is recognized that the speed at which the maximum torque will occur may be adjusted by a change in secondary resistance.

2. It is recognized that the slope of the braking curve from top speed to the maximum torque point can further be shaped by the inherent secondary reactance.

3. It is recognized that the amount of effectiveness of d-c braking secured will be a direct function of the d-c wattage input or the second power of the d-c amperes.

4. It is recognized that the shape of the speed-torque curve for d-c braking on squirrel cage motors is approximately correct for taking advantage of the change in the coefficient of friction between metal and a rotating conveying surface, such as between steel strip and a conveyor table roller.

With regard to the point 4 above, it has been frequently observed that plug reversing a group of induction motors, as on steel mill runout tables, for stopping them with material on the table may result in slippage of the material on the table because there is more braking torque available than the coefficient of friction and weight of material on the table can absorb. Consequently, slippage ensues. This may

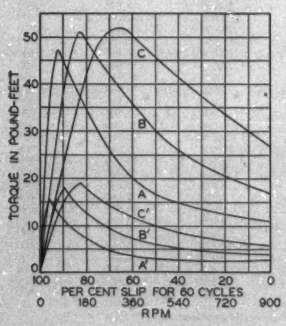


Fig. 7. Eight-pole squirrel-cage motor torque versus slip curves for d-c braking illustrating variation of torque for changes of rotor resistance up to 4:1 and changes in d-c amperes supplied to the stator up to 2:1

See text for meaning of curves

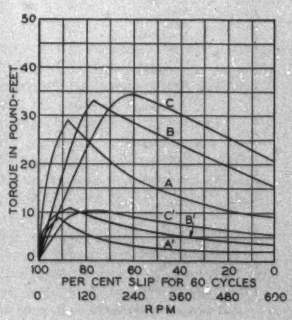


Fig. 8. Twelve-pole squirrel-cage motor characteristic torque versus slip curves for d-c braking illustrating variation of torque for changes in rotor resistance up to 4:1 and changes in d-c amperes supplied to the stator up to 2:1

See text for meaning of curves

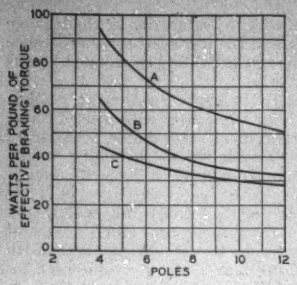


Fig. 9. Curves of power required for d-c braking of induction motors

A—Rotor having normal resistance

B—Rotor having twice normal resistance

C—Rotor having 4 times normal resistance

be compensated for in d-c braking, partially in the shape of the curve and then completely by adjusting the d-c excitation.

Tests Demonstrating Practical Application

For the purpose of making practical application of d-c braking to a squirrel-cage motor having a connected load of known inertia, a series of very enlightening tests on motors of the same physical frame size, but wound for 4, 8, and 12 poles, each with 3 different rotor resistances, have been conducted.

As conducted, a load of known moment of inertia (WR^2) was applied directly to the shaft of each motor, so that there was no added friction incident to extra bearings for the external load but only the windage of the flywheel, which was practically negligible. Data on starting, plug-stopping, and d-c braking of these motors with simultaneous readings of time, wattage, and current, together with the separately secured design and test data, are given in table I.

By way of further explanation, it should be pointed out that the value of average effective torque taken in each case, represents not a figure based upon the area under the speed-torque curve, but a value determined by formula from the known inertia and measured time as follows:

$$T = \frac{WR^2 \times \text{rpm}}{308 \times t} \qquad (2)$$

These test results may well be approached from the standpoint of their practical value. First, the economy of d-c braking seems impressive. In so far as power input is concerned, it is apparent that the watts per pound-foot expended in a-c plugging in the most optimistic case is 3 times that for d-c braking, as in the case of the multi-pole machine, and may be very much more in the case of machines with fewer poles and different rotors, as a ratio of more than 6:1 is evident on the 4-pole 1,800-rpm motor with a full high torque rotor.

Figures 9 and 10 are compiled from the data in table I together with a vast amount of additional data and are meant to be representative of average figures of wattage per pound-foot torque for d-c braking and plugging, respectively. Observing these curves it becomes apparent that the ratio of power saving incident to the use of d-c braking over plugging may vary from 4:1 with a normal torque rotor to 6:1 with a semi-high torque rotor, or 7:1 with a full high torque rotor in a 4 pole motor.

At the same time, however, it should be noted that the average total loss expended within the motor for any number of poles or any resistance rotor is approximately the same, and the ratio for a-c plugging to d-c braking is about 2.25 1. In other words, the economy of d-c braking as regards power supplied to the motors may be from 3:1 up to 6:1 over plugging, depending upon rotor character-

Table I—Data Obtained From Tests. Comparison of Starting, Plugging, and Dynamic Braking

Rotor	Operation	Time in Seconds	Watts-Seconds Input	Pound-feet Effective Torque	Watts per Pound-foot of Effective Torque	Pound-feet A-C Starting Torque	Watt-Seconds Load Kinetic Energy	Watt-Seconds Loss in Motor	60 Cycle Speed, Rpm
A	Start	7.6	113,420	24.3	620	30.0	23,600	89,820	1,800
A	Plug	4.4	73,800	42.0	400	30.0	23,600	97,400	1,800
A	D-c brake	4.6	20,000	41.2	106	30.0	23,600	43,700	1,800
B	Start	7.0	74,800	26.3	406	44.3	23,600	51,200	1,800
B	Plug	3.2	64,000	57.6	346	44.3	23,600	87,600	1,800
B	D-c brake	3.7	12,000	49.7	65	44.3	23,600	35,600	1,800
C	Start	8.0	61,000	23.0	330	47.8	23,600	37,400	1,800
C	Plug	3.2	53,000	57.6	288	47.8	23,600	76,600	1,800
C	D-c brake	3.1	8,350	59.5	45	47.8	23,600	31,950	1,800
A	Start	4.0	21,750	23.0	236	15.2	5,900	15,850	900
A	Plug	3.8	20,000	24.2	218	15.2	5,900	25,900	900
A	D-c brake	3.4	6,030	27.0	66	15.2	5,900	11,930	900
B	Start	4.8	16,900	19.2	184	22.2	5,900	11,000	900
B	Plug	3.0	15,000	30.8	163	22.2	5,900	20,900	900
B	D-c brake	2.8	2,960	32.8	33	22.2	5,900	8,860	900
C	Start	7.4	16,200	12.8	176	26.1	5,900	10,300	900
C	Plug	2.8	18,000	32.8	195	26.1	5,900	23,900	900
C	D-c brake	2.9	3,060	31.7	33	26.1	5,900	8,960	900
A	Start	6.0	10,500	10.2	172	8.8	2,620	7,980	600
A	Plug	4.2	11,640	14.6	190	8.8	2,620	14,260	600
A	D-c brake	4.2	3,150	14.6	51	8.8	2,620	5,770	600
B	Start	6.0	6,200	10.2	101	13.2	2,620	3,580	600
B	Plug	3.0	6,000	20.4	98	13.2	2,620	8,620	600
B	D-c brake	3.4	2,020	18.1	33	13.2	2,620	4,640	600
C	Start	7.0	7,540	8.8	123	15.7	2,620	4,920	600
C	Plug	2.8	7,000	22.0	114	15.7	2,620	9,620	600
C	D-c brake	3.0	1,760	20.5	29	15.7	2,620	4,380	600

A = rotor having normal resistance B = rotor having twice normal resistance C = rotor having 4 times normal resistance

istics and motor winding; but the net effect as regards heating of a given motor by using d-c braking over plugging is practically constant regardless of motor winding or rotor characteristic at a ratio of about 2.25:1 in favor of d-c braking. Greater liberality as regards heating, or a smaller frame size motor is thus permitted by the use of d-c braking for the deceleration cycle.

The above ratio is established from reference to table I, wherein the calculated kinetic energy of the rotating mass is converted to watt-seconds and added to the power input by both d-c braking and plugging.

It should be appreciated also that it is perfectly practicable to apply values of direct current to induction motors for the purpose of securing up to 4 times the braking effort that would be possible by applying full alternating voltages on a-c plugging. In other words, for duty cycle where the rate of deceleration is of primary importance but the running load and period for acceleration would permit of a lower torque motor, d-c braking is an entirely practicable solution.

Previous reference has been made to saturation effect preventing the effective braking torque from being a function of the square of the direct current applied, or a direct function of the d-c wattage. This is illustrated in figure 11, which shows the variation in watts per pound-foot braking torque for an 8-pole squirrel-cage motor with a semi-high torque rotor, taken over a 9:1 range. This particular case covers

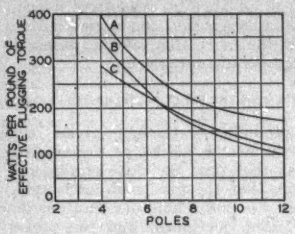


Fig. 10. Curves of a-c power required for a-c plugging of induction motors

A—Rotor having normal resistance
B—Rotor having twice normal resistance
C—Rotor having 4 times normal resistance

approximately $3^1/_2$ times the value of braking torque which would be secured by plugging this motor at full voltage.

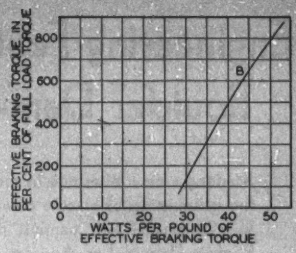
Calculation of Current and Voltage

In conclusion, it may be in order to point out an approximate means of calculating the current and wattage necessary for d-c braking a given load in a given time, independent of the additional retarding effect of the friction and windage of the motor and its load.

The assumed case will be a 6 pole motor using a semi-torque rotor with a connected load having a moment of inertia (WR^2) of 300 pounds-feet-squared connected through a reduction ratio of 4:1 and running from a 60 cycle supply at 300 rpm. The motor and its load are to be stopped in 1.5 seconds. The motor has a terminal resistance of 2.8 ohms.

Fig. 11. Curve illustrating change in d-c power requirements with change in effective braking torque

Eight-pole squirrel-cage motor with rotor having twice normal resistance



First it must be borne in mind that the inertia of the entire system must be referred to a common reference point, preferably the motor; second, that inertia transfer is accomplished through applying the square of the reduction ratio.

So to take the case at hand, the total inertia referred to the motor would be calculated as follows:

Moment of inertia of load, $WR^2 = \frac{300}{4^2} = 18.7$

Moment of inertia of motor rotor, $WR^2 = 1.5$

Moment of inertia of gear, $WR^2 = 0.3$

Total moment of inertia $= 20.5$ pound-feet^2

Referring to equation 2, the continuous braking torque is calculated as follows:

$$T = \frac{20.5 \times 1200}{308 \times 1.5} = 53.3 \text{ pound-feet}$$

Referring to curves in figure 9 giving a relation between poles, rotor characteristic, and watts per pound-foot torque for d-c braking for the subject case, a constant value of approximately 48 watts per pound is determined.

Then the power input to brake this load by direct current would be:

$$48 \times 53.3 = 2{,}560 \text{ watts}$$

Since watts equals I^2R, and R is the resistance between 2 terminals of the a-c stator, then the d-c braking current would be

$$I = \sqrt{\frac{\text{watts}}{R_t}}$$

$$I = \sqrt{\frac{2{,}560}{2.8}} = 30.2 \text{ amperes}$$

Thus, 30.2 amperes is the required value of direct current for the stator of this motor. To produce this current it is necessary to have a potential of IR_t or 30.2×2.8 equals 85 volts direct current.

Thus, it is deduced that a 2.56 kw input at 85 volts direct current applied to 2 terminals of the stator of a 6-pole semi-high torque rotor motor should brake it with its load in 1.5 seconds, irrespective of the friction which tends to assist in the braking effect.

The consideration of the strictly theoretical aspects which will lend themselves to calculation in order to predict accurately the full d-c braking speed-torque curves, may well be made the subject of further papers before the Institute.

Engineering Features of the Boulder Dam-Los Angeles Lines

Marking a new milestone in the history of the transmission of electric power, the 275 kv system that will transmit power from Boulder Dam to Los Angeles, Calif., embodies many novel engineering features. These features are discussed in this paper. The paper includes not only a description of the line and the terminal equipment and facilities, but also a discussion of the effects of the characteristics of each portion of the system on the performance of the system as a whole. The engineering studies and laboratory research on system stability, corona, high voltage impulses, lightning, conductor vibration, tower stresses, footing uplifts, and other factors are described, and the use of such data in the selection of line voltage, conductors, insulation, clamps, lightning protection, towers, and appropriate generating, transforming, and receiving end equipment is shown.

By
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THE Boulder Dam transmission system of the Bureau of Power and Light, Department of Water and Power, of the City of Los Angeles, Calif., will serve to transmit its allotment of power from Boulder Dam to Los Angeles, a distance of 266 miles, and consists of 2 60-cycle 3-phase circuits with a nominal line to line voltage of 275 kv. In the more or less built up section adjacent to Los Angeles, 40 miles of the line is carried on double circuit steel towers. The remainder of the line is carried on single circuit steel towers, with the conductors in horizontal configuration. Two sectionalizing switching stations are located at $^1/_3$ points.

Approximately 60 miles of the single circuit tower portion of line extends through mountainous territory, encountering 3 main mountain passes, at elevations of 4,862, 4,419 and 3,809 feet above sea level. Approximately 166 miles of the single circuit line is in desert territory of a hilly or flat topography, with a prevailing elevation of 2,000 to 3,000 feet. At least 225 miles of the line is subjected to the sparse and erratic rainfall associated with the desert. Such rainfall, at times, is of cloudburst proportions. The remainder of the line is in territory having the seasonal but somewhat limited rainfall experienced in the coastal plain of southern California. The desert section is subject to lightning storms at a frequency of 20 to 30 storm days per year.

The desire to achieve the utmost in high standards of continuous service, and the fact that this line will provide a relatively large portion of the total system power of the Bureau of Power and Light has made it necessary to regard reliability as the foremost consideration in the design of the line. A very liberal policy has been followed in conducting research to develop or verify and refine each step in the design of the line, and in establishing safety factors in order that the desired reliability might be assured. The newly developed features of the line, therefore, not only have a definite purpose, but have their performance well verified in advance by exhaustive investigation. The care in design has been carried on into the purchase and routine testing of the materials before they are incorporated into the line.

System Voltage and Equipment Characteristics

The earliest preliminary thought about this line centered on the use of 220 kv as the nominal rated voltage. At that time the state of the electrical art was such that the means of determining the dynamic stability or power limit of a transmission system had not been developed, and the proper method of determining the static power limit was a subject of discussion. It was realized that the most important factor in determining the voltage of the line was the power limit. In order definitely to obtain the required reliability, the ability of the system to withstand various types of disturbances without losing synchronism had to be determined. Such studies involve the terminal equipment and lay the basis for the selection of such equipment as well as line voltage. From a knowledge of the relative cost and the relative performance at each voltage, came the decision to use 275 kv.

In this work, methods of calculation were devised[1] that followed the fundamental theory set up in various papers on this subject[2,3,4]. Certain refinements were taken into account by setting up the circuits in terms of general circuit constants including all line characteristics and the exciting current and reactance characteristics of the terminal equipment. In addition, an approximate but fairly ac-

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1. For all numbered references see bibliography at end of paper.

curate method was devised of taking into account the characteristics of the load, by having the power component of the portion of the load admittance that represented induction motor load to increase inversely as the square of the voltage during disturbances, thus more closely representing the action of such load in consuming constant power, and drawing increased current as the voltage drops during synchronizing action on the system. Such motor load was assumed to comprise 40 per cent of the total load. In making these studies, the problem was reduced to a 2 machine problem, and the method of calculation was one giving results directly without making use of the point to point method of calculation and plotting time-angle curves.

Power limits are affected by many factors subject to variation, such as mechanical and electrical characteristics of the synchronous apparatus at each end of the line, frequency, voltage, spacing of conductors, location, type and duration of fault, number of sectionalizing points and manner and time required in switching faulted sections, nature of load, voltage drop between ends of line, reactance of transformers, and many other less prominent variables. As the preliminary work progressed, certain preliminary conclusions and assumptions became quite obvious and narrowed down the field to be investigated. These may be stated as follows:

1. The power limit is increased appreciably as the reactance between the internal voltages of the synchronous machine groups is reduced.

2. Corollary to the above, low reactance generators with large inertia effects were found to increase the power limit more than 40,000 kw, which justified the assumption of using the most liberal design of generators obtainable.

3. Sudden increasing of the reactance, such as occurs when a faulted line section is switched out, reduces the power limit very materially; hence it is essential that results be obtained principally for this case.

4. Three line sections are necessary, as the increase in power limit over that obtained by using 2 line sections is worth many times the investment in an additional switching station.

5. Within practicable limits, changes of spacing, diameter, or resistance of the conductors have negligible effects on the power limit.

6. Because of the effects of the equipment, the power limit varies almost directly as the transmission voltage, for lines of this length.

7. The fastest possible switching is exceedingly desirable to increase the power limit.

8. For the system arrangement contemplated for these lines, a fault near the sending end bus and involving one section of line to be switched out generally reduced the power limit to the lowest value.

9. Excepting for fault durations of less than 0.1 second the power limits for 3-phase faults are so low that it would not be considered economical to design the system to remain in synchronism for such conditions.

The rating of the system, that is its reliable transmitting capacity, of necessity depends on the criteria set up as to the type of fault that the system successfully must handle. Since a 3 phase fault is of exceptional occurrence and would be still less likely with reasonably rapid switching, and since it produced relatively low power limits, it finally was decided that the system would be rated on the load it could carry and not lose synchronism when subjected to 2 conductor-to-ground faults at the most unfavorable location, when the fault was removed by switching out a section of line in 0.2 second. When this switching duration was set it was considerably more rapid than generally seemed possible of achievement. However, confidence in this possibility was rewarded by switches and relays finally being supplied that will limit the fault duration to less than 0.11 second.

A single line diagram of a typical system setup is given in figure 1. Every element shown in the diagram was subject to variation in the study, which makes the tentative list of assumptions too long to include. The 2 groups of synchronous machines at the receiving end were combined into one equivalent machine. The load kept its separate identity.

In accordance with preliminary system studies,[8] it was desirable to transmit a load of approximately 240,000 kw to one receiving station. The first stability studies at 220 kv, using 2 circuits and 300,000 kva of low reactance generators, gave a theoretical power limit of the order of only 150,000 kw. If the generator ratings had been reduced accordingly, the value would have been still lower and more unsatisfactory. Further studies indicated that where under certain circumstances 3 220 kv lines would have a theoretical power limit of 280,000 kw, 2 275 kv lines would have a power limit of 265,000 kw and would transmit power at a cost per peak kilowatt of approximately 17 per cent less. Although more power could be transmitted by using a higher voltage, such as 330 kv, the use of such a voltage would result in excessive costs, because of the large diameter of conductor required, and would not be as economical per peak kilowatt. Since the 275 kv lines were the most economical and fitted in best with the desirable size of receiving station already established, this voltage was selected.

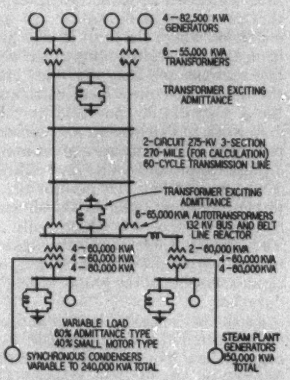
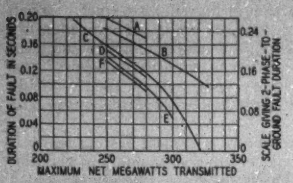


Fig. 1. Typical one line diagram of Boulder Dam-Los Angeles transmission system as used in stability studies

Sending End Equipment

The present system of the Los Angeles Department of Water and Power operates on a frequency of 50



Generator

Curve	Per Cent Reactance	$WR^2 \times 10^6$	Sections Lost
A	20	110	0
B	20	81	0
C	20	110	1
D	20	97.5	1
E	25	110	1
F	25	97.5	1

Generator speed 180 rpm

Fig. 2. Stability curves for 60 cycle operation of system with a 3 phase fault at sending end

cycles per second. There were many reasons, from the standpoint of engineering and practical economics for both the system and the consumer, that made a change-over to 60 cycles attractive. If such a change were to be made, it obviously should be made at the time of bringing in such a large amount of new power. Other reasons, of a nonengineering nature, delayed the possibility of an early decision, so that much of the work had to be done for both frequencies and the earlier equipment specifications and purchases had to be made so as to permit the use of either frequency.

A typical set of stability curves for 60 cycle operation is shown in figure 2. All curves are for the condition where the fault is on a line section just out from the high voltage bus at the sending end. If no line sections are lost, the short circuit would be on the bus. All curves were calculated and drawn for the 3 phase fault condition as this saved considerable work in calculation and served for comparative purposes. In addition, a great many calculations for 2-phase-to-ground faults had indicated that for such a system as this, the permissible duration of a 2-phase-to-ground fault for the shorter switching times was 4/3 that of a 3 phase fault at the same load. The curves, therefore, were made to serve for 2-phase-to-ground faults by adding a new scale at the right-hand side of the graph, giving such approximate durations.

From the foregoing curves and other similar ones, were plotted the data given in figure 3, where the curves show power limits, in accordance with the criteria set up for line rating. For the particular system setup used, the inertia constant H used as abscissa is given by the relation[2]

$$H = \frac{4 \times 0.462 \times WR^2}{250{,}000}\left(\frac{\text{rpm}}{1{,}000}\right)^2 = 7.4\,\frac{WR^2}{1{,}000{,}000}\left(\frac{\text{rpm}}{1{,}000}\right)^2$$

where W is the weight of the rotating parts of one machine in pounds, R is the radius of gyration in feet, and rpm is the synchronous speed of the generator in revolutions per minute.

The lowest practicable transient reactance that could be obtained in designing a generator for straight 50 or 60 cycle use was about 21 per cent, while a generator suitable for operation at either frequency would have reactances of 21 and 17.5 per cent at 50 and 60 cycles, respectively, if the rating were held at the same value in both cases. The maximum value of moment of inertia (WR^2) that could be worked into the design was a function of the runaway speed of the water wheels, being larger for the lower speed. A tabulation of data for the 5 typical generators is given in table I.

An important point in the selection of the generators of table I is that the turbine used on the double speed machine has such dimensions that its maximum overspeed is lower than that of a single speed design with the same synchronous speed, which, together with the reduced reactance, gave a more favorable 60 cycle condition than a machine designed exclusively for 60 cycles. The frequency decision could not be settled at the time the generators were specified; however, as the most probable frequency would be 60 cycles, and as the power limit at 50 cycles was adequate, the double frequency machines fulfilled requirements very satisfactorily. As the switching time has been decreased from that shown in table I to 0.11 second, the power limits have been increased, still further. As these theoretical limits have no safety factor, the actual operating capacity has been fixed at 80 per cent of the theoretical figure to allow for imperfection of assumptions in calculation and to allow for general system hunting. Such rating is 235,000 kw.

In fixing the rating of the generators, one is faced with the fact that if the rating were made in exact accordance with the kilovoltamperes required for normal peak, the machines would be smaller than those of table I and no longer would permit the required power to be transmitted because of their higher reactance. Therefore, the method of obtaining low reactance consisted partly of using increased rating. This increased rating serves other functions, namely, stand-by capacity in the power plant and also for emergency operation, when because of failures in other power sources it is desirable to transmit larger amounts of power over this system, even at the risk of losing synchronism if a fault should happen. Such emergency rating is 300,000 kw delivered, requiring 4 82,500 kva generators for the 2 circuits.

The generators finally selected are 40-pole vertical water-wheel-driven machines, with main exciter and pilot exciter on the same shaft, and are rated 150/180 rpm, 13,800/16,500 volts, 50/60 cycles, 82,500 kw at unity power factor. They are provided with amortisseur windings and have the type of insulation designated as Class B on the armature and field. (Class B insulation consists of inorganic materials such as mica and asbestos in built-up form combined with binding substances.) At 50 and 60 cycles, respectively, the short circuit ratios are 2.28 and 2.74 and the transient reactances are not more than 21 and 17.5 per cent. The flywheel effect of each

Table I—Generator Characteristics and Power Limit for 5 Generators

Frequency, Cycles per Second	Per Cent Reactance	Speed, Rpm	Over-speed, Rpm	WR^2 Lb-(Ft)^2	H	Theoretical Power Limit/(KW) at 0.15 Sec
50	21	150	280	127×10^6	21.1	301,000
50	21	187.5	350	75	19.5	297,000
60	21	150	280	127	21.1	273,000
60	21	180	335	80	19.2	271,000
50/60	21/17.5	150/180	320	110	18.3/26.3	291,000/280,000

generator will be not less than 105,000,000 pounds at a radius of one foot. The load on the thrust bearing is of the order of $1^3/_4$ million pounds. The total weight of the generator is about 2,000,000 pounds. Because of the long time constant of such machines, and the rapid switching contemplated, there was no need for the highest possible rates of excitation, so the exciter response was set at 0.5. The over-all diameter is 40 feet and the over-all height above the generator floor line is 22 feet. The rating of the turbines under the minimum head of 420 feet is 90,000 horsepower, corresponding to a generator output of 65,000 kw, which with 4 machines provides for the normal reliable peak capacity of the line. However, as the head is increased larger outputs become available. For all heads in excess of 525 feet the turbine can deliver the full rating of the generator corresponding to an output of the turbine of 115,000 horsepower.

Two generators are connected to each transformer bank consisting of 3 55,000-kva water-cooled 287,500 Y/16,320-volt single-phase transformers. The high voltage windings are of the circular coil nonresonating type and are designed to withstand a $1^1/_2$x40 microsecond impulse voltage sufficient to flash over an 88 inch rod gap on the tail of the wave. The impedance is as low as practicable and will not exceed 10.75 per cent; the exciting current at normal voltage is 4.5 per cent and the full load efficiency is 99.31 per cent. The transformers each require a floor space 13 by 21 feet and their over-all height is 32 feet. The total weight of each transformer is 385,000 pounds of which 150,000 pounds is oil.

Receiving End Equipment

The generally accepted method of controlling transmission line voltage is to operate with fixed voltages at the sending and receiving ends. Voltage regulators for the generator hold fixed voltage either at the generator terminals or are compensated to the high voltage bus at the sending end. Synchronous condensers or other synchronous machines are required at the receiving end. The regulators for

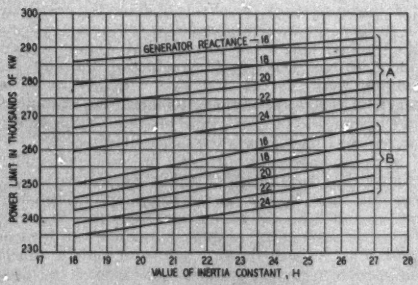


Fig. 3. Power limits of system for 60 cycle operation

A. Fault cleared in 0.15 second
B. Fault cleared in 0.20 second

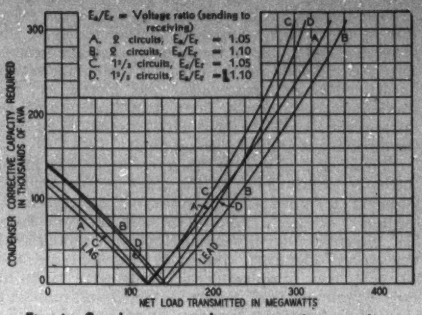


Fig. 4. Synchronous condenser corrective capacity required for operation at 60 cycles (transformers included)

these machines usually are compensated to hold fixed voltage at the load bus or the incoming voltage bus, depending on system connections. The exact amount or points of compensation have not been decided. Such methods of operation are equivalent to operating on a fixed voltage ratio circle on a receiving end circle diagram for the transmission line and equipment between the constant voltage points. From such a circle diagram, and the known characteristics of the system load, it is possible to estimate the required condenser capacity for all loads. Such a set of curves for the Boulder Dam system is given in figure 4. The curves are for full 2 circuit operation and for operation with one section out, designated as $1^1/_2$ circuits. The controlling points are the lagging requirement at very light loads and the leading requirement for the emergency rating of 300,000 kw delivered. Normal synchronous condenser design produces machines that have a lagging rating of 40 to 60 per cent of their leading rating. It is best, therefore, to select the voltage ratio between the 2 ends of the line of such value that approximately this adjustment is obtained. In this system the voltage ratio of 1.05 approximately does this and also approximately adheres to the established voltage ratings of equipment where the maximum operating voltage is 115/110 of the nominal. This latter ratio of 287,500 to 275,000 volts between sending and receiving ends was adopted. On this basis approximately 240,000 kva leading is required to deliver 300,000 kw and 115,000 kva lagging is required at zero load. There is the possibility that when emergency loads are being carried the voltage ratio can be increased, and approximately 200,000 kva of condenser capacity will be sufficient. This is very close to the requirement necessary to transmit the normal peak of 240,000 kw over the system with one section of one line out of service. At 50 cycles the requirements were about the same for high loads, but about 20,000 kva less lagging capacity was required at zero load. The capacity used to permit of the emergency rating essentially gives sufficient capacity to have the equivalent of a spare machine during ordinary operation.

The stability problem also entered into the selection of the proper equipment characteristics at the receiving end. For this purpose stability curves were plotted showing the effects of reactance of the autotransformers, reactance, and inertia of the condensers, location of fault, and fault duration. Some results were obtained without consideration of the auxiliary or stand-by steam plant.

The section of line at the receiving end included the same length of line as the other sections and, in addition, included the reactance of the autotransformers. Studies in connection with the generators had indicated that a sending end fault represented the worst operating condition. In studying the receiving end equipment, variations were made in such equipment and results obtained for faults at each of 3 locations, namely: sending end, losing adjacent line section; receiving end, losing receiving end line section; fault 180 miles ($^2/_3$ point) from generator, losing receiving end section. For any given setup, the sending end fault gave the lowest or controlling power limits or line ratings. The receiving end faults gave the highest power limits. The 180 mile fault gave limits slightly in excess of those for the sending end. For fault durations of the order of 0.1 second the power limits for the 180 mile fault were almost equal to those for sending end faults, and for quicker switching would be slightly less and thus establish the rating. For the switching times involved in this study, these results indicated that the proper correlation had been obtained in setting the electrical length or reactance of each section.

Decreasing the reactance of the autotransformers from 10 per cent to 7 per cent at 50 cycles increased the theoretical power limit 11,000 kw for sending end faults and about 15,000 kw for 180 mile faults, for the fault durations under consideration (0.14 and 0.11 second). For 60 cycles, decreasing such reactances from 12 to 8.4 per cent increased the power limits 14,000 and 20,000 kw, respectively, for the preceding 2 fault locations. Obviously such improvement is worth more than the increased cost of low reactance transformers so autotransformers of the lowest practicable reactance were purchased.

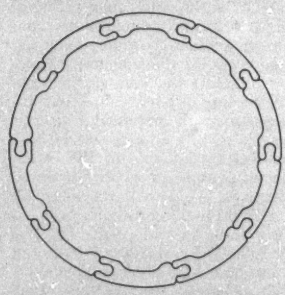


Fig. 5. Cross section of conductor selected

Area of cross section 512,000 circular mils
Wall thickness: maximum 115 mils, minimum 80 mils
Number of segments, 10

Two types of synchronous condensers were considered, one having a transient reactance of 35 per cent and a moment of inertia (WR^2) of 1,500,000 pounds at a radius of one foot, and the other having 50 per cent reactance and a moment of inertia of 1,250,000 pounds at a radius of one foot. In all cases, whether considered with or without auxiliary steam plant at the receiving end, it was found that the smaller high reactance machine gave the higher power limits. In either case the difference was small, being of the order of 3,000 kw. Under such circumstances, the lagging requirements controlled the selection of the condensers; and as the 50 per cent reactance machine satisfied these requirements, there was no object in purchasing more liberal equipment.

Within the range of the switching times considered, and for the final resulting system setup, the improvement in theoretical power limit is about 3,000 to 5,500 kw for each 0.01 second reduction in fault duration. On the basis of such improvement in performance, the selection of the most rapid switches, developed with an over-all switch and relay time of not more than $5^1/_2$ cycles, was made. With such switches the theoretical power limit in accordance with criteria previously referred to is 292,000 kw. A more detailed description of all the receiving equipment will be given in connection with the consideration of the receiving station.

Diameter of Conductor

For the voltages under consideration for this line, the primary consideration in the choice of conductor diameter is corona loss. In general, the diameter that will give an economical value of corona loss will be large enough but the amount of material required to construct such a conductor is likely to be more than is needed for conducting the currents that will exist in such a line.

No corona loss data were available for cables larger than approximately 1.1 inches in diameter.[6] Such tests indicated that existing corona loss formulas did not give accurate results for cables of such large diameter, particularly in the low loss portion of the curve which is the part a designer is most interested in. Accordingly, tests were made at the Ryan high voltage laboratory at Stanford University on stranded cables with diameters of 1.125, 1.49, and 2.00 inches to study the effects of diameter, condition of surface, spacing, atmospheric conditions, effects of cleaning, and other factors that would be pertinent to the selection of conductors for voltages ranging from 220 to 330 kv.[7] Further data on effects of surface conditions, temperature, humidity, and barometric pressure were provided by graduate student investigations in the same laboratory.[8,9]

Such laboratory tests cannot be conducted under exactly the conditions that will be encountered along the line, that is, the temperatures and barometric pressures will be different, as well as other less well known variables such as dust, humidity, and surface conditions. Furthermore, unless a great many cables were tested, it is likely that none of the sizes tested would be the final choice. In order to make use of fewer tests and in order to be able to make the design fit the line conditions, it was desirable to

derive a method of calculating losses that would agree with the tests and that could be used with some assurance for all the conditions anticipated along the line.[10]

A preliminary study of various designs of conductors was made to form the basis of an economic study to determine the proper conductor diameter to use. From data pertaining to the lighter designs, complete estimates of annual cost were made, after having determined the most economical combination of span and tension for each form and size of cable under consideration. The effects of conductor weight, strength, and diameter on tower and insulator costs were included, as well as those things directly pertinent to the conductor such as conductor cost, resistance, and corona losses. In this study the probable elevations and temperatures of the line were taken into account.

In the region of minimum cost, the annual cost of the conductor varies very gradually with the diameter. The corona tests had indicated that some uncertainties creep into the conditions that affect corona, so it is desirable to use some safety factor in the selection of the diameter. The economic choice in general comes near the knee of the corona loss curve. At such a point a small change in the uncontrollable and least known conditions makes large changes in the corona loss and could increase the annual cost possibly 30 per cent. Because of the relatively flat form of the cost curve, it was deemed advisable to be liberal by selecting a conductor diameter 0.1 inch larger than the theoretical but slightly uncertain diameter economy would dictate. From these studies the diameter of the conductor was fixed at 1.4 inches.

These preliminary corona and conductor studies provided appropriate information for making line estimates at various voltages when voltage selection was under way.

Type of Conductor

Conductor studies had indicated that when all features of cost were considered, the most economical cross section of a copper conductor of 1.4 inches in diameter was of the order of 500,000 circular mils, and that the maximum tension should be 40 per cent of the ultimate strength. The main influences on these values were those involving mechanical loading.

Essentially 6 different designs of cable were offered to meet the requirements of the line conductor:

Type *A*. A copper conductor weighing 2.226 pounds per foot, made up of a 7 wire strand surrounded by 6 twisted I beams with a single layer of round wires over all, this outer layer containing 30 wires each 0.125 inch in diameter.

Type *B*. A copper conductor, weighing 2.545 pounds per foot, made up with an inner structure composed of a central tube surrounded by layers of smaller tubes, with a single outside layer of 37 solid round wires each 0.104 inch in diameter; a variation of this conductor having thinner walled tubing and weighing 2.387 pounds per foot also was considered.

Type *C*. A hollow copper conductor weighing 1.57 pounds per foot, made up of 10 interlocking segments forming a self-supporting tubular structure; a similar conductor of heavier section weighing 2.3 pounds per foot also was considered.

Type *D*. An aluminum conductor, steel reinforced, weighing 1.852 pounds per foot containing 66 aluminum wires 0.1355 inch in diameter and 19 steel wires 0.117 inch in diameter; a conductor weighing 1.44 pounds per foot similar to this, excepting that a hemp filler of 0.213 inch radial thickness is used between 19 0.086 inch steel wires and 50 0.1355 inch aluminum wires, also was considered.

Type *E*. A copper conductor weighing 2.667 pounds per foot, of standard single-twisted I-beam construction, having 2 layers containing 66 wires 0.1077 inch in diameter.

Type *F*. A hollow copper conductor, weighing 1.80 pounds per foot, made up of 12 segments, grooved to take an oval wire acting as a tongue between adjacent segments.

Typical cross sections of these various cables are shown in figure 1 of a paper entitled "Corona Losses From Conductors of 1.4 Inches in Diameter."[11]

In selecting the conductor, comprehensive and accurate estimates of annual costs were worked out

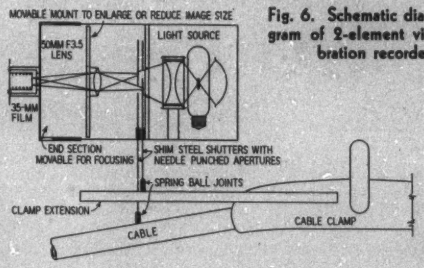


Fig. 6. Schematic diagram of 2-element vibration recorder

for each type for various tensions and span lengths, so that comparisons would be made between the most economical uses of each type. The lighter conductors showed savings of the order of $12^1/_2$ per cent over the heavier types, partly due to conductor price and partly due to the higher cost of towers and supports for the heavier conductors.

Comparative corona tests were made[11] and type *C*, the interlocked segmental type of hollow copper conductor, showed the lowest losses and preferable characteristics, although all conductors, as was anticipated, had low losses at the operating voltage, even with some allowance for elevations.

Because of the low weight for the diameter involved in all these cables, it was thought necessary to give due regard to the tendency for conductors to vibrate in light winds[12, 13, 14]. As a preliminary test to assist in the selection of conductors, a wind tunnel was used that provided an orifice 50 feet long and 2 feet high which was so baffled and controlled as to produce a quite uniform wind velocity across cables hung in front of the opening. In this manner the tendency of the cable to vibrate under the same type of forces and at the same tensions as in actual practice was simulated closely. Although from its diameter-weight relation, the light hollow copper cable might be expected to give greater amplitudes under such conditions, it actually gave the same amplitudes as the heaviest I beam type of conductor; this indicated a considerable degree of self-damping, a fact that was confirmed by later tests.

These data together with the successful operation of similar cables in Germany, led to the selection of the cable as previously described under the designnation "type *C*"; a cross section of this cable is shown in figure 5. The copper area is 512,000 circular mils. As a permanent lubrication between segments, graphite is introduced between the surfaces of the interlocking tongue and groove. The exterior of the cable is washed and cleaned thoroughly as was indicated to be necessary from the corona tests. The ultimate guaranteed tensile strength is 21,600 pounds.

Fig. 7. Cable testing frame for studying bending properties of conductor

Vibration Studies for Clamp Development

Having selected the cable, the next procedure was to determine accurately all the vibration characteristics of the cable, in order to ascertain what features had to be incorporated into the design of the clamps to be used therewith so that the possibility of fatigue failures would be eliminated. It had been decided to follow this program irrespective of what type of cable had been purchased for the line, as it was believed that the large diameter entered into a new range of stress relationships that had a bearing on fatigue failures.

The wind tunnel tests were continued, to introduce refinements and perfection of technique and to study the effects of variation in tension. As a standard of comparison, tests were made also on the 1.00-inch double-layer I-beam type of conductor used by the Pacific Gas and Electric Company, for which a considerable amount of field data was available.[12] It was not found possible to obtain as large amplitudes as found in the field, possibly because of the absorption of energy at the ends being large with respect to that imposed by the wind on such short lengths of cable.

The tendency of the cable to vibrate in conformance with recent theory as regards frequency and loop lengths was established. Where the wind frequency was not exactly resonant with possible loop frequencies, beat note effects were observed due to the nearest possible loop frequencies. There was a marked increase in vibration amplitude at any given wind velocity or air eddy frequency as the conductor tension was increased.

Because the tunnel tests apparently did not produce as high amplitudes as would be obtained under actual operating conditions, it was decided to make measurements on actual full length spans with natural wind. A site near one of the construction camps was selected as being most favorable for producing such vibration. The country is of even topography for many miles either side of the line and the prevailing winds are at right angles to the line. Standard suspension towers (3) were used to support 2 full spans; 100 feet beyond these towers temporary poles were erected for dead end connections. The recording devices were installed at the middle tower. Records of vibration were obtained for 2 values of normal tension, 4,350 and 6,500 pounds.

For obtaining the vibration records 2 photographic recorders were used. One recorder having a single element records the movement of the conductor 6 feet from the center of the suspension clamp, indicates time in 5 second intervals, and shows the direction and velocity of the wind. The other recorder has 2 elements and records simultaneously the movement of both the conductor and the suspension clamp, at a point $15^1/_4$ inches from the center of the clamp; 5 second intervals also are recorded. The purpose of this record is to show the relative bending between the cable and clamp.

Records are taken on standard moving picture film, run at a normal speed of one foot per minute, with the additional provision that the 2 element recorder automatically makes a 5 foot record at 10 times normal speed every 15 minutes of normal operation. The recorders are mounted on a platform which replaces the insulator string and is pivoted to move similarly in the wind. The alignment between cable, clamp, and recorder accurately is preserved for all wind conditions. A schematic sketch of the installation is shown on figure 6. In addition to the parts shown, the installation is equipped with an initiating device that permits the recorder to be shut down except when the vibration exceeds a predetermined amplitude.

The principal conclusions that might be drawn from these records are as follows:

1. The conductor vibration is extremely variable and complex showing considerable beat note phenomena or superposition of loop lengths.

2. With few exceptions, vibration of importance occurs at very low wind velocities, less than 6 or 7 miles per hour.

3. The portion of the total time that the cable has appreciable vibration is of the order of 3 to 5 per cent for the lower tension and 12 per cent for the higher tension.

4. The maximum angle of cable movement at a node point is 0.27 degree for the lower tension and 0.49 degree for the higher tension.

5. The maximum angle of relative bending between cable and clamp, when the phase relations are such that the cable is moving the same direction on each side of the clamp, is 0.033 degree for the lower tension and 0.132 degree for the higher tension.

In order to study the bending properties of the cable, tests were made using the rack shown in figure 7. For this test the cables were run over simple radius clamps of various radii from 28 to 42 inches. A keeper was bolted down to clamp the cable in place and the clamp was oscillated by the eccentric and connecting rod shown in figure 7. As the samples were short, care was taken to equalize the tension on each segment.

The essential conclusion drawn from this test is that for any radius longer than 28 inches, the conductor will have an indefinitely long life when the relative movement between the conductor and clamp does not exceed an angle of 0.4 degree, while at double this angle the life of the cable is very short. The actual relative bending encountered on the line is only about $^1/_{12}$ of that which the rack tests indicated would give long life.

In another set of tests, various suspension clamps were set up in a normal position between spans one per cent different in length. These spans were vibrated by means of 2 eccentrics with the same percentage difference in their frequencies. This successively subjected the clamp to in-phase and out-of-phase vibration at the 2 ends. A recorder, similar in principal to that shown on figure 6, was used to measure the relative movement of the cable and clamp. It was found that for those clamps that provided for trunnion action at or near the center line of the cable, the relative bending between cable and clamp was about 80 per cent of that obtained with clamps pivoted or hung approximately 2 inches above the center line of the cable.

Clamp Design

As a result of various facts ascertained from the cable vibration studies and detailed analysis, a suspension clamp of novel design was evolved, known as the free-center type, shown in figure 8. It consists of an outer housing or shell supported by knife edge trunnions on strap hangers. The shell in turn provides knife edge support for 2 saddles in which the cable rides. These knife edges are $^1/_2$ the cable spiraling pitch apart. The malleable cast shell is of a form that will avoid formation of corona. The saddles are die cast of bronze to avoid corrosion and to give a supporting surface free from pits, projections, and blemishes in which the curvatures could be controlled accurately within very small tolerances. Attached to the cable and normally free from the clamp is a center clamping piece consisting of a double conical wedge adjacent to the cable, which fits into the 2 halves of the clamping piece. In the event of a cable breaking, the central clamping piece engages bosses at the center of the shell, whereupon the conical wedge exerts clamping action on the cable and develops strengths in excess of 8,700 pounds.

Fig. 8. Free-center suspension clamp

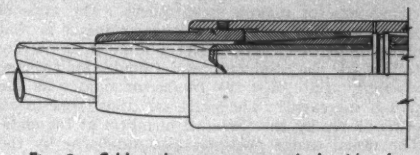


Fig. 9. Cable splicing connector (only $^1/_2$ of connector is shown)

With this type of suspension clamp, the bending of the cable resulting from vibration is not localized at one point, but is distributed essentially on nearly uniform curvature over a full pitch length, thus avoiding any concentration of bending stress on any one segment or single place in the cable. At points where the bending is taking place there are no superposed stresses due to clamping action.

All principal dimensions of the clamp parts were determined by special tests including such things as location of trunnion points, saddle pivots, curvature of saddles in both directions, length of saddles, and dimensions of parts in the center wedge system.

Clamp Life Tests

During the progress of the design of the clamp and after the final design, life tests of this clamp together with other types of clamps were made and are still in progress. Such tests were made by driving the cables on both sides of the suspension clamp by means of an eccentric attached to the cables approximately 6 feet from the clamp. In order to produce maximum bending for a given deflection of the cable and to avoid any trunnion action that would reduce the bending, the cables on each side of the clamp were driven in the same direction simultaneously. In this manner, without using unusual speeds or amplitudes, the fatigue failures could be tested with the kind of maximum bending that occurs for only a

part of the total time of vibration in actual service where considerable trunnion action takes place.

By means of such tests, refinements were made in the free-center clamp. The superiority of this type of support over more conventional types of clamps was demonstrated. There is every assurance that can be afforded by laboratory testing and field investigation that the line should be free from any difficulties arising from fatigue failures.

Connectors and Strain Clamps

In accordance with the specifications for the conductor, a suitable means of splicing had to be furnished with each length together with extra connectors for making field splices. The type of splice provided with the hollow conductor is that shown in figure 9. It consists of an inner supporting tube inside the conductor, and a double split wedge assembly that grips the conductor tighter as the pull is increased. The pulls are transferred to an outer sleeve by the threaded members at the ends. The radial wedge pressures also are borne by the outer sleeve. Refinements have been introduced in the wedges so that the intensity of grip is increased as the inner edge of the wedge is approached; also the outer threaded members are so shaped as to limit the bending of the cable that can occur at the wedge entrance so that vibration cannot cause a concentration of stresses at such a point. The connectors are made of high strength bronze, so as to be free from corrosion, and have accurate smooth surfaces and sufficient strength with light weight. The light weight is essential in order to avoid large bending stresses while the vibrating cable is accelerating the connector.

The dead end connector is similar to the splicing connector except that one half of the connector is replaced by a screw clevis fitting, shown in figure 10 (part *A*). A similar fitting with a single wedge (part *B*) is used for the jumper loop connecting the 2 dead ends on opposite sides of the tower arm. The jumper loop clamp and the strain clamp are interconnected by flexible copper braid of 307,000 circular mils, as a shunt around the mechanical interconnection provided by the yoke.

Insulation and Lightning Protection

For purposes of insulation design, the line is divided into 2 main sections as regards its exposure. The section from Cajon Pass to Boulder Dam (a distance in excess of 200 miles), which is on single circuit towers, can be considered as the lightning section, with lightning storm days probably not exceeding 30 per year. The insulation scheme for this section is based almost entirely upon lightning considerations. From Cajon Pass to the receiving station, the remaining section of the line 40 miles of which is on double circuit towers, the lightning storm frequency is of the order of 5 storm days per year. This section will be subject to troubles from insulator leakage that arise from dust accumulated during a long dry season followed by fog and rains, with the accompanying noise and flashing over of single units, at times involving the possibility of string flashovers at normal voltages or switching surge voltages.

Engineers of the Los Angeles Department of Water and Power have profited very considerably from a study of the results obtained from lightning research being carried on by various power companies and electrical manufacturing companies [15–22]. Consideration of the data obtained from such studies made it almost self-evident that in order to limit the number of flashovers per year to a small value compatible with the reliability desired for this line, 2 overhead ground wires per tower line should be used and probably some type of buried ground wire or counterpoise system as well, in lieu of trying to establish any other satisfactory form of tower footing grounds in such dry desert territory.

Studies indicated that lightning can be expected to strike with about equal frequency the transmission towers and the overhead ground wires. The danger of flashover of the insulator string is greatest when lightning strikes the tower. The danger of flashover between a ground wire and a conductor is greatest when lightning strikes the ground wire at the center of the span. Spacings at these points should be co-ordinated to withstand the same lightning streamer voltage.

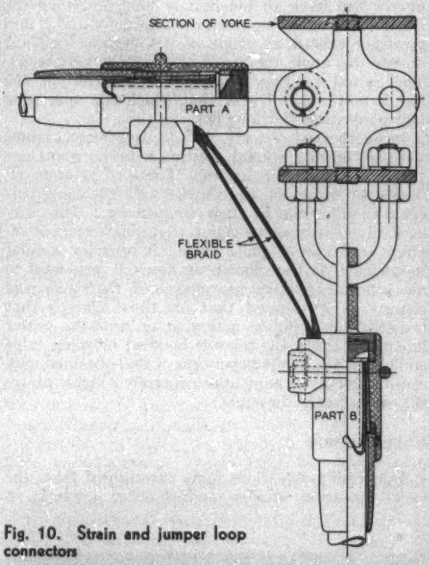


Fig. 10. Strain and jumper loop connectors

In the selection of the insulator string length on a lightning basis, the voltage of the line has small influence; however, to hold the danger of a power arc following lightning flashover within limits prescribed by existing practice, it was deemed advisable

to increase the string length in proportion to the voltage over the present trend in 220-kv line insulation. This gave a length of the order of 120 inches. This same string length was confirmed for the section affected by dirt and fog.

The dirt and fog problem was studied at the Ryan high voltage laboratory, where a wind tunnel was arranged so that controlled wind would carry dust and fog alternately past insulators while voltage was applied to them. The object of this test was to find insulator shapes that would be superior for the purpose and to determine the desirable number of units to use to reduce trouble from this source. These studies indicated a distinct advantage in using relatively long strings of closely coupled insulator units, such as 10 inch units with 5 inch spacing.

In selecting the insulator units for the single circuit tower section, the cost of the insulator units and the increased cost of towers necessitated by those units requiring longer strings to develop the same impulse flashovers were taken into account. It was found most economical to use suspension insulator units 10 inches in diameter, with a hanging distance or pitch of 5 inches; 24 such units constitute a standard suspension string for both the single and double circuit tower sections. For suspension strings carrying heavier loads because of horizontal or vertical line angles, 22 suspension insulator units $10^1/_2$ inches in diameter with 6 inch pitch are used. For dead end positions on the single circuit towers, double strings of 22 $10^1/_2$ inch units with 6 inch pitch are used. For dead end positions on the double circuit towers where the maximum pulls were reduced by the type of loading assumed, double strings of 24 10 inch units with 5 inch pitch are used. The insulators are of resilient pin construction. The light duty insulators have a mechanical and electrical ultimate strength of 11,000 pounds, while the heavier duty insulators have a similar strength of 15,000 pounds.

Clearances

In establishing clearance distances from the conductor or other parts at line potential to the tower, it was desirable that arcs be confined between arcing horns, which are to be provided at each end of the insulator strings, rather than between conductor and tower. However, it was realized that this ideal would not be economical to achieve at the highest wind velocities assumed in the mechanical design of the line. The highest wind velocities would endure for such a small part of the life of the line that it was thought reasonable to have an impaired clearance under such circumstances. At the time it was necessary to set clearances for tower design purposes, the question of arcing horns had not been investigated completely so a fairly liberal size was chosen, 30 inches in diameter in the plane of swing (suspension type) placed one foot above the conductor.

For all wind pressures up to 4 pounds per square foot (about 40 miles per hour) a full clearance of 11 feet to the tower is maintained, which is about 10 per cent in excess of the point-to-plane arcing distance equal to the insulator flashover. The conductor then is placed at its extreme position under a wind pressure of 12 pounds per square foot. At this position a clearance of 7 feet is maintained. The outer boundaries of the figures described by these

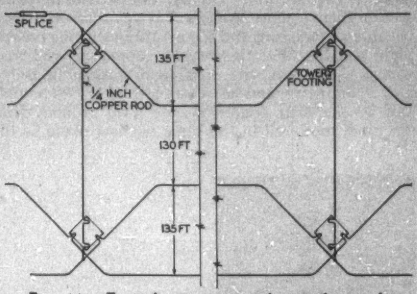


Fig. 11. Typical counterpoise layout for single circuit tower section of line

radii constitute the clearance diagram. The 7 foot flashover distance corresponds to approximately $4^1/_2$ times normal voltage, which is considered to be protection against switching surge flashovers. The same fundamental clearance diagram assumptions are applied to each type of tower. These clearance diagrams resulted in a horizontal spacing of 32.5 feet for single circuit towers, and a horizontal spacing of 40.5 feet and a vertical spacing of 24.5 feet for double circuit towers.

Overhead Ground Wires

For the single circuit tower section, each tower line is protected by 2 overhead ground wires of $^1/_2$-inch 7-strand galvanized wire with a guaranteed ultimate strength of 18,800 pounds. At the towers the ground wires have a horizontal separation of 50 feet and are 32 feet above the main conductors, while at the center of the span they are 40 feet above the conductors. Two wires are used because of the advantages resulting from the decreased surge impedance, the increased coupling factor to the conductors, a more balanced relation to each conductor, and, most important, because of the more complete and reliable shielding of the conductors from lightning streamers, without going to unreasonable heights. Surge calculations indicated that co-ordination of flashover across an insulator string caused by a stroke hitting a tower, and a similar flashover caused by a stroke hitting a ground wire at mid-span, required that the spacing between conductor and ground wire be 40 feet. Economical tower design then led to the location of the ground wire attachment at the tower about 32 feet above the conductor. It was thought that such height should give very reliable shielding. Too high ground wire pulls at such heights were quite uneconomical.

Steel wire of a size that will meet the mechanical requirements of the line has more than adequate conductivity from the standpoint of lightning protection. Investigations in other similar desert areas had indicated that over very long periods of time the corrosion of such wire was negligible. With this in mind the material having the lowest cost, steel, is used in this section. On the double circuit tower section there is more likelihood of corrosion occurring, because of moisture and fog conditions in the coastal plain section. For this reason, copper covered steel wire is used; this wire consists of 7 strands, is $^7/_{16}$ inch in diameter, and has a strength of 18,500 pounds and 30 per cent conductivity. Two ground wires are used, mounted in the same vertical plane as the conductors, and at heights above the conductors similar to those of the steel wire on the single circuit towers.

Fig. 12. Typical suspension insulator assembly

Buried Counterpoise

Successful operating results achieved by a few power companies as a result of very limited installation of counterpoise at exposed positions,[20] made it attractive to consider the extensive use of the counterpoise for this line, where grounding conditions are particularly severe. A large part of the desert soil is gravel, sand, or both, with the water table in general measured in hundreds of feet below the surface and with an annual rainfall of the order of 3 inches. In such high resistant earth, the counterpoise serves to provide a low impedance conducting system to permit the lightning discharge to terminate at the opposite charges on the surface of the earth under the cloud area. As an outcome of the studies, the counterpoise was installed in the single circuit tower sections as shown on figure 11, giving 2 continuous counterpoise wires for each tower line with cross ties at each tower between circuits. The 45 degree spreading at the towers was adopted to obtain the low surge impedance advantages of the radial type of counterpoise, and the continuity of the counterpoise eliminated the possibility of end reflections from such points of discontinuity in the purely radial counterpoise. The continuity also has advantages in permitting the fault currents to be large enough to avoid too much difficulty in relaying the line at points distant from power sources. The particular pattern adopted also facilitated the laying of the counterpoise by means of a specially devised plow and counterpoise laying machine.

Table II—Effect of Tower Footing Impedance on Lightning Streamer Crest and Flashovers

Tower Footings Impedance, Ohms	Lightning Streamer Crest, Volts	No. Flashovers per Year per 100 Miles of Circuit
17	18,500,000	0.5
21	16,000,000	0.75
27	13,500,000	1.1
38	9,000,000	2.9

The wire used for the counterpoise is $^1/_4$-inch diameter black rolled copper rod. This diameter was adopted as representing the smallest size that might be expected to withstand corrosion for the life of the line and be mechanically strong enough to withstand the stresses involved in laying the wire. The softness of the rolled copper was also an advantage in handling.

From test data that were available[21] some judgment could be formed of the value of the counterpoise. Theoretical values of surge impedance required the use of a large dielectric constant for the soil in order to agree with the tests. By using such a constant and making allowance for corona effects caused by the higher voltage on such wires resulting from natural lightning, estimates of surge impedance were made. All factors entering into the calculation of surge impedance of counterpoise systems are not fully understood, and no method of calculation has met with universal approval. However, this does not deprive one of the advantages of making comparisons in terms of definite relative figures, even though the actual accuracy of such figures is subject to limited doubt. Taking into account the surge impedances of the lightning stroke, ground wires,

and counterpoise system, and the coupling effects between the ground system and the main conductors, the crest voltages of the oncoming lightning wave in the streamer were calculated for various tower footing or counterpoise surge impedances as shown in table II. In this table are included also the numbers of flashovers per year per 100 miles of circuit for a region having 30 lightning storm days per year.[10] For comparison with these values, the surge impedances of various combinations of continuous counterpoise wires were estimated as follows:

1 tower line, 1 counterpoise wire	38 to 50 ohms
2 tower lines, 1 counterpoise wire each, cross-connected	27 to 40 ohms
1 tower line, 2 counterpoise wires	21 to 30 ohms
2 tower lines, 2 counterpoise wires each, cross-connected	17 to 25 ohms

Considerations of reliability and relatively low cost of counterpoise compared with other methods of obtaining equal protection, that is, by use of additional insulators, dictated a choice of 2 counterpoise wires per tower line, cross-connected in the single circuit tower section. In the double circuit tower section, the lightning storm frequency is much lower so the double counterpoise for a single tower line will give excellent performance there.

In connecting the counterpoise wires to the towers, it was considered inadvisable to attach the copper directly to the towers because of the possibility of electrolytic action between the copper and steel corroding the tower footing steel. Consequently, attachment is made through a spark gap that is essentially 2 concentric bronze cylinders with a $^1/_{16}$ inch air gap. A very small percentage of any fault potential will be capable of arcing over the gap and bring the counterpoise into action.

Transpositions

A complete transposition "barrel" is arranged within the sending end section and the middle section of the line. Transposition towers are, therefore, approximately 30 miles apart. Another complete "barrel" is arranged in the single circuit tower portion of the line beyond the second switching station. The double circuit portion of the line, because of communication line interferences, has 3 complete transposition "barrels" of 13, 4, and 23 miles.

Hardware

Aside from the suspension and dead end clamps that were discussed in connection with the conductor, the 2 main items of hardware to be considered are the arcing protectors and the dead end yokes. The principal functions of the arcing protectors is to avoid cascading of the insulators and burning of the conductors.

The arcing horns adopted for suspension type insulator strings consist of a twisted and bent $^3/_8$x$1^1/_4$ inch strap arcing horn at the top or grounded end of the string and a "figure 8" horn of bent $1^1/_4$ inch pipe at the bottom of the string as illustrated in figure 12. For the dead end assemblies, each yoke carries on its top side an arcing horn made of bent $1^1/_4$-inch pipe, as illustrated in figure 13.

These particular forms of arcing horns were developed in the high voltage laboratory of the Ohio Brass Company with the assistance and co-operation

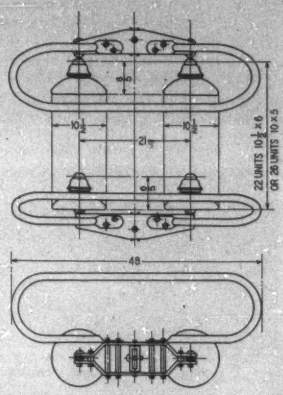


Fig. 13. Typical strain insulator assembly

All dimensions are in inches; string lengths show diameter and spacing of individual units

of the engineers of that company. Impulse voltage tests were conducted on these devices for the purpose of determining the maximum separation, with the most favorable location of each horn tip, that could be obtained and have all arcs form between the horns and not cascade over the insulators. Similar tests also were conducted at an earlier date at the high voltage laboratory of the General Electric Company on the oval ring type of shield. Both types of shields as finally developed by these tests gave satisfactory performance in both flashover and protection from cascading. The greater tower clearances and the economy of the simpler horn types led to their adoption.

In the yokes, which also are illustrated in figure 13, 2 new features of design have been incorporated: approximately a 50 per cent increase over standard practice in the distance between strings, and a short offset distance between the pin for the strain clamp and pins for the ball and socket fittings to the insulators. The distance between strings was set at 21 inches to try to avoid the possibility of cross-flashing of strings because of the poor voltage distribution that occurs under dirt and moisture conditions. The short coupling distance mentioned is to obtain a long natural period of vibration in the vertical plane, so that the yoke will not be set in harmonic vibration within the range of vibrations existing on the conductor and thus introduce special bending forces at the entrance of the cable into the dead end clamps.

The width of opening of the yoke is to accommodate the dead end clamp in the position it will take if one string of insulators should break. The central inner clevis of the yoke, to which is attached the dead end clamp, has on its opposite side another

clevis opening to which can be attached a strain bar with turnbuckle arrangements connecting to a similar clevis at the other yoke, so that tension can be removed from the insulators and the whole insulator and yoke assembly removed for maintenance work without affecting the conductor. The yoke members are of $^1/_2$ inch steel plates 5 inches wide at the center, and the complete yoke has an ultimate strength of 30,000 pounds.

The jumper loop at the dead ends is hung from a U bolt underneath the yoke. Its suspension is independent of the main conductor so that its swing angle will not be influenced by the wind movements

Fig. 14. Ground wire strain clamp

of the main conductor and thus require more clearance space. The jumper loop is stiffened by the insertion of a 20 foot length of $^3/_4$ inch (iron pipe size) extra heavy copper tubing, so that it can be bent and held to the proper form to give clearance under the tower arm. This added weight reduces the swing of the loop caused by wind. The electrical connection is made by means of the braid previously described.

Special clevises and attachments were designed so as to keep the string lengths to a minimum.

At all suspension towers, the ground wire is supported on standard trunnion type suspension clamps. At all towers of special strength, the ground wire is connected by means of a special strain clamp illustrated in figure 14. This clamp is designed to have an ultimate strength of 20,000 pounds, and is a modification of existing types of clamps in order to develop increased strength. This type of clamp was selected primarily in order to have a clamp that would have a high natural frequency of oscillation, so that it would follow the natural vibration frequencies of the ground wire without causing large relative bending between clamp and cable at the entrance.

Single Circuit Towers

A diagram of a typical standard suspension tower is shown in figure 15. Exclusive of the footing steel, this tower weighs 18,100 pounds. It is designed for use on 1,000 foot spans and has a height to the cross arm of 90 feet. Its over-all height is 109 feet. It may be modified by leg extensions in 10 foot intervals up to 40 feet, none of which need be equal. Where very short towers are desired, the portion of the tower below the "waistline" is omitted. The tower is of the narrow waisted type with a rotated base, that is, the base is rotated 45 degrees with respect to direction of the line. The types of towers are standard suspension, angle suspension for vertical and horizontal angles that can be taken on the heavy duty suspension insulator strings, strain towers for all large angles and other points where such construction is required, and transposition towers which accomplish the transposition of conductors at one tower. All towers are of the same general appearance and have the same system of lower leg extensions.

The total number of single circuit towers in 225.3 miles, of double circuit line is 2,422, producing an average span of 984 feet. The longest span is 1,811 feet and the shortest 431 feet.

All single circuit towers are designed for the loadings imposed by $^1/_2$ inch radial thickness of ice on the conductor, with a wind pressure of 8 pounds per square foot of projected area at 10 degrees Fahrenheit. Under such circumstances the stress in the conductor is 40 per cent of its ultimate strength, or 8,700 pounds. The height of the towers is such as

Table III—Tower Design Stresses

	Stresses in Pounds per Square Inch	
	Structural Steel Grade	High Elastic Steel Grade
Axial tension on net section	20,000	22,500
Axial compression on gross section for L/R ratios of 60 to 150	20,000–85 L/R	25,350–110 L/R
Axial compression on gross section for L/R ratios of 150 to 200	15,500–55 L/R	17,400– 57 L/R
Maximum compressive stress	15,000	18,750

to give a minimum center span clearance to the surface of the ground of 27 feet at a conductor temperature of 150 degrees Fahrenheit with no wind. The normal tension at 60 degrees is 4,370 pounds. Under similar loadings the maximum ground wire tension is 5,000 pounds, with a normal tension at 60 degrees of 1,800 pounds.

Suspension towers are designed to withstand 1 broken conductor and 1 broken ground wire simultaneously under maximum tension in the same span on the same side of the tower. Angle suspension towers, used where small horizontal or relatively large vertical angles are encountered, are designed to withstand under maximum load 3 broken conductors and 2 broken ground wires on the same side of the tower. Strain towers, used at large horizontal angles and other points of special nature requiring dead end construction, also are designed to withstand 3 broken conductors and 2 broken ground wires on one side of the tower. The towers are designed also for the torques imposed by the worst case of other combinations of the specified broken wires. The wind load on the towers was specified as 20 pounds per square foot on $1^1/_2$ times the net projected area of one face of the tower.

The towers are built largely of steel having a high elastic limit. The schedule of design stresses is

given in table III. The slenderness ratio (L/R) was not in excess of 135 for leg members and 200 for web members. (The slenderness ratio of a compression member is the ratio of its unsupported length to its radius of gyration.)

In response to the specifications, several types of towers were offered embodying conventional designs, narrow waisted type, and narrow waisted type with rotated base. The latter design was slightly lighter in weight, had advantages from the standpoint of smaller footing reactions, and was less costly—hence its selection.

Double Circuit Towers

A diagram of a typical double circuit suspension tower is shown in figure 16. Its height to the bottom crossarm is 75 feet, and its over-all height 144 feet. It weighs 23,000 lbs. This tower with extensions in multiples of 10 feet, is used on normal spans of the order of 850 feet in the populous territory adjacent to the City of Los Angeles, where the minimum clearance to the ground is maintained at 45 feet. The tower is of the conventional double circuit type, and has the same general classification of towers as the single circuit type. The total number of double circuit towers in 40.8 miles is 257, giving an average span of 839 feet. The longest span is 1,620 feet and the shortest 331 feet.

Double circuit towers are designed for a maximum pull of 8,700 pounds. The wind loading on the conductor at maximum tension is assumed at 12 pounds per square foot of projected area, with no ice and a temperature of 25 degrees Fahrenheit. The broken wire assumptions are 1 conductor and 1 ground wire broken for suspension towers, 3 conductors and 2 ground wires broken for angle suspension towers, and all 6 conductors and 2 ground wires broken for the strain towers. The basis of design is the same as for the single circuit towers.

Footings

All towers are provided with reinforced concrete footings of the pad and pedestal type, set in an undercut excavation so as to develop uplifts in largely undisturbed soil. A series of footing stubs of different lengths, capable of further limited length adjustment, were designed to take care of various depths of footings to meet conditions imposed by differences in soil, slope of the ground, and soil erosion. The footings were designed for bearing, uplift, shear, bending caused by shear, and punching. The uplifts are computed on a 30 degree cone basis. In connection with the footing design, full sized footings were set in various types of soil and pulled to failure. Those in uniform soil indicated quite close agreement with the 30 degree cone theory. Attempts to fasten appropriate anchor bolts in hard rock did not give satisfactory test results, so none of the towers have such footings. The selection of the type and dimensions of footing for a given location depended on examinations of the character of the site as excavation was in progress.

A typical footing for a single circuit suspension tower is 7 feet deep and has a diameter at the base of 4 feet. The reinforcing steel and the footing stub were put together and tack welded, so as to constitute one complete unit that could be placed in the holes and held in place by the template. Steel forms were used for the concrete, and in many cases were designed to be adjustable as to depth. The aggregate was ob-

Fig. 15 (below). Standard single circuit suspension tower

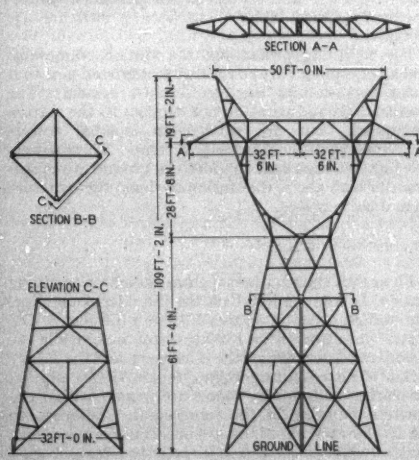
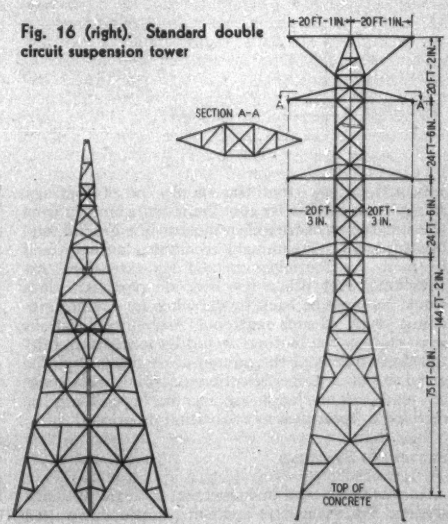


Fig. 16 (right). Standard double circuit suspension tower



tained from several favorable locations along the line. The quality of the concrete was maintained by checks on sample test pieces. A waterproofing compound was applied to the concrete preliminary to backfill.

Tower Location

Selection of right of way for this line was facilitated considerably by aerial observation and aerial mapping, which together with field observation made an accurate ground work upon which to proceed with the running of center lines and profiles.

In anticipation of the large amount of span, sag, and tension data that would be necessary for stringing the conductors and laying out the line on the profiles, an improved method of calculation was devised that was entirely analytical, adhered to catenary formulas, and readily could be reduced to a calculation form. For most of the tower locations a template was used that gave the center span sags for maximum hot day conditions for various spans. Within the ordinary span lengths, this curve did not depart very far from the true complete catenary curve for any one span. When especially long spans were studied, special templates would be made for the precise condition. For the single circuit tower section spans were held as near 1,000 feet as was desirable with due consideration to the topography.

Office analysis and layout was followed by a field check to verify that such a location and tower height

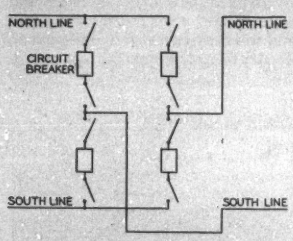


Fig. 17. One line diagram of intermediate switching station

was satisfactory from the standpoint of footings, safety from erosion by cloudburst, satisfactory from the standpoint of wire clearances to the ground, and other factors. Preliminary recommendations would be made for footings, unequal leg extensions, excavations, and other features, or pertinent data would be brought back to the office for further economic study of such matters. After final locations were chosen, the footings would be located, and detailed elevations of the ground at each leg would be given so that a proper selection of footing stubs could be made. The judgment on footings would be rectified or confirmed as excavation progressed.

Switching Stations

As was mentioned in connection with the stability studies, 2 intermediate switching stations are used for line sectionalizing, so as to switch out faulted line sections with the least possible disturbance to the continuity of power flow. These stations are located at almost exact $^1/_3$ points. The arrangement of oil circuit breakers and disconnecting switches is indicated in figure 17. This arrangement gives the required amount of flexibility for switching and maintenance with a minimum number of circuit breakers.

Switching stations are of the conventional outdoor, latticed column and girder type, occupying an area of 550x580 feet. The busses are supported with strain and suspension insulator strings and are constructed of cable similar to that used for the line.

Of special interest in these stations are the recently developed high speed impulse type of circuit breakers, the first and largest of their type ever built for commercial purposes.[23] Each breaker is rated at 287 kv, 1,200 amperes, and will interrupt up to 5,000 amperes. The over-all time of breaker action from energizing trip to extinguishing of the arc is not more than 3 cycles. The breakers have 8 contacts in series, housed within tubular horizontal members. These contacts are operated by springs, which are wound up by a motor driven mechanism; when the breaker is open the springs automatically are put in position to take care of the next closing and opening cycle. The extinguishing of the arc is accomplished by forcing a jet of oil across each contact at a pressure of 100 pounds per square inch.

As installed, the switch will be 27 feet high and will occupy a space of 22x54 feet. The amount of oil required is only 2,600 gallons for a complete 3 pole switch, of which only 210 gallons is exposed to arcing.

Although this circuit breaker constitutes a radically new development, every feature of its operation has been investigated and tested to the satisfaction of all parties concerned, such tests including 60 cycle and impulse voltage flashover, interrupting capacity, voltage distribution while opening, and mechanical life. On each side of the circuit breakers, motor-operated vertical-break disconnecting switches are installed.

For lightning protection, the station framework and all equipment are connected to a ground mat that is an extension of the counterpoise system. The overhead ground wires do not connect to the station framework, but are carried to isolated towers connected to the counterpoise system. These towers are 150 feet high and support the ground wires sufficiently high above the station to shield the structure from direct strokes.

Receiving Stations

Figure 18 shows a perspective sketch of receiving station *B*, the terminal of the Boulder Dam line. The station occupies an area of 1,600 x 677 feet. The central structure is the 132 kv switch rack, while the 4 similar structures at the 4 corners are the 33 kv racks. The operating room, repair shops, station auxiliaries, and storage rooms are housed within the concrete building in the foreground. Adjacent to the 132 kv rack are 2 banks of autotransformers, each bank of which is connected directly to a transmission

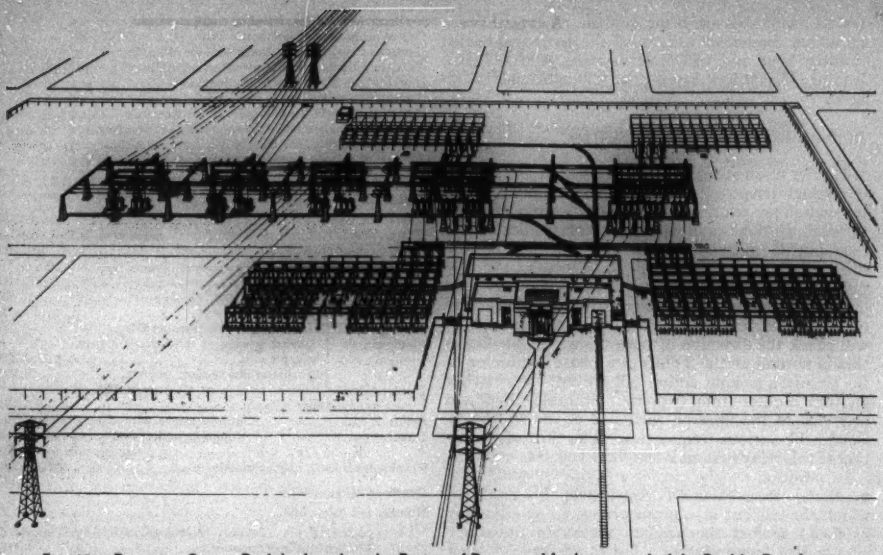


Fig. 18. Receiving Station B of the Los Angeles Bureau of Power and Light, terminal of the Boulder Dam Lines

circuit and serves to transform the voltage to 132 kv, thus eliminating the use of 287 kv circuit breakers at this station. Under the system of operation proposed for the lines, each of these transformer banks was required to have a self-cooled capacity under normal conditions of 120,000 kw. After carrying that load continuously, they were required to be capable of carrying 240,000 kw for 2 hours using forced air cooling when the other receiving end line section was out. They also had to be capable of carrying 150,000 kw continuously with forced air cooling to provide for the emergency rating of the line. In meeting these requirements, the actual ratings obtained for each single phase autotransformer were: 48,750 kw without blowers, 65,000 kw continuous with blowers, 80,000 kw for 2 hours with blowers. A 13,200 volt tertiary winding of 16,000 kva is provided for delta connection for circulating exciting current harmonics. These transformers have an impedance of 8.4 per cent at 65,000 kva, which is the lowest practicable impedance for the voltages involved. At this same load they have an efficiency of 99.47 per cent and a normal exciting current of 2.75 per cent. They are the largest autotransformers ever built to date.

Since these autotransformers are operated as parts of the lines, and their continuity of service is highly important, they will be protected on the 275 kv side with autovalve lightning arresters, which so far are the highest voltage arresters ever furnished commercially.

These autotransformers are connected to the 132 kv bus by means of 4 138-kv 1,200-ampere oil circuit breakers of the impulse type having the same speed and interrupting capacity as the circuit breakers in the switching stations. Four series breaks per pole are used at this lower voltage. The remaining 132 kv oil circuit breakers, which operate on the various double-circuit belt-line interconnections to 3 other receiving stations and on the 132/34.5 kv transformer banks, are of the conventional tank type and have a speed of 5 cycles and an interrupting capacity of 2,500,000 kva. Each of the 33 kv bus sections is supplied by a bank of 3 winding transformers. The bank rating on the secondary or 34.5 kv winding is 80,000 kva, which load is approximately at 0.75 to 0.80 power factor. The tertiary windings have a rating of 60,000 kva at 13,200 volts and are designed to be connected to the synchronous condensers, which furnish correction so that the primary windings operate at or near unity power factor with a rating of 60,000 kva. These transformer banks are connected star-star with a delta tertiary connection. At 70,000 kva these transformers have a primary to secondary impedance of 10.8 per cent. They have an efficiency at full load of 98.82 per cent.

For the initial installation, only 2 33 kv bus sections will be placed in operation at this point. A pair of "belt" transmission lines to station *D* will serve to extend the 132 kv bus to that similar receiving station, which will have 2 more similar transformer banks.

Full final details regarding the synchronous condenser installation cannot be given at this time, as they are dependent on stand-by steam plant arrange-

ments which still are being studied. A typical synchronous condenser will be of the hydrogen-cooled outdoor type and will have a rating of 60,000 kva leading, 36,000 kva lagging, at 600 rpm and 13,200 volts.

Relay and Communication System

Carrier frequencies will be imposed on the line for 4 distinct purposes: relaying, supervisory control of switching stations, telephone communication between stations, and telephone communication to patrolmen's automobiles in the vicinity of the line.

The carrier current relay system is of the lockout type. When given a fault signal from a ground relay or an overcurrent relay, directional element relays will check the direction of power flow. If the direction is normal at the 2 ends of a phase conductor of the circuit, a lockout action will prevent the switches on that section from tripping. Suitable filters are provided in the lines on each side of the station to isolate the various frequencies. The time of operation of this relay system is less than 3 cycles.

In addition to the carrier relaying system, conventional cross-balanced relays will be used, in which the current in a given phase of one circuit is balanced against the similar current in the other circuit at a given station. For most troubles, this relay system will be slightly more rapid than the other, except where the fault is near a station and cascade action of switching takes place.

Telephone communication will be provided over a separate wired line as well as over the carrier system. Patrolmen's cars will be provided with radio receiving sets tuned to the carrier frequency so that they can be given instructions when on the transmission line road, which is in the vicinity of the line for its entire length.

Conclusion

It is believed that this line not only has established a new voltage step in the transmission of electric power on the North American continent, but also has served to stimulate advances in the art and science of electric power transmission and related electrical fields. It is a milestone of current progress. In a project of this magnitude, it is unavoidable, or perhaps incidental, that many features are notable for their size, or capacity; but the ideal of the designers will have been realized if the system delivers the required power with the reliability and continuity of service that it seems reasonable at this time to expect.

Appendix—Statistical Data of Boulder Dam-Los Angeles Transmission System

Line

Number of 3-phase 60-cycle circuits	2
Line-to-line kilovolts, receiving end	275
Line-to-line kilovolts, sending end	287.5
Reliable operating capacity, kilowatts	235,000–240,000
Emergency capacity, kilowatts	300,000
Approximate full load loss, including transformers and synchronous condensers, per cent	8
Length of single circuit tower section, miles	225.3
Length of double circuit tower section, miles	40.8
Total length of double circuit line, miles	266.1
Length of sending end section, miles	91.7
Length of middle section, miles	90.8
Length of single circuit tower portion of receiving end section, miles	42.8
Length of double circuit tower portion of receiving end section, miles	40.8

Conductor

Diameter, inches	1.40
Type	segmental hollow copper
Total circular mils	512,000
Number of segments	10
Spiral pitch, inches	28
Weight per foot, pounds	1.57
Ultimate strength, pounds	21,600
Single circuit: Maximum line tension, pounds	8,700
Single circuit: Normal tension at 60 degrees Fahrenheit, pounds	4,370
Double circuit: Maximum line tension, pounds	6,400
Double circuit: Normal tension at 60 degrees Fahrenheit, pounds	4,750
Splice	Bronze sleeve with double wedge grip
Installation	Pulling in under tension controlled by 8 foot capstan and brake
Total pounds used, approximately	13,455,000

Overhead Ground Wire

Number per tower line	2
Single circuit towers: Material	1/2 inch galvanized steel, stranded
Single circuit towers: Weight per foot, pounds	0.517
Single circuit towers: Ultimate strength, pounds	18,800
Single circuit towers: Maximum tension	5,000
Single circuit towers: Normal tension	1,800
Single circuit towers: Total pounds used, approximately	2,461,000
Double circuit towers: Material	0.4395 inch copper covered steel, stranded
Double circuit towers: Weight per foot, pounds	0.421
Double circuit towers: Ultimate strength, pounds	18,500
Double circuit towers: Maximum tension, pounds	2,500
Double circuit towers: Normal tension, pounds	1,600
Double circuit towers: Total pounds used, approximately	181,000
Counterpoise: Material	1/4 inch rolled black copper rod
Counterpoise: Weight per foot, pounds	0.205
Counterpoise: Total pounds used, approximate	1,300,000
Counterpoise: Depth, feet	not more than 3
Counterpoise: Method of installation	by plow
Counterpoise: Method of attachment	4 spark gaps per tower

Span

Single circuit towers: Normal span, feet	1,000
Single circuit towers: Average span, feet	984
Single circuit towers: Maximum span, feet	1,811
Single circuit towers: Minimum span, feet	431
Single circuit towers: Normal sag, feet (1,000 foot span)	45
Single circuit towers: Sag at 150 degrees Fahrenheit, feet (1,000 foot span)	48.5
Double circuit towers: Normal span, feet	850
Double circuit towers: Average span, feet	839
Double circuit towers: Maximum span, feet	1,620
Double circuit towers: Minimum span, feet	331
Double circuit towers: Normal sag, feet (850 foot span)	30
Double circuit towers: Sag at 130 degrees Fahrenheit, feet (850 foot span)	33.5

Insulation

Light duty suspension unit: Size, inches	10 x 5*
Light duty suspension unit: Strength, pounds	11,000
Heavier duty suspension unit: Size, inches	10 1/2 x 6*
Heavier duty suspension unit: Strength, pounds	15,000
Standard suspension insulator string	24–(10 x 5)
Standard angle suspension insulator string	22–(10 1/2 x 6)
Heavy duty strain insulator string	double 22–(10 1/2 x 6)
Light duty strain insulator string	double 26–(10 x 5)

* Diameter of unit by spacing between units.

Clearances

Up to 4 pounds per square foot wind, feet	11
At 12 pounds per square foot wind, feet	7
Suspension horn arcing distance, inches	110
Angle suspension arcing horn distance, inches	121
Heavy duty strain arcing horn distance, inches, approximate	117
Light duty strain arcing horn distance, inches, approximate	115
Minimum vertical distance to surface of ground:	
desert and mountain sections, 150 degrees Fahrenheit, feet	27†
coastal plain section, 130 degrees Fahrenheit, feet	45‡

† Some inaccessible locations 22.5 feet.
‡ Some nonagricultural hilly locations 40 feet.

Hardware

Conductor	Strain clamp	Bronze sleeve, double wedge grip
	Suspension clamp	Free center, double saddle type
	Lower arcing horn	Figure "8"—1¼ inch pipe
	Upper arcing horn	Steel strap—⅜ x 1½ inches
	Strain string arcing horns	1¼ inch pipe ovals above yokes
	Yokes, low frequency vibration	21 inch string spacing
Ground wire	Strain clamp	Special 315 degree snubbing type
	Suspension clamp	Standard trunnion type

Single Circuit Towers

Loading		½ inch ice, 8 pounds per square foot wind
Suspension type	Broken wire assumptions	1 conductor, 1 ground wire
	Conductor spacing, feet	32.5
	Crossarm height, standard tower, feet	90
	Ground wire spacing, feet	50
	Ground wire height, standard tower, feet	109
	Extensions, feet	10, 20, 30, 40
	Tower base, feet	32 x 32
	Weight, pounds	18,100
Angle suspension	Broken wire assumptions	3 conductors, 2 ground wires
	Horizontal line angles, degrees	0 to 10
	Weight of 10 degree tower, pounds	25,400
Strain type	Broken wire assumptions	3 conductors, 2 ground wires
	Horizontal line angles, degrees	0 to 50
	Weight of 50 degree tower, pounds	27,925

Double Circuit Towers

Loading		no ice, 12 pounds per square foot wind
Suspension type	Broken wire assumptions	1 conductor, 1 ground wire
	Conductor spacing, Vertical, feet	24.5
	Conductor spacing, Horizontal, feet	40.5
	Lower crossarm height, standard tower, feet	75
	Ground wire spacing, feet	40.5
	Ground wire height, standard tower, feet	144
	Extensions, feet	10, 20, 30, 40
	Tower base, feet	32 x 32
	Weight, pounds	23,050
Angle suspension	Broken wire assumptions	3 conductors, 2 ground wires
	Horizontal line angles, degrees	0 to 10
	Weight of 10 degree tower, pounds	38,300
Strain type	Broken wire assumptions	6 conductors, 2 ground wires
	Horizontal line angles, degrees	0 to 90
	Weight of 50 degree tower, pounds	41,150

Standard Footings

Type		reinforced concrete, pad and pedestal
Diameter and depth	Single circuit suspension tower, feet	4 x 7
	Single circuit 10 degree angle tower, feet	5 x 7 (side)
		6.5 x 9.5 (long)
	Single circuit 50 degree strain tower, feet	7 x 9.5
	Double circuit suspension tower, feet	4.25 x 8
	Double circuit 10 degree angle tower, feet	7 x 10.5*
	Double circuit 50 degree strain tower, feet	8.5 x 12*

* Preliminary and approximate.

Generators

Number used on 2 circuits	4
Kilovolt amperes each at unity power factor	82,500
Voltage	13,800/16,500
Number of poles	40
Speed, revolutions per minute	150/180
Short circuit ratio	2.28/2.74
Direct axis transient reactance, per cent	21/17.5
Moment of inertia (WR^2) each	not less than 105,000,000
Total weight, pounds, approximate	2,000,000
Outside diameter, feet	40
Type of insulation	Class *B*
Excitation	nominal 250 volts, main and pilot exciter direct connected
Exciter response	0.50

Sending End Transformers

Number used on 2 circuits (2 banks)	6
Type	Water cooled, outdoor
Rating of each, kilovoltamperes	55,000
Voltage	287,500Y/16,320 delta
Frequency, cycles per second	60
Impedance, per cent	not more than 10.73
Exciting current at normal voltage, per cent	4.5
Full load efficiency, per cent	99.31
Three-quarter load efficiency, per cent	99.33
Total weight per unit, pounds	385,000
Floor space and height, feet	13 x 20 x 32

Receiving End Autotransformers

Number used on 2 circuits	6
Type	forced air cooled
Rating of each, kilovoltamperes	48,750, no blowers; 65,000, blowers; 80,000, 2 hours, blowers
Tertiary winding rating, kilovoltamperes	16,000
Voltage	275,000Y/132,000Y/13,200
Frequency	60
Impedance, primary to secondary, per cent on 65,000 kilovolt-amperes	8.4
Exciting current at normal voltage, per cent	2.75
Full load efficiency at 48,750 kva, per cent	99.487
Full load efficiency at 65,000 kva, per cent	99.466
Full load efficiency at 80,000 kva, per cent	99.422
Total weight per unit, pounds	332,000
Floor space and height, feet	11½ x 23½ x 36

Three Winding Transformers

Number used for 2 circuits	12
Type	forced air cooled outdoor type
Kilovoltamperes each	primary 60,000, secondary 80,000, tertiary 60,000
Voltage	76,200/20,000/13,200 delta (132,200Y/84,500Y/13,200)
Frequency, cycles per second	60
Impedance, Primary to secondary (23,333 kva), per cent	10.8
Impedance, Primary to tertiary	12.3
Impedance, Secondary to tertiary	3.3
Exciting current, normal voltage, per cent	2.75
Full load efficiency, per cent	98.988

Synchronous Condensers

Kilovoltamperes, each	60,000 lead/36,000 lag
Voltage	13,200
Number of poles	12
Speed in revolutions per minute	600
Direct axis transient reactance, per cent	45
Moment of inertia (WR^2) each, pound-feet²	1,250,000
Type of insulation	Class *B*
Excitation	motor generator, main and pilot exciter, 250 volts
Exciter response	0.5

Oil Circuit Breakers for Switching Stations

Type	porcelain clad, impulse
Voltage class, kilovolts	287.5
Interrupting capacity, kilovoltamperes	2,500,000
Normal current rating, amperes	1,200
Speed of operation, cycles	3
Weight, pounds	113,300
Floor space and height, feet	22 x 54 x 27
Gallons of oil	2,600

Oil Circuit Breakers for Receiving Stations

Type	porcelain clad, impulse
Voltage class, kilovolts	138
Interrupting capacity, kilovoltamperes	2,500,000
Normal current rating, amperes	1,200
Speed of operation, cycles	3
Weight, pounds	51,000

Floor space and height, feet	20 x 22 x 22
Gallons of oil	750

Oil Circuit Breakers for Receiving Stations

Type	tank
Voltage class, kilovolts	138
Interrupting capacity, kilovoltamperes	2,500,000 (convertible to 4,000,000)
Normal current rating, amperes	1,200
Speed of operation, cycles	5
Weight, pounds	100,000
Floor space and height, feet	8 x 26 x 17
Gallons of oil	7,380

Lightning Arresters

Voltage class, kilovolts	287.5
Kilovolts, line to ground	235.0
Mounting	suspension
Crest voltage at 1,500 ampere discharge, kilovolts	825
Impulse voltage breakdown, kilovolts	800
Over-all height, feet	33

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Time-Temperature Tests to Determine Machine Losses

Time-temperature tests as a means of measuring losses in electrical machines are described in this paper, and some of the results which have been secured with such tests are described. The method consists principally in determining by test the initial slope of the time-temperature curve of some part of the machine, immediately after a steady load is thrown off. In this paper, application to the analysis of losses in turbine generators is described, although the method can be applied to other electrical apparatus.

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In the early days of the electrical industry the design of electrical machines was largely a matter of rule of thumb and progress was made through the trial and error method. As designers worked out the underlying theory of machine performance the apparatus produced soon took on general forms which have existed with little fundamental change to the present day. Calculation of the losses in machines has, within the past 10 years, reached a point where most of them can be estimated in advance of the tests with very good accuracy. Most of these calculations, however, still involved the judicious use of empirical factors depending upon the machine proportions, materials, etc. Load losses in machines still presented a considerable problem as they were made up of a number of losses whose distributions were little known.

It will, therefore, be seen that the machine designer, while having very useful tools in these calculation methods, had no means of checking the distribution and location of the losses throughout the various parts of the machine by actual test. An accurate knowledge of their distribution was essential if further refinements in design were to be made. In 1926, certain preliminary tests were made by C. M. Laffoon and J. F. Calvert[1] to determine the feasi-

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1. For all numbered references see list at end of paper.

bility of measuring the rate of heat input to various parts of a turbine generator. They indicated that a new tool in the form of time-temperature tests was available to the designer to examine more closely the location of various losses and their causes. Since that time a notable contribution to this subject was made in an article by Prof. S. Parker Smith.[2]

The present paper covers the work carried on by one manufacturer in analyzing losses in turbine generators. The method, however, is not limited to such machines only, but can be applied to many lines of electrical apparatus.

General Theory of Time-Temperature Tests

Briefly, the method of determining losses by time-temperature tests is to bring the machine under test up to constant temperature at the load condition to be checked. The load is then suddenly thrown off, reducing the electrical losses to zero. If the cooling system is not changed during the test the initial slope of the time-temperature curve after throwing off the load will be a measure of the heat input to the part under consideration.

Assume

q_i = the rate of heat flow into the part
q_o = the rate of heat flow to the cooling medium
θ = temperature of the part under test
θ_0 = temperature of the part previous to dropping the load
θ_o = temperature of the cooling medium
t = time
c = specific heat of the material
k = thermal conductivity of heat path to the cooling medium

Assume the part under consideration consists of a homogeneous material with uniform loss generated in it. The heat balance equation for this part at any time may be represented by the following equation:

$$q_i = q_o + c\frac{d\theta}{dt} = k(\theta - \theta_o) + c\frac{d\theta}{dt} \tag{1}$$

where the factor $c\frac{d\theta}{dt}$ represents the rate at which heat is stored in the material.

With the machine at steady temperature under load, $c\frac{d\theta}{dt} = 0$. At the instant that the load is dumped the heat input q_i becomes zero. To maintain the heat balance, the following must hold true:

$$c\frac{d\theta}{dt} = -q_o = -k(\theta - \theta_o) \tag{2}$$

From this the equation of the time temperature curve is:

$$\theta = \theta_o + (\theta_0 - \theta_o)\epsilon^{-\frac{k}{c}t} \tag{3}$$

The slope of this curve at time $t = 0$ (when the load is dropped) is:

$$-\frac{d\theta}{dt} = \frac{k(\theta_0 - \theta_o)}{c} = \frac{q_i}{c}$$

Therefore,

$$q_i = -c\frac{d\theta}{dt} \tag{4}$$

Before throwing off the load the heat input q_i equals the heat dissipated through the cooling system. When q_i becomes zero, the temperature of the material begins to fall at such a rate that, for a short time, the heat flowing to the cooling system does not change. It is, therefore, only necessary to determine this slope accurately by test and apply the proper specific heat value in equation 4 to obtain the heat input to the part under consideration.

It will be noted that the material under consideration was assumed to be of a homogeneous nature. Many materials encountered in machines are not of this type, and it is necessary in that case to obtain an equivalent specific heat value by testing a sample or the part itself with a known heat input and determining the slope of the time-temperature curve with this known loss. The second assumption made was that the loss was generated uniformly throughout the material. Analysis of this problem will disclose that equation 4 still holds true, the heat transfer in the material itself during the cooling down period only affecting the shape of the time-temperature curve some time after the load is dropped. The losses are usually generated in electrical machines with sufficient uniformity that these transients due to unequal distribution do not materially affect the first 5 minutes of the time-temperature curve.

Fig. 1. Arrangements for testing 100,000 kva turbine generator. Potentiometers, dial switches, and thermocouple cold junctions in vacuum bottles are on tables in the foreground

Procedure in Testing A-C Machines

In testing a turbine generator to determine the distribution of the electrical losses, thermocouples are soldered to the parts of the stator whose losses are to be measured and leads are brought out to a potentiometer for measuring the temperature. The usual arrangement when a number of couples are to be used is to connect about 4 to 6 of them to a dial switch

and from the switch to the potentiometer so that one operator can read the temperatures of a number of couples. The cold junction for the group is immersed in a vacuum bottle, which is maintained at constant temperature during the test. Several such meters may be required to read all the thermocouples installed in the machine. Figure 1 shows the arrangement of temperature measuring equipment for testing a 100,000 kva generator. The machine to be tested is arranged to be driven by a direct connected motor so that the ventilation will not change when load is thrown off. The machine is held on load until constant temperatures are reached. The field switch is then opened. If the machine is operating at zero per cent power factor in parallel with another machine, the main circuit breaker is opened before opening the field switch. Readings of temperature and time are then taken for each couple over a 20 minute period. A typical time-temperature curve of a thermocouple embedded in the stator laminations is shown in figure 2. As it is important to obtain as large a number of accurate readings as possible in the 20 minute period, 2 readers are used to each potentiometer, one to read the potentiometer and the other to record the time and the temperature readings.

All tests were made with the usual low range portable potentiometers, which could be operated quickly but left something to be desired in accuracy in measuring low loss densities, as it is desirable to determine the temperature readings with an accuracy of better than ± 0.1 degree centigrade when the initial slope of the curve is below 0.5 degree centigrade per minute. The accuracy obtained seemed to be of the order of ± 0.2 degree centigrade. For rates of temperature change exceeding 0.5 degree centigrade per minute, the portable potentiometer has satisfactory accuracy. As the tests described here were not intended to be made with laboratory precision, the equipment used gave sufficiently accurate results for design purposes.

Measurement of Losses in Armature Coils

In one case thermocouples were built into an armature coil connected to the neutral of the star winding so that losses could be measured at a number of points in the coil. While very satisfactory results were obtained by this method, it is not applicable to most cases as it is undesirable to install such couples on account of the necessity of removing the coil from the machine after test. A method of measuring the total loss in the armature copper, including both the so-called d-c loss and eddy current losses, was, therefore, worked out as follows. Direct current was circulated through the armature winding with the rotor at standstill until the temperature of the winding became constant. The d-c supply circuit was then opened and a time-temperature curve of the stator winding was obtained by measuring the stator temperatures by resistance of the windings. The apparent specific heat of armature windings was found to be 1.7 to 2.1 times the theoretical value for copper. With the machine running under load, arrangements were made as shown in figure 3 to measure the winding resistance as soon as the load was dropped. It was found necessary to use a filter circuit, to reduce the a-c current in the circuit generated by the residual magnetic field of the rotor. The filter shown in figure 3 was made up of a standard potential transformer and a condenser which happened to be available at the time tests were made. A low value of d-c current was circulated through the windings when taking temperature readings after dropping the load and the voltage drop across the winding measured, in preference to the use of a wheatstone bridge, as it was found that more consistent readings could be obtained by the volt-ampere method. The initial slope of the time-temperature curve of the armature winding was a measure of the total loss of the armature coil and this could be determined accurately using the specific heat value obtained by the calibration test.

Calibration Tests on Steel Materials

Time-temperature tests were made on ring samples of armature laminations and solid iron rings to determine the proper specific heat values to be used in calculating the loss values. The sample to be tested was connected to the usual core loss measurement apparatus and excited so as to obtain a certain loss in it. After the sample reached constant temperature the excitation was cut off and a time-temperature test was run. In testing the laminated material, thermocouples were soldered to a lamination at the

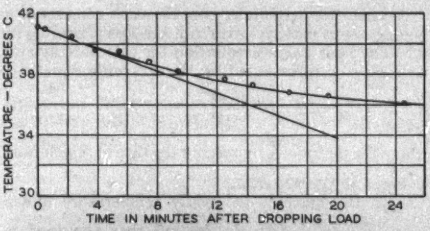

Fig. 2. Typical time-temperature curve taken with a thermocouple embedded in a tooth in the stator core. Initial slope of the curve equals 0.365 degrees centigrade per minute. Watts loss per pound equals 1.65

middle of the ring sample. Thermocouples in the solid steel ring sample were peened into holes drilled in the material. The same method of attaching thermocouples to solid machine parts was carried out in all tests. The apparent specific heat value for a one inch square solid iron ring was 4.0 watt-minutes per pound per degree centigrade, which is only slightly higher than the theoretical specific heat of steel, but the apparent specific heat value for the 0.014 inch thick laminated material was found to be 4.55 watt-minutes per pound per degree centigrade, which is 30 per cent higher than that of steel. This difference in specific heat value is believed due to the

thermal lag of the thermocouple with regard to the iron temperature. This difference in specific heat value was also noted in Professor Smith's article. Losses set up at machine frequency or higher in solid iron parts are confined to a thin skin on the outside of the material due to the well-known "skin effect." Analysis of the heat flow due to this unequal distribution of losses indicated that the transients due to distribution of the heat throughout the material would be very rapid when the thickness of the steel did not exceed an inch—a common material thickness used in machines. The specific heat value obtained with the one inch square sample of steel was, therefore, considered to be representative of most cases encountered in machines, and the loss was figured on the basis of the total weight of material involved rather than that of the outer skin, which was of unknown extent.

Measurement of Rotor Surface Losses

So far only losses measured in the stationary parts have been under discussion. An attempt was made to measure the losses on the surface of the rotor of one machine by means of thermocouples embedded there and brought out through holes in the shaft to slip rings. The readings obtained were somewhat erratic due to variations in the resistance of the current collecting mechanism and to induced a-c currents in the thermocouple wiring, which were sufficiently rectified in some of the points in the circuit to affect the d-c voltage at the potentiometer. This rectification of stray a-c currents was first noticed when attempts were made to measure stator losses by throwing on load rather than throwing it off as later adopted. Sufficient stray fields existed, with the load on, to cause erratic temperature readings. The practice of bringing the machine up to full temperature and then dropping the load was, therefore, adopted, with a marked improvement in the consistency of temperature readings due to the absence of stray fields. So far as is known, no satisfactory method of measuring rotor temperatures with sufficient accuracy has been developed to determine losses in the steel parts.

Some Results of Tests

In all, 5 turbine generators ranging from 3,750 kva to 100,000 kva have been given time-temperature tests, from which valuable design information was obtained. With 3 of the 5 machines sufficient readings were taken to determine quite accurately the total stator loss, which was found by multiplying the weights of the various parts by their test loss per pound and summing up these losses. The stray losses in the rotor in these cases were known to be relatively small, from calculations made of these factors. The total stator losses checked quite closely with the values obtained by the usual segregated loss method as carried out in regular tests of a-c machines, which indicates that the method of testing was sufficiently accurate for the designer's purpose.

While it is impossible to go into detail here as to the findings of these tests, a few of the more important points might be of interest:

1. The losses in the laminated iron parts were found to be from 25 per cent to 80 per cent higher than the Epstein tests for the same material and the same flux density would indicate.

2. The losses in some of the frame parts in one case were found to be as high as 40 watts per pound at over-voltage. As a result of this information later machines have been designed with certain changes to eliminate most of these frame losses which appeared in the core loss.

3. The 100,000 kva generator mentioned above had a single conductor coil with strands transposed throughout the length of the embedded parts of the coil by the Roebel method to eliminate eddy currents. The calculated eddy factor for the coil using the usual formulas was 1.20. When tested, the eddy factor was found to be 2.0 instead of the calculated 1.2, or the eddy losses were 5 times higher than the calculated value. A check was then made to find where the extra loss was coming from. It was found that the coil (which was made in halves) had all its strands short-circuited at each end of each half coil and, while satisfactorily transposed to avoid extra losses due to cross flux in the embedded portions, was totally untransposed so far as fluxes in the end windings were concerned. A rough check of this factor, which is too complicated to lend itself to accurate analysis, indicated the possibility of obtaining such a high eddy factor due to this cause. A factor which had always been considered negligible was, therefore, found to be a very important one. As a result of this information a later machine of similar construction was connected at the ends of the half coils in a number of independent groups which were suitably transposed so as to eliminate almost entirely the extra losses due to end winding fluxes.

A filter made up of a potential transformer and condenser is used to shunt out alternating current due to residual magnetic field

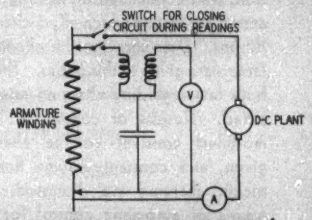

Fig. 3. Meter connections to measure resistance of stator windings by volt-ampere method

Attention to details of design such as mentioned here has been largely instrumental in the reduction in size and improvement of performance that is steadily going on in the design of turbine generators. The data obtained on turbine generators has been applied to other a-c machines resulting in improved performance, particularly in large a-c synchronous apparatus. As stated above, the use of time-temperature tests is not confined to the measurements of turbine generator losses, but can be applied profitably to solve a large number of electrical and mechanical problems where a sudden decrease of the losses may be obtained and the ventilation can be maintained constant throughout the test.

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Storage Battery Charging

The fundamental reactions in accordance with the generally accepted "double-sulphate" theory of storage battery charging are comparatively simple. Additional reactions and phenomena, such as gas evolution, acid concentration, heating, and local action are factors which affect charging conditions. Data showing the effects of these factors are given in this paper. The ampere-hour law regarding charging rates is illustrated. Results of constant voltage and modified constant voltage charging are given, and constant voltage floating and trickle charging are discussed. Various means of automatic control for charging batteries in different classes of service are given, some of these schemes involving the use of ampere-hour meters and voltage relays.

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WHILE the reactions which take place during the charge and discharge of the lead-acid storage cell are not in all respects fully understood and have been the subject of some controversy, the fundamental facts, in so far as they affect the practical industrial application and control of the storage battery, are well established and may be recapitulated briefly here as a foundation for the discussion of storage battery charging to follow.

In view of the more recent investigations on the subject there appears to be no good reason for questioning the so-called "double sulphate" theory originally advanced by Gladstone and Tribe as expressed in the following equation:

$$PbO_2 + 2H_2SO_4 + Pb \rightleftarrows PbSO_4 + 2H_2O + PbSO_4$$

the left hand member representing the charged condition and the right hand member the discharged condition. This equation presents the initial and final condition of such parts of the active material and the electrolyte as are involved in the reactions. In both positive and negative plates there must necessarily be an excess of active material over that theoretically required and a similar surplus of electrolyte must also be present.

It will be observed from the above equation that during discharge a part of the sulphuric acid in the electrolyte is combined with the active material, forming lead suphate in both positive and negative plates, while a corresponding amount of water is produced, giving rise to the well-known reduction in the specific gravity of the electrolyte during discharge and the corresponding increase during the charge.

Up to this point the charging of a storage battery appears to be a very simple matter consisting merely in passing current through the cell in the charging direction until all the active material has been restored to full charge condition. In fact, during the early commercial development of the storage battery very little was done in the matter of a comprehensive study of storage battery charging. There are, however, several other phenomena and conditions which develop during the charge which are not indicated by the fundamental formula, which will now be briefly discussed.

Acid Concentration in the Plates

A further study of the reactions indicated by the fundamental equation given above will show that during the charge strong sulphuric acid is formed in the active material of both plates, the sulphate radical (SO_4) dissociated from the lead combining with the hydrogen from the water present, whose oxygen, (part of which is transferred by ionic migration from the negative to the positive plate) combines with the lead of the positive plate to form lead peroxide (PbO_2). This gives rise to a higher concentration of acid in the pores of the plates than that of the free electrolyte outside, on account of the time required for diffusion. Diffusion takes place more readily near the surface so that the acid concentration is greater in the more inaccessible parts, producing higher counter electromotive force to oppose the charging current. These inaccessible regions charge more slowly, therefore, and are the last to be fully charged. The gradual rise of acid concentration produces gradual rise of voltage. The effect of high acid concentration in retarding the charge is more marked in the case of the negative plate and if the acid concentration is sufficiently high, it is impossible to reduce the sulphate to spongy lead.

Gassing

The conversion of the lead sulphate ($PbSO_4$) into lead peroxide (PbO_2) in the positive plate and lead in the negative plate is not the only reaction occurring while charging current is passing. These are the preferential reactions and take place so long as there is sufficient sulphated active material accessible to absorb the current, and diffusion can take place at a rate which will prevent excessive acid concentration in the pores of the plates. Whenever the charging current exceeds this value, the excess which cannot

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be used for charging the active material causes decomposition of the water of the electrolyte into hydrogen and oxygen which are released as bubbles of gas—the hydrogen at the negative plate and the oxygen at the positive—and the familiar phenomenon of gassing appears. A higher voltage is required to release gas than to charge the active material so the beginning of active gassing is indicated by a comparatively rapid rise of voltage at the cell terminals. The accompanying diagram, figure 1, shows a typical charge curve and illustrates the phenomena just referred to, namely, the gradual rise of voltage during the early part of the charge caused by increased concentration of acid density and the rapid rise of voltage toward the end of the charge at the point where gassing begins, followed by a flattening of the curve when the cell is fully charged and all of the charging current is consumed in the evolution of gas, the conditions then becoming constant.

The rate of gas evolution is also shown on this curve, as well as the rise of specific gravity as the charge progresses. The more rapid rise of this specific gravity curve after gassing begins is the effect of the gas bubbles in forcing out the heavier electrolyte from the pores of the plates as well as the stirring up of heavier electrolyte which may have settled to the bottom of the cell.

Faraday's Law

According to Faraday's law a given amount of current passing through an electrolytic cell can produce only a definite amount of electrochemical reaction. Hence, that part of the current which produces gas by decomposing the water in the electrolyte cannot have any effect in charging the active material. This applies separately to the positives and

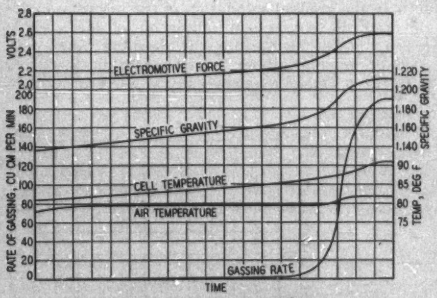


Fig. 1. Typical curves of charge voltage, specific gravity, and gassing. Charge at 8 hour discharge rate following 8 hour discharge

the negatives—that is, the same current which produces gas (oxygen) at the positive plate after that plate is fully charged may still be charging the active material of the negative plate if that plate is not fully charged, but any part of the charging current which produces gas at both plates is absolutely

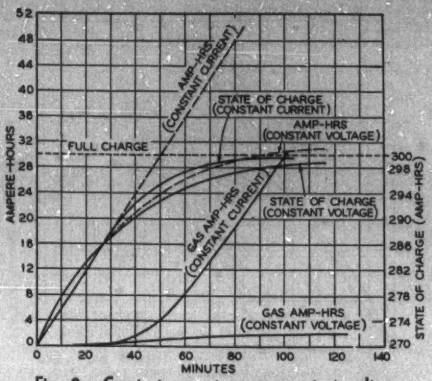


Fig. 2. Constant current versus constant voltage charge following one hour discharge at 10 hour rate (30 amperes)

Constant current = 36 amperes
Constant voltage = 2.25 volts per cell
Constant temperature = 26.5 degrees C

wasted as far as charging the active material is concerned.

The accompanying diagram, figure 2, illustrates this fact, showing the results of 2 charging tests following a 10 per cent discharge, in one of which the cell was charged at constant current and in the other at constant voltage. The rate of evolution of gas was measured in each case and converted into ampere-hours by well-known electrochemical constants, and plotted in the form of curves. The ampere-hours actually put into the cell are shown in dotted lines, and from this was subtracted the ampere-hour equivalent of the gas evolution, leaving the net ampere-hours used for charging the active material, indicated by the curves marked "state of charge." It will be noted that the constant voltage method, at 2.25 volts, charged the cell almost as rapidly as the constant current method, and much more efficiently. The next curve, figure 3, shows a similar test following a 20 per cent discharge.

Heating Effects

The heat produced in a cell during the charging period is due to 3 causes. First, there is the ordinary resistance loss (I^2R) determined by the current and the true ohmic resistance of the cell. The internal resistance of commercial storage battery cells is comparatively small so that unless abnormally high charging rates are used the temperature rise during the early stages of the charge is not excessive, notwithstanding the fact that the internal resistance of a discharged cell is somewhat greater than when fully charged.

The second cause of heat generation is that due to the sum of the normal chemical reactions. Also, the mingling of the sulphuric acid produced by the charging current with the water of the electrolyte

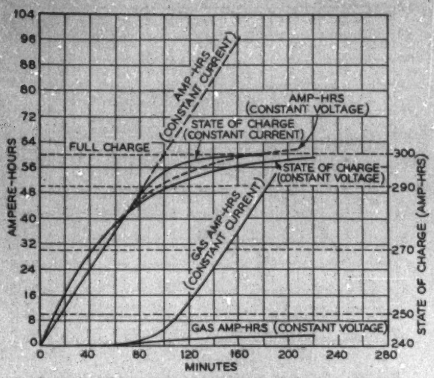


Fig. 3. Constant current versus constant voltage charge following 2 hour discharge at 10 hour rate (30 amperes)

Constant current = 36 amperes
Constant voltage = 2.25 volts per cell
Constant temperature = 25 degrees C

produces some heat. These heating effects are small and practically negligible under ordinary operating conditions.

Toward the end of charge another quantity of heat is developed, the source of which is somewhat obscure. The total energy represented by the product of the charging current by the final charge voltage is appreciably greater than the sum of the resistance loss and the electrochemical energy involved in the decomposition of the water of the electrolyte into oxygen and hydrogen. This difference appears in the form of heat. One of the theories advanced to account for this is the production of ozone at the positive plate as an intermediate reaction, which is immediately converted into oxygen with the development of heat. This theory is plausible, as the familiar odor of ozone is often noted. Another theory involves the formation of atomic hydrogen at the negative plate. It has thus far been impossible to establish these theories quantitatively. However, the rapid rise of temperature after gassing begins is a well-known fact.

Stratification

Stratification of the electrolyte is another phenomenon which may sometimes be observed. As already pointed out, concentrated sulphuric acid is produced in the pores of the plate by the charging current. In the early stages of a high rate charge this strong acid can be observed coming out of the plates and on account of its density sinking toward the bottom, during which process it mingles with the weaker acid between the plates. A small amount of this heavier electrolyte may settle into the region below the plates, but most of this will be stirred up by the convection currents produced by the gas bubbles during the later stages of the charge. In stationary cells the electrolyte in the dead space from the bottom of the cell to a point about $^3/_4$ inch to 1 inch below the bottoms of the plates will usually show a slightly higher density than that of the active electrolyte above this level, but when this increased density has reached a value equal to that of the heavier electrolyte which comes out of the plates during the charge after it has mingled with the weaker electrolyte between the plates, no further effect of this kind can occur.

The only result of stratification is a slight weakening of the active electrolyte which, while beneficial in respect to the life of the plates, will somewhat reduce the available capacity. This result will ordinarily be more than offset by the building up of the capacity of the plates in service. This phenomenon does not occur in batteries maintained by floating or trickle-charging, and any mechanical vibration or disturbance to which a battery is subjected will tend to minimize it.

Effect of Local Action

It is well recognized that a certain amount of local action or self discharge is taking place continually in a storage battery cell. By far the greater amount of this local action occurs in the negative plate. A full discussion of this subject would call for a separate treatise, but a few of its most important features may be mentioned as having a bearing on charging conditions. Local action takes place continuously, whether the battery is charging or discharging or standing on open circuit. It increases rapidly with increase of temperature and with increase in the specific gravity of the electrolyte. The accompanying curves, figure 4, will illustrate these effects. Local action is evidenced by the gassing of the negative plates when standing on open circuit. It results in the gradual sulphation of the negative material and the consequent falling off of the specific gravity of the electrolyte. It must be taken into account in determining the charging routine for a battery. Certain impurities in the electrolyte such

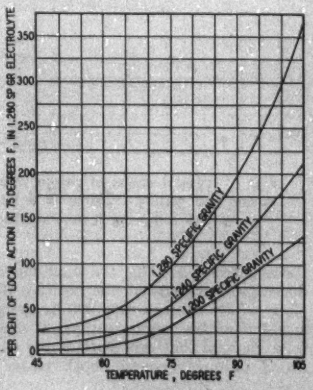


Fig. 4. Variation of local action with temperature and specific gravity of electrolyte

as platinum have a profound effect on this phenomenon. However, such impurities are unusual and it is not difficult to guard against this source of trouble. Cells which have been in service for a considerable length of time will usually exhibit some increase in the amount of local action. There also appears to be a quite definite relation between the amount of local action and the final voltage of the cell at the end of charge. The accompanying charge curves, figure 5, of 3 cells will illustrate this.

The 3 cells had been fully charged and then stood on open circuit for 5 days. They were then charged in series, and the charge voltage readings plotted as shown. The difference in the amount of local action is clearly indicated. In cell *A* the local action is comparatively little, the voltage rising rapidly to the gassing point. Cell *B* shows more local action, the rise in voltage being slower and the final voltage lower. In cell *C* the local action is pronounced, the final maximum voltage being reached only after about 4 hours' charging and being still lower than that of the other 2. The first sharp rise of voltage in curve *C* evidently corresponds to the charging of the positive plate, while the second rise is due to the negative plate.

Efficiency

The efficiency of a storage battery, that is the ratio of the output to the input, may be divided into 2 parts, namely, voltage efficiency and ampere-hour efficiency, the product (provided the charging rate is constant) being the energy or watt-hour efficiency. The voltage efficiency depends upon the difference between the charge voltage and the discharge voltage, the principal factor in this difference being the rates of charge and discharge. Obviously, at higher rates the discharge voltage will be lower and the charge voltage higher.

The ampere-hour efficiency depends upon 2 factors, *viz.*, the loss due to local action and that due to gassing during charge. The local action loss varies with the elapsed time as well as with the temperature, etc., and is independent of the amount of work done by the battery. The loss due to gassing depends entirely upon the charging conditions. If the local action loss is negligible compared to the work done, as is the case where the cycle is short and includes a considerable amount of discharge, the ampere-hour efficiency may be brought very close to

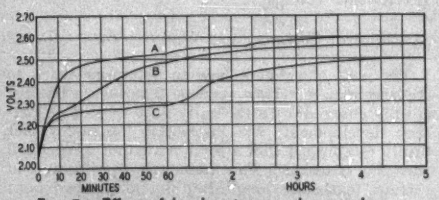
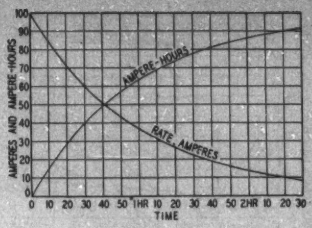


Fig. 5. Effect of local action on charge voltage. Three cells charged in series after 5 days' stand on open circuit

Fig. 6. Charging by ampere-hour law



100 per cent by careful control of the charging rate below the gassing point.

Charging Rates—The Ampere-Hour Law

With these various phenomena in mind the groundwork has been laid for discussing the question of how to charge a discharged storage battery. This question may be divided into 2 principal parts: (1) what charging rates to use; and (2) how to determine when to stop the charge. As to charging rates, the general rule is that any rate may be used that does not cause violent gassing or excessive temperature. Just what rates may be used without exceeding these limits must be determined by experience. In the early stages of the charge comparatively high charging rates may be employed but as the charge progresses a point is reached when the rate should be reduced. As a result of numerous tests, it has been found that if the charging rate in amperes is kept below a value equal to the number of ampere-hours then out of the battery the conditions as to gassing and temperature will be met. For example, if the battery has been discharged to the extent of 100 ampere-hours, any rate less than 100 amperes may be used. When the charge has been continued until 10 ampere-hours have been put in, leaving 90 ampere-hours still out, the rate must be reduced below 90 amperes, etc., the rate being continually reduced or tapered to keep within the value fixed by the ampere-hour law. When the rate is finally reduced to the prescribed "finishing" rate for the particular type of battery, the charge may be finished at that rate without further reduction. This law may be expressed by the differential equation

$$di = -i dt$$

which results from the condition that the charging rate i is continually reduced by the amount of charge in ampere-hours put in in the interval of time dt. The integration of this expression gives the exponential equation

$$i = Ae^{-t}$$

in which i is the charging rate in amperes, t the time in hours, and A the ampere-hours out of the battery when the charge starts ($t = 0$). This law is shown graphically in figure 6 from which it will be noted that 90 per cent of the capacity taken out may be put back in 2 hours and 20 minutes.

While this ampere-hour law is entirely empirical it is useful as an approximate guide in determining

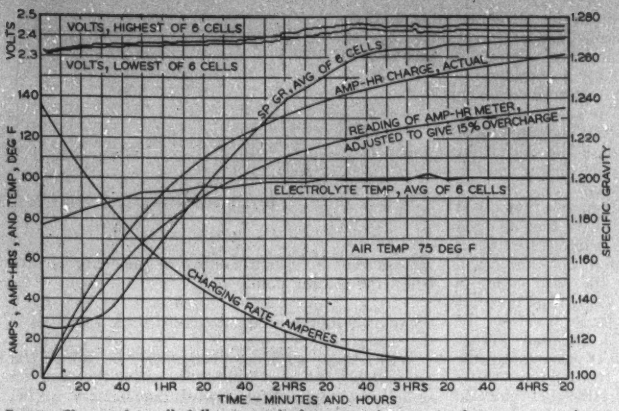


Fig. 7. Charge of 6 cells following a discharge equal to rated 6 hour capacity of 135 ampere-hours

Charging current in amperes kept equal to 135 minus ampere-hour meter reading

safe charging rates. Any lower rates may of course be used with a corresponding increase in the time required.

The accompanying diagram, figure 7, shows the results of another interesting test. A discharged battery was recharged in accordance with the ampere-hour law above mentioned, the charging rate being adjusted at frequent intervals to keep it equal to the ampere-hours out. The cell voltage was taken throughout the charge and it will be noted that this voltage is substantially constant until about 90 per cent of the previous discharge had been restored. This indicates that a fully discharged battery may be charged in about 4 hours by maintaining a constant voltage of about 2.4 volts per cell across the battery. At lower constant voltage, even as low as 2.15 volts per cell, the battery may be fully charged if sufficient time is available. Either of these 2 methods, that is, either a tapering charge, the rate being continually adjusted to follow the ampere-hour law, or the constant voltage method, will permit charging a battery in minimum time, the results being substantially the same in both. Each method presents certain disadvantages if minimum time is imperative. The first calls for constant manual control to maintain a carefully predetermined schedule of charging rates for given intervals of time. The second requires a practically constant voltage to be maintained, the correct value of which will depend upon the temperature of the cells. Both methods require a comparatively high capacity in the charging source to supply the initial charging rates.

The straight constant voltage method is also somewhat unstable if comparatively high voltage is employed since small variations of voltage or temperature cause excessive variations in the charging rates. Thus, an unobserved increase in voltage resulting in excessive charging rate will produce a rise in cell temperature causing a reduction in the counter electromotive force and a further increase of current, the effect being cumulative.

To obviate these disadvantages, the modified constant voltage method has been adopted and is very generally used for charging batteries in motive power and similar service. In this method, the voltage of the charging bus is maintained substantially constant at a value somewhat higher than that required for straight constant voltage charging, and a fixed resistance is included in the charging circuit. The time required for a complete charge is somewhat greater than with straight constant voltage but no manual control is required, the charging rate tapering down automatically as the charge progresses, and conditions are practically stable. The curves in figure 8 illustrate the results of constant voltage and modified constant voltage methods. Figure 9 shows the results of straight constant voltage charging at 2.15 volts and 2.27 volts per cell.

The methods above described permit establishing conditions for charging a battery safely in minimum time. If more time is available, lower charging rates may of course be used and in some respects are preferable, as they provide a greater margin of safety and call for less capacity in the charging source. The constant current method is entirely satisfactory, provided the rate is not greater than the prescribed finishing rate; or a 2 step charge may be used starting at a comparatively high rate and dropping to the finishing rate when appreciable gassing begins as indicated by the rapid rise of the charge voltage curve. As previously mentioned, very low charging rates throughout the entire charging period are entirely satisfactory, provided sufficient time is allowed to complete the charge, the principal difficulty in such cases being the less definite indication of the completion of the charge by maximum specific gravity and voltage.

Methods of Determining When to Stop Charge

The next question is how to determine when to stop the charge. How can one tell when a battery is fully charged? In the early days of storage battery development, the impression became rather firmly established that a final voltage of 2.5 per cell was the criterion. This idea was perpetuated in certain textbooks long after its fallacy had been demonstrated. It was usually tied in with a charging rate equal to the 8 hour discharge rate, but nothing was said about temperature or other factors

which affect the final voltage. Figure 10 shows a series of curves giving final charge voltage of a certain type of cell at different rates and temperatures. Different designs of cell will exhibit somewhat different characteristics. As a matter of fact, the actual voltage of a cell is a very unreliable indication of the completion of the charge. The specific gravity of the electrolyte is a better guide but even this requires certain precautions, since the specific gravity of a fully charged cell will vary with temperature and the height of the electrolyte, increasing at low temperatures and with reduction in level caused by loss of water from the electrolyte by evaporation and decomposition due to gassing. The most reliable indication is the attainment of maximum voltage and specific gravity, as indicated by a number of identical readings taken at stated intervals. Even then a temperature correction should be applied, if appreciable temperature change has occurred.

Ampere-Hour Meter for Stopping Charge

Another method for determining when a battery has been fully charged is to measure the ampere-hour output during the previous discharge, and continue the charge until the same number of ampere-hours have been put in plus a certain percentage of overcharge to compensate for losses. An ampere-hour meter is the most practical means for measuring the output and input, and these meters are designed to run slow in the charge direction by a certain percentage which may be adjusted within limits so that, when the indicator hand has returned to zero, the necessary overcharge will have been given. These meters are also provided with a contact at the zero point which may be used to trip a circuit breaker in the charging circuit and thus terminate the charge automatically.

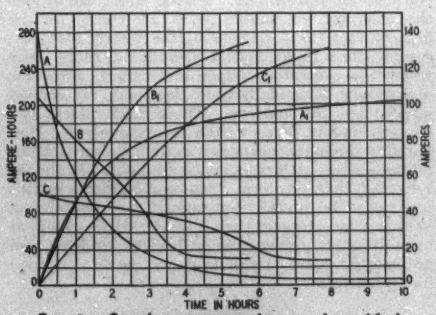


Fig. 8. Straight constant voltage and modified constant voltage charging

A, B, and C—Amperes
A_1, B_1, and C_1—Ampere-hours
A and A_1—Straight constant voltage charge at 2.25 volts per cell
B and B_1—Modified constant voltage charge. Bus voltage 2.53 volts per cell. Fixed resistance 0.00306 ohm per cell
C and C_1—Modified constant voltage charge. Bus voltage 2.63 volts per cell. Fixed resistance 0.0095 ohm per cell

The percentage of overcharge required will vary considerably under various operating conditions. In the case of daily discharges calling for nearly the full capacity of the battery followed by a recharge in 7 or 8 hours, a 15 per cent overcharge is usually satisfactory for lead-acid cells. It must be remembered, however, that practically all the loss due to gassing occurs at the end of the charge, and the overcharge in ampere-hours required to compensate for this is nearly constant for a given charging rate and independent of the amount of discharge. The *percentage* of overcharge required will therefore be greater if the operating cycle involves only a partial discharge. If the discharge is intermittent in character or at very low rates and therefore spread over a long period of time, calling for a recharge say once a week or less frequently, the loss due to local action may be appreciable in proportion to the total useful work, requiring a comparatively high percentage of overcharge.

The "Equalizing" Charge

On account of the difficulty of determining exactly how much overcharge is required by a battery subjected to daily cycles, and in order to avoid unnecessary overcharge, it is common practice to stop the daily charge a little short of full charge and give the battery a so-called "equalizing" charge at stated intervals, say once a week for service involving daily charges; this equalizing charge consists of a prolongation of the regular charge, at the finishing rate, until the proper values of specific gravity and voltage have been shown for a maximum period of one hour or longer, depending upon the rate of charge. The one hour maximum applies when the rate at end of charge is equal to the specified finishing rate for the cell. At lower rates, the maximum is longer in inverse ratio; for example, 3 hours at $^1/_3$ the finishing rate.

The purpose of the equalizing charge is to insure that occasionally every plate in every cell of the battery is brought with certainty to a state of full charge. This is especially important in respect to the negative plates. It is not to be expected that all the plates in a battery will remain exactly alike

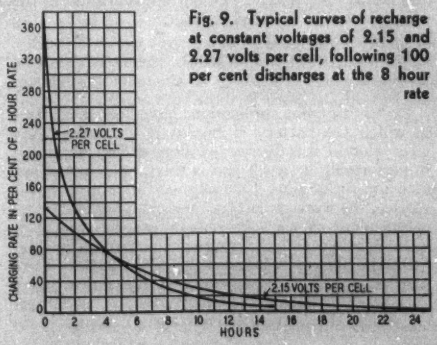


Fig. 9. Typical curves of recharge at constant voltages of 2.15 and 2.27 volts per cell, following 100 per cent discharges at the 8 hour rate

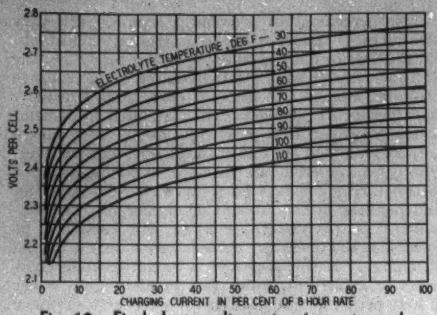


Fig. 10. Final charge voltage at various rates and temperatures

throughout its life, and those that develop a little more local action than the rest will probably not be fully charged at the end of the normal charge. The difference therefore is cumulative and can only be corrected by the equalizing charge.

Voltage Relay for Stopping Charge

For automatically terminating the charge another principle has been successfully employed. While a definite final voltage is not a reliable indication of the completion of the charge, the point where gassing begins and the voltage rises rapidly occurs at about the same state of charge for a given charging rate and temperature. Since the voltage curve is quite steep at this point a voltage value can be established say between 2.35 and 2.4 volts per cell which is certain to fall on this part of the curve, even with considerable variation in charging conditions, and a relay employed to respond to this voltage need not be designed for such extreme accuracy as to be impractical. This principle is used in several arrangements for the automatic control of battery charge. In one of these, the voltage relay starts a clock mechanism when the battery voltage reaches the selected value, and the clock, after running for a definite period of time, say 1 or 2 hours, opens a switch in the charging circuit and stops the charge. Other applications of this principle will be referred to later.

Constant Voltage Floating and Trickle Charging

Up to this point applications have been considered in which the battery is employed for "cycle" service—that is, it is discharged more or less completely in performing its work and is then taken out of service for recharging. Usually, as in motive power service, the work circuit and the charging circuit are independent of each other. In other cases, as in farm lighting, the charging source carries the load while the battery is being charged, the battery being used when the charging source is shut down.

In another and very extensive class of battery applications, the battery is constantly floating on the supply circuit, and kept fully charged except for occasional momentary discharges to carry the load peaks or for emergency discharges to tide over interruptions to the normal source of current. These applications may be conveniently divided into 2 classes, *viz.*, those in which the battery is continuously connected to a substantially *constant voltage* bus or circuit, and those in which the battery is continuously connected to the load circuit and a *constant current* is supplied to the circuit sufficient to carry the load and in addition to furnish a small trickle charge current to the battery to compensate for local action and keep the battery fully charged.

In the first, or "floating" system, the bus voltage is maintained at an average value equivalent to 2.15 volts per cell (assuming 1.215 specific gravity electrolyte) and it is desirable to keep this voltage as nearly constant as possible, since variations above and below the average value will cause the battery to charge and discharge, subjecting it to a certain amount of useless work. This constant voltage floating automatically compensates for the effects of varying temperatures, since at higher temperatures the battery will take more current at the same voltage, thus compensating for the corresponding increase in local action. In these strictly constant voltage floating systems the operating conditions for the battery are independent of the load since, if the voltage of the source is not affected by load fluctuations, such fluctuations must fall on the source and not on the battery. In certain installations falling essentially in this class, the generator is designed with a flat-compound characteristic up to full load, at which point the voltage drops off decidedly with further increase of load. Such a combination is ideal for handling a combination of load in which a part of the load is steady but may vary from time to time while upon this steady load is superimposed intermittent momentary demands of considerable magnitude. Under these conditions the generator will handle the trickle charge for the battery and the variations in the steady load, assuming that these do not exceed the range over which the generator voltage is constant, while the momentary demands beyond this range are carried largely by the battery. These momentary discharges amount to very little in ampere-hours compared to the battery capacity so that the actual work falling on the battery is relatively light. It should be noted that the term "flat-compounded" in this case must be literally interpreted as signifying a voltage characteristic that is substantially constant over the entire range from no load to full load, and not merely equal at full load and no load with a hump between.

Intermittent Charge With Constant Discharge

There is another class of battery applications in which the load circuit carrying a variable load is constantly connected to the battery, while the charging source is available only at more or less frequent intervals. A typical example is the usual railway axle-lighting system. Here constant voltage control of the charging generator is employed (modified to

prevent overloading the machine), but on account of the intermittent application of the charging source a higher value of constant voltage must be used than the 2.15 volts per cell adopted for continuous floating. Owing to the uncertainty as to the proportionate time during which the charging source is available as well as the variation in amount of discharge, under different operating schedules, it is impossible to determine an ideal value for the constant voltage to be maintained when the generator is running, and in order to minimize the possibility of a discharged battery and a resulting light failure, the generator voltage is controlled at a point which produces some overcharging under average operating conditions, a voltage of 37 to 38 volts for 16 cells being usual. This will recharge a discharged battery rapidly but will not produce injurious overcharging, considering the small proportion of the time each day during which the battery is subjected to this voltage while fully charged. The effect of this constant voltage control of an axle lighting generator in compensating for variations in operating conditions is shown in figure 11, which is taken from the chart of a graphic ammeter recording the ampere output of the generator. The area above the lamp load line represents the charge to the battery. It will be noted that after each stop, during which the battery is discharging to carry the lamp load, the generator output is maintained at a comparatively high value until the amount of the previous discharge has been restored, whereupon the generator output automatically drops to a low value continuing the battery charge at a comparatively low rate. The difference between the charge following a 10 minute stop and that following a 1 minute stop is quite marked.

Various Cases Involving Automatic Control

The next cases to be considered are those in which the source of current has a decidedly drooping voltage characteristic, adapted to furnish a substantially constant current, and is continuously connected across the battery. These cases present a number of interesting problems in automatic control, depending on the character of the load. A few typical examples will be considered.

Take, first, the case where the only load is an occasional momentary demand, occurring at infrequent intervals, as in many railway signal systems. Here it is sufficient to supply from the source a constant current equal to the trickle charge current required by the battery plus a small surplus equal to the average value of the intermittent load. It is then necessary to adjust to the proper value the output from the source (which is generally a rectifier connected to the a-c transmission line). The most satisfactory way to do this is to note the floating voltage of the battery and make the adjustment such as to maintain this at an average of 2.15 volts per cell. This adjustment should not be attempted until some time has elapsed after the termination of a discharge to permit stable conditions to be re-established. In making such adjustment it must be borne in mind that the battery voltage responds rather slowly to a small change in the charging current so that time must be allowed, after making a tentative adjustment, before deciding that such adjustment is correct. Furthermore, since the ouput of these rectifiers is a substantially constant current, varying but little with temperature or battery voltage, and since the battery requires more trickle charge current in warm weather than in cold weather, ideal conditions would call for readjustment in the spring and fall. Where this is not practical it is better to adjust for summer temperatures and allow the battery to be somewhat overcharged in winter. After a prolonged discharge due to a power outage, the output of the rectifier should be temporarily increased until the discharge has been restored. If, in addition to the intermittent load there is also a constant steady load, the output of the rectifier is increased by the amount necessary to provide for this, so that the battery is still called upon to take only the intermittent momentary demands.

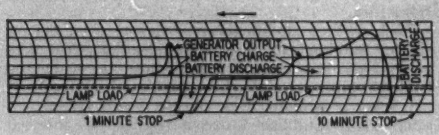


Fig. 11. Chart of graphic ammeter recording output of axle-lighting generator, controlled for constant voltage

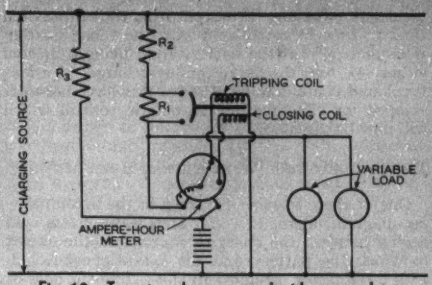


Fig. 12. Two step charge control with ampere-hour meter

Consider now the case where there is a more or less variable steady load with or without intermittent momentary demands as in some telephone installations. If the average value of these combined loads can be predetermined or at least closely approximated, the output of the rectifier or other source of constant current may be adjusted to this average value plus the necessary trickle charge for the battery. The latter will be maintained in a state of charge approaching full charge, but it will of course discharge when the load is greater than the output from the source and will charge when the load is less.

If, however, the load varies in a manner that cannot be predetermined and the fluctuations are appreciable as compared with the ampere-hour capacity of the battery it is important to provide automatic

means for adjusting the output from the source from time to time to correspond with these load fluctuations and prevent the battery from being subjected either to over-discharge or overcharge. Various types and combinations of apparatus have been developed for effecting this automatic control which will now be discussed.

Two Step Control With Ampere-Hour Meter

One of these schemes is shown in the accompanying diagram, figure 12. A 2 step resistance is connected between the charging source and the circuit to which the battery and the load are connected, with a contactor arranged to short-circuit a part of the resistance. An ampere-hour meter is permanently connected into the battery circuit with 2 auxiliary contacts, one at the full charge point and the other at a point corresponding to a certain percentage discharge. The first contact is connected to the tripping coil of the contactor and the second to the closing coil. Thus when the arm of the ampere-hour meter is at zero, indicating that the battery is fully charged, the contactor is tripped open and the minimum current is transmitted from the source. This should be adjusted to give the battery its normal trickle charge rate when the load is at its minimum value. Whenever the load is appreciably greater than this minimum, the battery will discharge until the arm of the ampere-hour meter reaches the second contact, when the contactor will be closed, and the maximum current will be transmitted from the source. This maximum current should be sufficient to insure that the battery will be recharged. This maximum current may be greater or less than the maximum load depending upon the duration of the latter. Thus, if the maximum load is of short duration the maximum current from the source may be considerably less and still recharge the battery when the load is less than its maximum. The ampere-hour meter is adjusted to run slow in the charge direction to provide the necessary overcharge; however, as already pointed out, this adjustment is usually only approximately correct but this inaccuracy may be compensated for by the proper adjustment of the low or trickle charge rate.

As a further refinement, a comparatively high resistance, shown on the diagram at R_3, may be connected to transmit from the source directly to the battery, without passing through the ampere-hour meter, a trickle charge current sufficient to compensate for local action. This arrangement is theoretically correct since the local action current does not register on the ampere-hour meter. The total charging resistance, i. e., the sum of R_1 and R_3, would then be adjusted to provide for the minimum load without any excess.

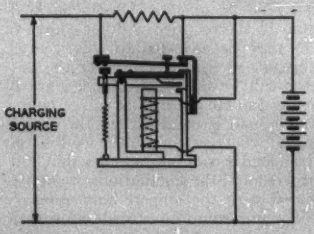


Fig. 13. Temperature compensated relay for 2 step charge control

This ampere-hour meter control of a 2 rate charge has been used successfully in a number of battery installations, but it has certain inherent defects. It necessarily throws on the battery a certain amount of work, at least a part of which could be carried by the source, and as already pointed out, the overcharge adjustment of the ampere-hour meter is only approximate. If set too low, the battery will be starved and a battery failure may result. To guard against this, the tendency will always be to set the overcharge too high. Another difficulty lies in the fact that at very low currents the ampere-hour meter is inaccurate and may fail to register.

Two Step Control With Voltage Relay

Another method of controlling a 2 rate charging scheme is by means of the voltage relay already referred to. The exciting coil of this relay is connected directly across the battery terminals, and when the battery voltage reaches a value corresponding to a point on the charge voltage curve where gassing begins and the voltage rises rapidly, the relay operates to reduce the charging rate from the high to the low value. The battery is not fully charged at this point, but the low rate may be so adjusted that the charge will in time be completed, yet the charge may be continued at this rate without injurious overcharge. It is then necessary to provide for re-establishing the higher rate of charge as may be required, which is accomplished by momentarily opening the circuit of the voltage relay exciting coil. This may be effected by a second relay whose exciting coil is connected into the load circuit, so that whenever the load is thrown on, the higher rate is restored. If the load is thrown on and off manually, as is often the case in telephone service, an auxiliary contact on the load switch may be used.

Another method is to re-establish the higher rate at definite time intervals, regardless of the load. For this purpose a slowly revolving contact-making disk may be employed, driven by a small a-c motor such as is used in electric clocks.

This 2 rate charging scheme controlled by a voltage relay is proving very satisfactory. It automatically adjusts the amount of charge to varying load conditions. If the battery has been subjected to an appreciable amount of discharge, the high-rate charge will be maintained for a longer time before the voltage relay acts than if the discharge has been less.

In a further modification of this method only a single charging rate is provided, sufficient to take care of the maximum requirements, and when the battery voltage reaches the value for which the voltage relay is adjusted, the charge is entirely cut off until it is re-established after a definite time interval by means of the timing device. It is found that even without the trickle charge rate following the high charge rate, the battery can be fully recharged if

the high charge rate is applied at sufficiently frequent intervals even though the voltage relay cuts off the charge at a voltage which would not ordinarily correspond to the fully charged state.

If the battery is subjected to considerable variation of temperature, the voltage relay should be provided with automatic temperature adjustment since the voltage corresponding to a given state of charge with the same charging rate will be higher at lower temperatures. A voltage relay designed for this purpose, with temperature compensation, is shown in figure 13. The temperature compensation is effected by means of a bimetallic strip attached at one end to the armature while the other end bears against a fixed stop. Increase of temperature causes the bimetallic strip to move the armature nearer to the magnet poles, thus reducing the air gap and causing the relay to function at a lower voltage.

In following up these automatic charging schemes, it is necessary to ascertain whether the adjustments of the various factors, such as time intervals, charging rates, and cut off voltage are correct to maintain the battery properly, giving it sufficient charge to make up for the discharges and the losses without an unnecessary amount of overcharge. The accuracy of these adjustments can be determined by 2 observations, first the specific gravity of the electrolyte and second the amount of water required for refilling. If the charge is not sufficient, the specific gravity of the electrolyte will gradually fall off. If the charge is excessive, this will be indicated by an excessive amount of water required for maintaining the level of the electrolyte in the cells. The normal amount of water required for different types of cell over a given period of time can be obtained from the manufacturer as a guide in following up these automatic installations.

The "Float-Meter"

Another device has recently been developed called a "float-meter," designed to indicate the *average* voltage which has been maintained across the battery terminals over a given period of time. In many situations, this floating voltage is subject to appreciable variation at different times of the day or from day to day, and it is quite burdensome or wholly impractical to take voltage readings at sufficiently frequent intervals to determine the true average. This float-meter is of the electrolytic type in which mercury is deposited from a solution of a mercury salt on the cathode from which it drips into a tube of small diameter provided with an appropriate scale indicating the amount of mercury thus deposited in a given length of time. This instrument gives accurate measurements where the current is but a few milliamperes, and by connecting it in series with a high resistance across the battery terminals it indicates *average impressed voltage*. The scale is so chosen that the quotient obtained by dividing the reading by the time interval in hours will equal the average voltage during that interval. (See figure 14.)

This meter must be reset periodically, when the measuring tube becomes filled with mercury, by tilting the tube so as to transfer the mercury to the anode reservoir. These limitations are not, however, seriously objectionable in this particular application.

Control for Automobile Batteries

The design of automatic equipment for charging the starting and lighting battery on an automobile presents some additional problems owing to limitations imposed by considerations of space, cost, and

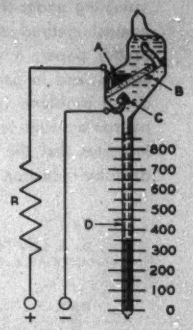


Fig. 14. Schematic diagram of "float-meter" for registering average voltage over a given time period

A - MERCURY ANODE.
B - POROUS GLASS DISC.
C - CATHODE
D - MEASURING TUBE.
R - ZERO TEMPERATURE COEFFICIENT RESISTANCE.

wiring. This problem was not so serious when lighting loads were comparatively small, the battery capacity being determined by the starting requirements. The generator output required to supply the lights and ignition did not constitute a very excessive charging rate for the battery when the lights were turned off, especially in view of the usual characteristic of the third brush generator whereby the output is appreciably reduced at the high speeds usual in prolonged summer touring by daylight. The recent increase in the steady load requirements for radio, more powerful lights, heaters, defrosters, and other accessories has led to marked increase in generator output with little or no increase in battery size to meet starting requirements, and unless provision is made for automatically reducing the output when the battery is full and the load is cut off serious overcharging results. Two kinds of automatic control equipments have recently been developed to take care of this problem. In one, constant voltage regulation is provided for the generator (instead of the constant current characteristic of the third brush machine) modified to prevent generator overload when the battery is in a discharged condition and the load is connected; while the other provides constant current output of 2 different values, controlled by battery voltage and in some cases also by the closing of the load switch. Adjustment of the voltage responsive control devices for winter and summer temperatures is important and is provided in some of these recently developed equipments.

The curves and data given herein are typical or illustrative and subject to variation with differences of cell design such as density and volume of electrolyte, plate thickness and spacing, and composition and distribution of the active material.

An Analysis of the Induction Motor

For problems involving induction motors other than the usual balanced winding type operating under steady-state conditions, a general method of analysis is necessary. In this paper, a general analysis is presented, and in particular, its use in short-circuit problems is described. The comparison between tests and calculated results indicates that the method does properly describe induction motor phenomena.

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THOUGH much has been written about the analysis of induction motors when operating at constant speed and driving a steady load, comparatively little has been published concerning the analysis of induction motors when driving pulsating loads, or when short circuits are applied, or when special cases of winding unbalance occur. (Two papers known to the writer to have dealt with these problems are listed at the end of this paper.) It is the aim of the present paper to present an analysis which makes it possible to deal with any induction motor under any condition of operation, and to present the results obtained in solving several problems involving short circuits on induction motors.

Preliminary Discussion

From the foregoing, it may be correctly inferred that practically any induction motor may be analyzed by the method to be described, but of course, subject to the assumptions which are made in the analysis. Since, obviously, in a paper of this nature it is impossible to deal specifically with all possible induction motors, the method is applied to the balanced 3 phase induction motor. From this, the method by which any other induction motor may be treated will be evident.

For the purpose of determining short-circuit currents, it is sufficient to deal only with relationships of instantaneous voltages, currents, and speed. Thus, this paper may be said to deal with the general $e = iz$ relations of the induction motor; e, i, and z representing, of course, voltage, current, and impedance, respectively.

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General $e = iz$ Relations

Assumptions. The following major assumptions are to be made in the derivation of these general relations.

1. Magnetic saturation is negligible.
2. Core losses are negligible.
3. Changes in resistance due to heating are small.

Derivation. The derivation of the general relations depends entirely upon the following general relation for any electric circuit:

$$e = ri + p\psi 10^{-8} \tag{1}$$

where

e = instantaneous voltage *applied* to the circuit, volts
i = instantaneous current into the circuit from the positive terminal of applied voltage, amperes
r = circuit resistance, ohms
ψ = instantaneous flux linkages with circuit including linkages due to current in coupled circuit such mutual linkages being taken as positive when they are in the same direction as self-linkages due to positive circuit current
p = derivative operator indicating that derivative with time is to be taken.

From the definition of self and mutual inductance, it is evident that equation 1 may be written as

$$e = ri + p(Li) + \sum_n p(M_n i_n) \tag{2}$$

where

Li = self-linkages $\times 10^{-8}$
$M_n i_n$ = mutual linkages $\times 10^{-8}$

and the summation sign is used to indicate that there may be several mutually coupled circuits.

Now, in a 3 phase induction motor, there are 6 electric circuits, 3 on the stator and 3 on the rotor. Each winding has a self-inductance. Mutual inductance exists between stator phases, between rotor phases, and between stator and rotor phases. The self-inductances are substantially constant, the slight variations due to the motion of a slotted rotor by a slotted stator being negligible in effect for a well designed motor. Similarly, the mutual inductance between 2 stator phases or 2 rotor phases is essentially constant.

However, the mutual inductance between a stator phase and a rotor phase is not constant but depends upon the position of the rotor phase with respect to the stator phase. When the magnetic axes of a stator phase and a rotor phase are opposite each other, the mutual inductance is a maximum; when they are displaced $\frac{\pi}{2}$ electrical radians the mutual inductance has a zero value. To a very close approximation, this "across the gap" mutual inductance varies as the cosine of the electrical angle between the magnetic axes of the windings.

In figure 1*a* is shown a circuit diagram of the 3 phase induction motor. In figure 1*b* is shown a diagram of an instantaneous relation between the positions of the magnetic axes of the 6 circuits or windings.

In figure 1*b*, the angle θ is the instantaneous electrical angle in radians between a reference stator

phase and a reference rotor phase, in this case taken to be the a stator phase and the a rotor phase.

From the figures drawn and from the discussion on flux linkage above it follows at once that,

$$\left.\begin{aligned}
10^{-8}\psi_{a1} &= L_1 i_{a1} + M_1 i_{b1} + M_1 i_{c1} + M\cos\theta\, i_{a2} + \\
&\quad M\cos\left(\theta+\frac{2\pi}{3}\right) i_{b2} + M\cos\left(\theta+\frac{4\pi}{3}\right) i_{c2} \\
10^{-8}\psi_{b1} &= M_1 i_{a1} + L_1 i_{b1} + M_1 i_{c1} + \\
&\quad M\cos\left(\theta+\frac{4\pi}{3}\right) i_{a2} + M\cos\theta\, i_{b2} + M\cos\left(\theta+\frac{2\pi}{3}\right) i_{c2} \\
10^{-8}\psi_{c1} &= M_1 i_{a1} + M_1 i_{b1} + L_1 i_{c1} + M\cos\left(\theta+\frac{2\pi}{3}\right) i_{a2} + \\
&\quad M\cos\left(\theta+\frac{4\pi}{3}\right) i_{b2} + M\cos\theta\, i_{c2}
\end{aligned}\right\} \quad (3)$$

$$\left.\begin{aligned}
10^{-8}\psi_{a2} &= L_2 i_{a2} + M_2 i_{b2} + M_2 i_{c2} + M\cos\theta\, i_{a1} + \\
&\quad M\cos\left(\theta-\frac{2\pi}{3}\right) i_{b1} + M\cos\left(\theta-\frac{4\pi}{3}\right) i_{c1} \\
10^{-8}\psi_{b2} &= M_2 i_{a2} + L_2 i_{b2} + M_2 i_{c2} + M\cos\left(\theta-\frac{4\pi}{3}\right) i_{a1} + \\
&\quad M\cos\theta\, i_{b1} + M\cos\left(\theta-\frac{2\pi}{3}\right) i_{c1} \\
10^{-8}\psi_{c2} &= M_2 i_{a2} + M_2 i_{b2} + L_2 i_{c2} + M\cos\left(\theta-\frac{2\pi}{3}\right) i_{a1} + \\
&\quad M\cos\left(\theta-\frac{4\pi}{3}\right) i_{b1} + M\cos\theta\, i_{c1}
\end{aligned}\right\} \quad (4)$$

where

L_1 = self-inductance of a stator phase in henrys
L_2 = self-inductance of a rotor phase in henrys
M_1 = mutual inductance between stator phases in henrys
M_2 = mutual inductance between rotor phases in henrys
M = maximum mutual inductance between any stator phase and any rotor phase

Also from figure 1a, the following relations between currents are seen to exist.

$$\left.\begin{aligned}
i_{a1} + i_{b1} + i_{c1} &= 0 \\
i_{a2} + i_{b2} + i_{c2} &= 0
\end{aligned}\right\} \quad (5)$$

To simplify expressions 3 and 4 the relations 5 are introduced and the trigonometric functions are expanded. The result is written as follows:

$$\left.\begin{aligned}
10^{-8}\psi_{a1} &= (L_1 - M_1) i_{a1} + \\
&\quad \frac{3}{2} M\left[\cos\theta\, i_{a2} - \frac{1}{\sqrt{3}}\sin\theta\,(i_{b2} - i_{c2})\right] \\
10^{-8}\psi_{b1} &= (L_1 - M_1) i_{b1} + \\
&\quad \frac{3}{2} M\left[\cos\theta\, i_{b2} - \frac{1}{\sqrt{3}}\sin\theta\,(i_{c2} - i_{a2})\right] \\
10^{-8}\psi_{c1} &= (L_1 - M_1) i_{c1} + \\
&\quad \frac{3}{2} M\left[\cos\theta\, i_{c2} - \frac{1}{\sqrt{3}}\sin\theta\,(i_{a2} - i_{b2})\right]
\end{aligned}\right\} \quad (6)$$

$$\left.\begin{aligned}
10^{-8}\psi_{a2} &= (L_2 - M_2) i_{a2} + \\
&\quad \frac{3}{2} M\left[\cos\theta\, i_{a1} + \frac{1}{\sqrt{3}}\sin\theta\,(i_{b1} - i_{c1})\right] \\
10^{-8}\psi_{b2} &= (L_2 - M_2) i_{b2} + \\
&\quad \frac{3}{2} M\left[\cos\theta\, i_{b1} + \frac{1}{\sqrt{3}}\sin\theta\,(i_{c1} - i_{a1})\right] \\
10^{-8}\psi_{c2} &= (L_2 - M_2) i_{c2} + \\
&\quad \frac{3}{2} M\left[\cos\theta\, i_{c1} + \frac{1}{\sqrt{3}}\sin\theta\,(i_{a1} - i_{b1})\right]
\end{aligned}\right\} \quad (7)$$

Now, the quantity $L_1 - M_1$ is none other than the apparent self-inductance of the 3 phase induction motor stator winding. It is the stator self-inductance used in the familiar equivalent circuit. Similarly, $L_2 - M_2$ is the apparent 3 phase self-inductance of a rotor winding and $\frac{3}{2}M$ is the apparent mutual or magnetizing inductance. To work in terms of these more familiar constants, the true machine inductances are redefined.

$$\left.\begin{aligned}
L_1 - M_1 &= L_1' \\
L_2 - M_2 &= L_2' \\
\frac{3}{2} M &= M'
\end{aligned}\right\} \quad (8)$$

As will be brought out very soon, the quantities $\psi_{a1} - \psi_{b1}$, $\psi_{b1} - \psi_{c1}$, $\psi_{a2} - \psi_{b2}$, and $\psi_{b2} - \psi_{c2}$, are of interest. Using the new symbols for inductance, and equations 6 and 7,

$$\left.\begin{aligned}
10^{-8}(\psi_{a1} - \psi_{b1}) &= L_1'(i_{a1} - i_{b1}) + \\
&\quad M'\left[\cos\theta\,(i_{a2} - i_{b2}) + \sqrt{3}\sin\theta\, i_{c2}\right] \\
10^{-8}(\psi_{b1} - \psi_{c1}) &= L_1'(i_{b1} - i_{c1}) + \\
&\quad M'\left[\cos\theta\,(i_{b2} - i_{c2}) + \sqrt{3}\sin\theta\, i_{a2}\right]
\end{aligned}\right\} \quad (9)$$

$$\left.\begin{aligned}
10^{-8}(\psi_{a2} - \psi_{b2}) &= L_2'(i_{a2} - i_{b2}) + \\
&\quad M'\left[\cos\theta\,(i_{a1} - i_{b1}) - \sqrt{3}\sin\theta\, i_{c1}\right] \\
10^{-8}(\psi_{b2} - \psi_{c2}) &= L_2'(i_{b2} - i_{c2}) + \\
&\quad M'\left[\cos\theta\,(i_{b1} - i_{c1}) - \sqrt{3}\sin\theta\, i_{a1}\right]
\end{aligned}\right\} \quad (10)$$

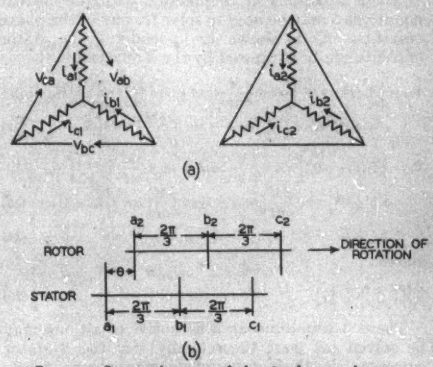


Fig. 1. Circuit diagram of the 3 phase induction motor (above) and an instantaneous relation between the positions of the magnetic axes of the 6 circuits or windings (below)

Using the fundamental relation given in equation 1, the following may be written for each of the motor phases:

$$\left.\begin{aligned}
e_{a1} &= r_1 i_{a1} + p\psi_{a1}\, 10^{-8} \\
e_{b1} &= r_1 i_{b1} + p\psi_{b1}\, 10^{-8} \\
e_{c1} &= r_1 i_{c1} + p\psi_{c1}\, 10^{-8}
\end{aligned}\right\} \quad (11)$$

$$\left.\begin{aligned}
e_{a2} &= r_2 i_{a2} + p\psi_{a2}\, 10^{-8} \\
e_{b2} &= r_2 i_{b2} + p\psi_{b2}\, 10^{-8} \\
e_{c2} &= r_2 i_{c2} + p\psi_{c2}\, 10^{-8}
\end{aligned}\right\} \quad (12)$$

where

r_1 = stator resistance per phase in ohms
r_2 = rotor resistance per phase in ohms

Since the applied voltages are known, the foregoing equations are written in terms of the applied voltages by direct reference to figure 1a:

$$\left.\begin{aligned}
V_{ab} &= e_{a1} - e_{b1} = r_1(i_{a1} - i_{b1}) + p10^{-8}(\psi_{a1} - \psi_{b1}) \\
V_{bc} &= e_{b1} - e_{c1} = r_1(i_{b1} - i_{c1}) + p10^{-8}(\psi_{b1} - \psi_{c1})
\end{aligned}\right\} \quad (13)$$

$$\left.\begin{aligned}
0 &= e_{a2} - e_{b2} = r_2(i_{a2} - i_{b2}) + p10^{-8}(\psi_{a2} - \psi_{b2}) \\
0 &= e_{b2} - e_{c2} = r_2(i_{b2} - i_{c2}) + p10^{-8}(\psi_{b2} - \psi_{c2})
\end{aligned}\right\} \quad (14)$$

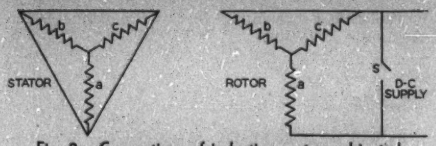


Fig. 2. Connections of induction motors subjected to tests for short-circuit currents

Now using the results of expressions 9 and 10

$$\left.\begin{aligned} V_{ab} &= (r_1 + pL_1')(i_{a1} - i_{b1}) + pM' \left[\cos\theta\,(i_{a2} - i_{b2}) + \sqrt{3}\,\sin\theta\, i_{c2}\right] \\ V_{bc} &= (r_1 + pL_1')(i_{b1} - i_{c1}) + pM' \left[\cos\theta\,(i_{b2} - i_{c2}) + \sqrt{3}\,\sin\theta\, i_{a2}\right] \end{aligned}\right\} \quad (15)$$

$$\left.\begin{aligned} 0 &= (r_2 + pL_2')(i_{a2} - i_{b2}) + pM' \left[\cos\theta\,(i_{a1} - i_{b1}) - \sqrt{3}\,\sin\theta\, i_{c1}\right] \\ 0 &= (r_2 + pL_2')(i_{b2} - i_{c2}) + pM' \left[\cos\theta\,(i_{b1} - i_{c1}) - \sqrt{3}\,\sin\theta\, i_{a1}\right] \end{aligned}\right\} \quad (16)$$

These equations in conjunction with the current equations 5 may be used to solve for any of the phase currents. As is shown in appendix I the stator currents can be expressed by the 3 relations

$$V_{ab} = \left\{Z_1(p) - pM'\left[\cos\theta\,\frac{pM'}{Z_2(p)}\cos\theta + \sin\theta\,\frac{pM'}{Z_2(p)}\sin\theta\right]\right\}(i_{a1} - i_{b1}) + \sqrt{3}\,pM'\left\{\cos\theta\,\frac{pM'}{Z_2(p)}\sin\theta - \sin\theta\,\frac{pM'}{Z_2(p)}\cos\theta\right\} i_{c1} \quad (22)$$

$$V_{bc} = \left\{Z_1(p) - pM'\left[\cos\theta\,\frac{pM'}{Z_2(p)}\cos\theta + \sin\theta\,\frac{pM'}{Z_2(p)}\sin\theta\right]\right\}(i_{b1} - i_{c1}) + \sqrt{3}\,pM'\left\{\cos\theta\,\frac{pM'}{Z_2(p)}\sin\theta - \sin\theta\,\frac{pM'}{Z_2(p)}\cos\theta\right\} i_{a1} \quad (23)$$

$$i_{a1} + i_{b1} + i_{c1} = 0 \quad (24)$$

where

$$\left.\begin{aligned} Z_1(p) &= r_1 + pL_1' \\ Z_2(p) &= r_2 + pL_2' \end{aligned}\right\} \quad (25)$$

These 3 simultaneous differential equations may be solved (at least theoretically) for the 3 stator currents. In these equations instantaneous values of motor currents, motor voltage, and motor speed are related, subject to the restrictions already stated. They then are the general $e = iz$ relations.

Short-Circuit Currents

To illustrate the use of these general relations, problems involving short circuits of induction motors turning at constant speed are considered. The transient currents attendant upon induction motor short circuits decay to a very small value in a short time. It is reasonable to consider that the rotor turns at constant speed during this time, the speed which it had at the instant before short-circuit. Thus, the first step in determining the short-circuit currents is to reduce the general relations to the constant speed relations.

From the definition of the angle θ it follows that,

$$\theta = \alpha + \int_0^t u\,dt = \alpha + ut \quad (26)$$

where

t is measured from the instant of short circuit
α = initial angle between phase a of stator and phase a of rotor
u = constant rotor speed in electrical radians per second

If this value of θ is introduced into equations 22, there results,

$$V_{ab} = \left\{Z_1(p) - M'^2\left[\frac{p(p+ju)}{Z_2(p+ju)} + \frac{p(p-ju)}{Z_2(p-ju)}\right]\right\}(i_{a1} - i_{b1}) + \frac{\sqrt{3}}{2j}\,M'^2\left[\frac{p(p+ju)}{Z_2(p+ju)} - \frac{p(p-ju)}{Z_2(p-ju)}\right] i_{c1} \quad (27)$$

The equation corresponding to equation 23 is obvious. Lack of space does not permit including the detailed procedure involved in obtaining equation 27 from equations 22 and 26.

At this point 2 fundamental motor impedances are defined; they should be noted carefully.

$$Z_{P1}(p) = Z_1(p) - M'^2\,\frac{p(p-ju)}{Z_2(p-ju)} \quad (28)$$

$$Z_{B1}(p) = Z_1(p) - M'^2\,\frac{p(p+ju)}{Z_2(p+ju)} \quad (29)$$

If a descriptive equivalent is required for these definitions they may be described as,

$Z_{P1}(p)$ = generalized constant speed positive phase sequence impedance of an induction motor viewed from the stator
$Z_{B1}(p)$ = generalized constant speed negative phase sequence impedance of an induction motor viewed from the stator

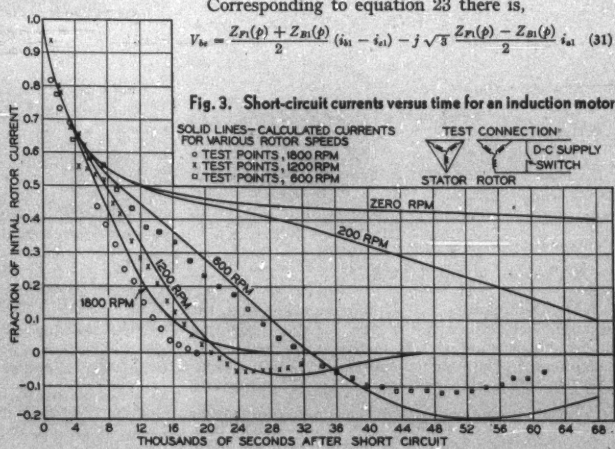
Substituting equations 28 and 29 into equation 27 there results

$$V_{ab} = \frac{Z_{P1}(p) + Z_{B1}(p)}{2}\,(i_{a1} - i_{b1}) - j\sqrt{3}\,\frac{Z_{P1}(p) - Z_{B1}(p)}{2}\,i_{c1} \quad (30)$$

Corresponding to equation 23 there is,

$$V_{bc} = \frac{Z_{P1}(p) + Z_{B1}(p)}{2}\,(i_{b1} - i_{c1}) - j\sqrt{3}\,\frac{Z_{P1}(p) - Z_{B1}(p)}{2}\,i_{a1} \quad (31)$$

Fig. 3. Short-circuit currents versus time for an induction motor



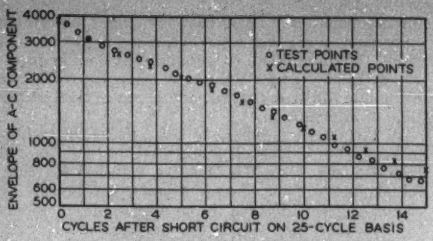


Fig. 4. Short-circuit current versus time for a Scherbius frequency converter

12,500 kva set, self-excited
External short circuit impedance equals 20 per cent reactance and 9.75 per cent resistance

The third equation completing the simultaneous set is of course equation 24.

The voltages applied to the motor stator are, for such cases as a simultaneous 3 phase short circuit,

$$V_{ab} = V_s e^{j\omega t} e^{j\beta} (1 - 1) \tag{32}$$

$$V_{bc} = V_s e^{j\omega t} e^{j\beta} \epsilon^{-j2\pi/3} (1 - 1) \tag{33}$$

where

V_s = peak value of line voltage, volts
ω = frequency of line voltage, electrical radians per second
β = initial electrical angle of voltage wave measured in electrical radians from positive peak of voltage
1 = unit function, a function whose value is zero for negative time and unity for positive time. Thus V_{ab} is the applied voltage for negative time and is zero for positive time indicating a sudden short circuit at time $t = 0$

By writing the voltages as in equations 32 and 33, it is inferred that only the real part of a solution involving these voltages is to be kept. Substituting them into the general constant speed relations of equations 30 and 31 and solving for the phase currents there results,

$$i_{a1} = \frac{V_s e^{j\omega t} e^{j\beta} \epsilon^{-j\pi/6}}{\sqrt{3}} \frac{1}{Z_{P1}(p + j\omega)} (1 - 1) \tag{34}$$

This equation is readily solved for the short-circuit current in phase a.

Tests for Short-Circuit Current

In a series of tests made by the writer, a 3 phase induction motor was connected as shown in figure 2.

The rotor was driven at some constant speed and then switch S was closed. The transient current in phase a of the rotor was recorded by an oscillograph. The curves of figure 3 show the comparison between test and calculated results. The analysis was made using the procedure already described, merely solving for the rotor currents instead of stator currents, and considering that a rotor voltage was impressed.

As another example of the use of this analysis, figure 4 indicates a comparison of test and calculated short-circuit currents for a self-excited Scherbius frequency changer. In making this analysis, it is necessary not only to include the effect of short-circuiting the stator terminals but also the effect of the transient voltage impressed on the rotor must be considered.

Appendix I—Derivation of General Equations for Stator Currents

The following equations, 15, 16, and 5, are derived in the body of the report:

$$\left.\begin{aligned} V_{ab} &= (r_1 + pL_1')(i_{a1} - i_{b1}) + pM' [\cos\theta\,(i_{a2} - i_{b2}) + \sqrt{3}\sin\theta\, i_{c2}] \\ V_{bc} &= (r_1 + pL_1')(i_{b1} - i_{c1}) + pM' [\cos\theta\,(i_{b2} - i_{c2}) + \sqrt{3}\sin\theta\, i_{a2}] \end{aligned}\right\} \tag{15}$$

$$\left.\begin{aligned} 0 &= (r_2 + pL_2')(i_{a2} - i_{b2}) + pM' [\cos\theta\,(i_{a1} - i_{b1}) - \sqrt{3}\sin\theta\, i_{c1}] \\ 0 &= (r_2 + pL_2')(i_{b2} - i_{c2}) + pM' [\cos\theta\,(i_{b1} - i_{c1}) - \sqrt{3}\sin\theta\, i_{a1}] \end{aligned}\right\} \tag{16}$$

$$\left.\begin{aligned} i_{a1} + i_{b1} + i_{c1} &= 0 \\ i_{a2} + i_{b2} + i_{c2} &= 0 \end{aligned}\right\} \tag{5}$$

For conciseness of notation the following 2 impedance functions are introduced.

$$\left.\begin{aligned} Z_1(p) &= r_1 + pL_1' \\ Z_2(p) &= r_2 + pL_2' \end{aligned}\right\} \tag{17}$$

and from equations 16 and 5

$$\left.\begin{aligned} i_{a2} - i_{b2} &= -\frac{pM'}{Z_2(p)} [\cos\theta\,(i_{a1} - i_{b1}) - \sqrt{3}\sin\theta\, i_{c1}] \\ i_{b2} - i_{c2} &= -\frac{pM'}{Z_2(p)} [\cos\theta\,(i_{b1} - i_{c1}) - \sqrt{3}\sin\theta\, i_{a1}] \\ i_{a2} + i_{b2} + i_{c2} &= 0 \end{aligned}\right\} \tag{18}$$

From equation 18:

$$i_{c2} = \frac{\begin{vmatrix} -\frac{pM'}{Z_2(p)} [\cos\theta\,(i_{a1} - i_{b1}) - \sqrt{3}\sin\theta\, i_{c1}] & -1 & 0 \\ -\frac{pM'}{Z_2(p)} [\cos\theta\,(i_{b1} - i_{c1}) - \sqrt{3}\sin\theta\, i_{a1}] & 1 & -1 \\ 0 & 1 & 1 \end{vmatrix}}{\begin{vmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ 1 & 1 & 1 \end{vmatrix}} \tag{19}$$

$$i_{c2} = -\frac{pM'}{Z_2(p)} \left[\cos\theta\, i_{c1} + \frac{1}{\sqrt{3}} \sin\theta\,(i_{b1} - i_{c1}) \right] \tag{20}$$

Similarly

$$i_{a2} = -\frac{pM'}{Z_2(p)} \left[\cos\theta\, i_{a1} + \frac{1}{\sqrt{3}} \sin\theta\,(i_{a1} - i_{b1}) \right] \tag{21}$$

Substituting equations 18, 20, and 21 into 15

$$\begin{aligned} V_{ab} = \Big\{ Z_1(p) - pM' \cos\theta \frac{pM'}{Z_2(p)} \cos\theta + pM' \sin\theta \frac{pM'}{Z_2(p)} \sin\theta \Big\} \times \\ (i_{a1} - i_{b1}) + \sqrt{3} \Big\{ pM' \cos\theta \frac{pM'}{Z_2(p)} \sin\theta - \\ pM' \sin\theta \frac{pM'}{Z_2(p)} \cos\theta \Big\} i_{c1} \end{aligned} \tag{22}$$

$$\begin{aligned} V_{bc} = \Big\{ Z_1(p) - pM' \cos\theta \frac{pM'}{Z_2(p)} \cos\theta + pM' \sin\theta \frac{pM'}{Z_2(p)} \sin\theta \Big\} \times \\ (i_{b1} - i_{c1}) + \sqrt{3} \Big\{ pM' \cos\theta \frac{pM'}{Z_2(p)} \sin\theta - \\ pM' \sin\theta \frac{pM'}{Z_2(p)} \cos\theta \Big\} i_{a1} \end{aligned} \tag{23}$$

References

1. Transient Conditions in Electric Machinery, W. V. Lyon. A.I.E.E. Trans., v. 42, 1923, p. 157–76.

2. Sudden Short Circuit of Alternator, Bekku. Research No. 203 of the Electrotechnical Laboratory, Tokyo, 1927.

The Determination of Circuit Recovery Rates

Actual interruption of an a-c circuit depends upon the ability of the circuit breaker to prevent the re-establishment of the arc after the current goes through zero and the arc goes out. In some circuits full voltage appears across the contacts as quickly as 40 to 80 microseconds following the current zero. This recovery rate in volts per microsecond depends upon the triple product of: the current interrupted, the normal frequency of the system, and the recovery impedance in ohms of the external circuit. The calculation of circuit recovery rates is given in this paper by presenting in curve and table form the ohmic recovery impedance, and its components, for all the practical circuits found in the field.

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THE recovery voltage rate of an a-c power circuit is the term given to the rate, in volts per microsecond, at which the voltage rises across the terminals of a circuit breaker immediately following the interruption of current by that breaker. The introduction of the knowledge of circuit breaker recovery voltages and the speed with which these voltages can appear has played an important rôle in correlating a group of seemingly unrelated phenomena regarding circuit breaker performance. Space will not permit here the enumeration of the many cases in which circuit breakers of similar design and apparently under similar conditions have behaved so differently, only to find on investigation that the respective recovery rates were different, explaining quite satisfactorily their behavior. When a breaker is reported to be having difficulty in clearing the circuit, exhibiting these difficulties by throwing oil or by producing abnormally long arc lengths, from experience it has been found that the recovery rates for the circuit attached to such a breaker are usually abnormally high. In the past, the problem has masked itself behind other seemingly unimportant details. A single breaker, for example, will appear almost human in its behavior, sometimes performing very nicely and other times exhibiting a great deal of grief. When studied, it is found that 2 or more recovery rates exist for the one breaker, the difference being due to the particular circuit connections at the time of interruption.

In the recent purchase of the 3-cycle 287-kv impulse (piston driven oil blast) breakers for the 270 mile Boulder Dam-Los Angeles transmission line, the engineers of the bureau of power and light, city of Los Angeles, included in the breaker specifications the recovery rate which the breakers must withstand. The breaker performance was predetermined[1] from equations, developed over a period of years, employing recovery rate as one of the most important criterions for high speed circuit interruption. Completed tests on these and other impulse breakers have been quite satisfactory, which fact lends the greatest support to the correctness of the theory and design. In the summary of these tests[1] the relation between recovery rate and oil pressure stands out as the most striking and useful correlation supporting both qualitatively and quantitatively the correctness of this principle of circuit interruption.

Realizing the importance of this problem, it is the object of this paper to present a method of predetermining recovery rates and at the same time to discuss the physics or mechanics of the problem whenever necessary. The method presented herein was developed in a special effort to simplify the calculation without sacrifice of accuracy. The method will be found particularly useful in a mass determination of the recovery rates for a complete high or low voltage system, and will enable a close comparison of recovery rate for various circuits in such a system. The concept of recovery impedance has been introduced as a definite ohmic factor which defines the severity of the circuit or circuits in which the breaker is to be placed. In short, the recovery impedances for all practical circuits encountered in the field are calculated and appear in curve form in this paper. Their intelligent use will permit the rapid determination of recovery rates, the accuracy of the result being dependent upon the accuracy of the assumed circuit. These questions will be discussed below.

Recovery Voltages—Hydraulic Analogy

Imagine a large water wheel runner driving a generator under full load. Should the butterfly valve at the bottom of the penstock be suddenly closed, the velocity flow v of the penstock water of mass M would be suddenly interrupted. The stored energy in this body of water ($^1/_2Mv^2$) would no longer have its normal outlet in the load of the water wheel runner and the result would be that an enormous force F would be built up at the valve. This force would be limited only by the combined elastic properties C of the water, adjacent penstock and valve. Should this force reach such proportions as to exceed the mechanical limit of the valve, causing the valve to burst, the flow would be continued and the valve would have failed to interrupt the flow

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1. For all numbered references see list at end of paper.

due to the high recovery pressure of the circuit.

Should a circuit breaker feeding a heavy d-c current be suddenly opened, the current flow I would be suddenly interrupted. The stored energy in the inductance L of the circuit ($^1/_2LI^2$) would no longer have its normal outlet in the load of the system and the result would be that a very high voltage V would be built up at the circuit breaker terminal. This voltage would be limited only by the electrical elastance or capacitance C of the adjacent circuit. Should this voltage reach such proportions as to exceed the insulation strength of the opening breaker, causing a flashover between the contacts, the current flow I would be continued and the breaker would have failed to interrupt the current due to the high recovery voltage of the circuit.

The above analogy is not only figuratively correct but mathematically the 2 problems are the same. In the d-c circuit the problem is 2-fold, not only must the magnitude of the recovery voltage be

Table I—Average Values of Circuit Constants Which Depend Upon the System and Nature of the Fault

Type of Fault	k_d	k_g	k_q	$k_0 = k_d k_g k_q$	$k = 1.028\ k_0$
One line to ground	1.0	1.0	1.0	1.0	1.028
Two line to ground	1.0	Approx. 1.73	1.0	Approx. 1.73	Approx. 1.78
Line to line	1.0	1.73	1.0	1.73	
Three phase short circuit	1.0	0.9 to 1.05	1 to 1.05	1.02	1.05
Three phase ungrounded short circuit or grounded short circuit on an ungrounded system	1.0	1.5	1.0 to 1.1	1.5	1.54

restricted but also the rate at which this voltage appears must be kept as low as possible. In the a-c circuit, fortunately, the current passes through zero twice each cycle and normal circuit interruption occurs at such a current zero, with the result that the magnitude inherently cannot exceed twice the crest value of the normal voltage; however, the rate at which this voltage recovers is quite important, as the breaker is endeavoring to establish insulation between the contacts immediately following interruption. The criterion for satisfactory interruption, therefore, is that at all times the recovery of insulation strength exceeds the recovery of voltage to the extent that no breakdown occurs during this period to re-establish the arc.

Type of Fault

The rate of rise of recovery voltage for the first phase to clear depends upon the magnitude of the normal frequency recovery voltage. Park and Skeats[2] give for the maximum voltage of the first phase to clear:

$$E_m = k_g \cdot k_d \cdot k_q \cdot E$$

where

k_g depends upon the ground conditions
k_d = decrement factor
k_q = quadrature reactance factor
E = normal phase voltage

Grouping these constants into one constant k_0, we have:

$$E_m = k_0 \cdot E$$

Table I gives the average values of these constants for various types of faults. For a more complete discussion of these constants the reader is referred to the above reference.[2]

Nomenclature

The following nomenclature will be used throughout this paper:

E = normal voltage—line to line
f = normal system frequency
ω = $2\pi f$
L = inductance which limits the short circuit current
I = root-mean-square short-circuit current in amperes
C = electrostatic capacitance
f_n = natural frequency
$\omega_n = 2\pi f_n = \frac{1}{\sqrt{L_n C_n}}$
rr = recovery rate in volts per microsecond
$Z_n = \sqrt{\frac{L_n}{C_n}}$ = impedance in ohms
Z_r = recovery impedance in ohms
k = circuit constants. (See table I.)

The maximum recovery rate is defined as "the slope of steepest line which can be drawn from the point of interruption to any point on the recovery voltage oscillations." See figures 2 and 7.

Interruption is assumed to occur at a normal current zero. The faults are assumed totally reactive;

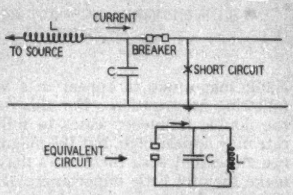


Fig. 1. A field condition which may be approximated by a single frequency equivalent circuit

i. e., zero power factor. Only the case of a symmetrical current is considered as this gives the maximum recovery rate. No factor has been included for the decrement of the recovery voltage. This phenomena tends to reduce the recovery rate several per cent.

Effect of Circuit Breaker

In this paper recovery rates are calculated without including any of the effects of the circuit breaker itself upon the recovery rate. This practice has been tentatively agreed to among the various manufacturers for the following reasons:

1. Inasmuch as the circuit breaker is solely a device to interrupt the circuit, regardless of how it accomplishes this feat, it would be unjust to rob the breaker of any of its qualities by imposing a recovery rate specification, which included the effect of the breaker itself. In other words, if any breaker has the property through high

electrostatic capacitance, arc drop, conducting properties after interruption, or any other incorporated scheme to reduce materially the severity of any test below the severity of the test circuit alone and in this way help to accomplish interruption, such a reduction will be credited to the breaker and the test record will state that the breaker has withstood the severity of the external test circuit.

2. This allows the recovery impedance, which is a measure of circuit severity, to become a straightforward circuit calculation independent of all the effects of the breaker.

In this connection it must be kept in mind that high recovery rate in itself can do no harm, and is only important when it allows voltages of appreciable magnitude to appear in a very short period following interruption. For this reason, in some of the double frequency cases to follow the recovery rate may appear high, but the magnitude of the voltage associated with these rates may be so low as to make them of little importance. This point will be discussed later.

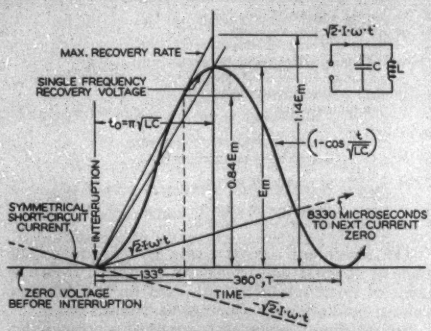


Fig. 2. Composite diagram showing the nature of the recovery voltage for the circuit of figure 1. Maximum recovery rate is shown

When L = 0.16 henrys and C = 0.01 microfarads, then t_0 = 126 microseconds

Single Frequency Recovery Voltage

In many cases the recovery voltage circuit can be represented by a single frequency circuit, as shown in figure 1. Consider the above fault to be on a 110-kv grounded 60-cycle system. With a short-circuit of 200,000 kva, the inductance limiting the current is 0.16 henrys. The symmetrical value of the short-circuit current is 1,050 amperes. An analysis of the circuit has shown that the total effective electrostatic capacitance C to ground between the circuit breaker and the current limiting inductance is about 0.01 microfarad. The equivalent circuit of this condition is shown in figure 1.

The artifice[8] employed in calculating the recovery voltage in this and all recovery rate problems (see figure 2) is to introduce at the current zero at which interruption occurs, a current equal and opposite to the short-circuit current which would have continued to flow had interruption not taken place. The resultant of these 2 currents is zero and satisfies the condition of interruption. As the only factor which is of interest is the maximum rate of rise immediately following interruption, all of which usually takes place within several hundred microseconds, the assumption that the current change during this period is linear introduces a negligible error. The current which is applied to the circuit is, therefore:

$$i = \sqrt{2} \cdot I \cdot \omega \cdot t \tag{1}$$

where

$\sqrt{2}\,I$ = crest value of the short-circuit current
$\omega = 2\pi f = 377$
t = time in seconds

It is interesting to note here that the slope of the current which generates the recovery voltage is:

$$i/t = \sqrt{2} \cdot I \cdot \omega \cdot 10^{-6} \text{ amperes per microsecond} \tag{2}$$

Introducing the current of equation 1 in the circuit of figure 1, the resultant voltage will be:

$$V_r = \sqrt{2} \cdot I \cdot \omega \cdot L(1 - \cos bt) \text{ volts} \tag{3}$$

where

$$b = \frac{1}{\sqrt{LC}} \tag{4}$$

and

V_r = recovery voltage

The form of this voltage is shown in figure 2. By inspection the product $I \cdot \omega \cdot L$ is recognized as the rated root mean square voltage to ground. The crest value of the above recovery voltage is, therefore:

$$V_{r(\max)} = 2\sqrt{2} \cdot I \cdot \omega \cdot L \text{ volts} \tag{5}$$

and occurs at a time:

$$t = \pi\sqrt{LC}\, 10^6 \text{ microseconds} \tag{6}$$

Hence the rate of recovery of the *crest voltage* in this case would be:

$$rr = \left\{ \frac{2 \cdot \sqrt{2} \cdot I \cdot \omega \cdot L}{\pi\sqrt{LC}} \right\} 10^{-6} \text{ volts per microsecond} \tag{7}$$

The maximum rate of rise for single frequency cases is 1.14 times that given by equation 7. A study of figure 2 will make this clear. Introducing this value and simplifying, there results:

$$rr = 1.028 \cdot I \cdot \omega \cdot \sqrt{\frac{L}{C}}\; 10^{-6} \text{ volts per microsecond} \tag{8}$$

For the above example, $k_0 = 1$, and this value is 1,630 volts per microsecond, which is a relatively high recovery rate. Properly interpreted, it says that in 93 microseconds after interruption 151,000 volts was available across the contacts in an effort to rekindle the arc and prevent interruption.

Equation 8 above is worthy of study. The circuit factor $\sqrt{\frac{L}{C}}$ appears and is here termed the recovery impedance of the circuit. It is purely ohmic in value and is that value which when multiplied by the

short-circuit current and system constants gives the recovery rate. In the above case it has a value of 4,000 ohms. The dimensional relationships between equations 8 and 2 should be closely studied.

Adopting the notation:

$$\sqrt{\frac{L}{C}} = Z_r = \text{recovery impedance in ohms} \tag{9}$$

Then the recovery rate formula becomes:

$$rr = k \cdot I \cdot \omega \cdot Z_r \cdot 10^{-6} \text{ volts per microsecond} \tag{10}$$

For values of k, see right-hand column of table I.

If all recovery rate problems dealt with the simple single frequency circuit here analyzed, the above equations might be used and this discussion would terminate at this point. Study shows that the above circuit will represent only the very simple cases, these

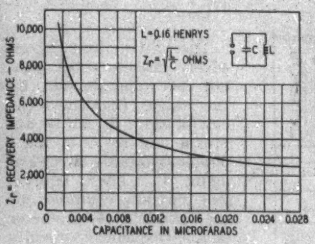


Fig. 3. Relationship between capacitance and recovery impedance for a single frequency recovery voltage

cases usually involving only a transmission line, and except where reactors are critically located, the recovery rates are quite low. The majority of circuits which are of real interest, those in the high recovery rate class, cannot be represented by a single frequency circuit, it requiring at least a double frequency circuit to give a close approximation.

It is when attention is transferred from the single frequency circuits to the double frequency circuits, the concept of recovery impedance is found particularly adaptable. In short, it has been found that for all practical double frequency recovery voltage circuits, the recovery impedance is determinable and still retains the desirable ohmic properties that it had in the single frequency case. This allows the adoption, for all circuits, of the simple formula:

$$rr = K \cdot I \cdot \omega \cdot Z_r \cdot 10^{-6} \text{ volts per microsecond} \tag{11}$$

To the system engineer all the factors will be known except the recovery impedance and he can set about to determine this impedance for any particular circuit condition. This impedance, being expressed in ohms and ranging from 30 ohms to 10,000 ohms or higher, lends itself readily to interpretation. It is the accurate criterion for comparing one circuit with another independently of the current which is being interrupted. The recovery impedances for all double frequency circuits encountered in recovery rate problems have been calculated and appear in curve form in this paper. They will now be discussed.

Recovery Circuits—General

The major problem in accurately determining recovery rates lies in the selection of the circuit and the constants to be used. At best, the circuits given in this paper, when used for recovery rate calculations, are only approximations. They are the practical lumped circuit equivalents of the circuits connected to the breaker terminals and describe roughly the manner in which the electrostatic capacitances are distributed among the inductances of the circuit. The selection of the proper circuit to be used in any particular case and the value of the constants to be used to approximate the recovery circuit conditions is a matter of experience. No small part of this selection concerns just what parts of the circuit are important and what parts may be neglected without materially affecting the ultimate solution. A plot of the dependence of recovery impedance upon the electrostatic capacitance in the single frequency case already described is shown in figure 3. This

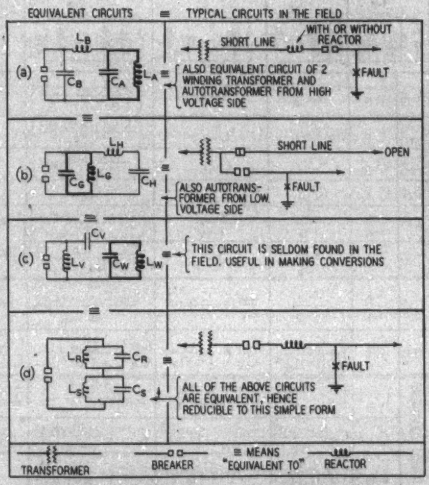


Fig. 4. Four double frequency equivalent circuits with one representative field condition. All of the above equivalent circuits are equivalent to each other and reducible to the simple form of (d)

curve shows the importance of determining the electrostatic capacitance as accurately as possible, especially when this capacitance is small.

The accumulation of data, particularly the effective electrostatic capacitances of electrical equipment, has been in progress for some time.[2,6,7] In many of the simpler cases of lines, cables, busses, bushings, reactors, etc., these constants are well known and calculations may be made readily. The major source of reliable data for the more compli-

cated equipment such as transformers and rotating equipment, especially when studied in the field, comes from the cathode ray oscillograph. These tests not only determine the particular recovery rates by actual measurement, but play an all-important part in establishing the effective constants of circuits consisting of a multiplicity of equipment. It is not within the scope of this paper to enlarge upon the problem of the circuit selection and constants, but to proceed on the assumption that these selections have been made and the approximate circuits formed. It is hoped that the calculations here presented will prove useful to the extent of creating a greater interest in a more accurate determination of these constants as related to circuit breaker performance.

Table II—Master Table Giving in Compact Form the Equivalent Relationships for Determining Frequencies, Magnitudes, and Recovery Impedance. Conversion Equations to the AB Circuit Also Appear in This Table

1. General Use: All curves may be entered with n_o and m_o to determine frequencies, magnitudes, or recovery impedance for all circuits shown in this table. When so used the following relations hold:

$\omega_R = \omega_B/K_B$, $L_R = J_B L_A$, Recovery Impedance $= Z_A = W_T Z_B$ (See figure 7)

$\omega_S = K_S \cdot \omega_A$, $L_S = J_S L_A$, Recovery Rate $= k \cdot I \cdot \omega \cdot Z_c\, 10^{-4}$ volts/microsecond (See text)

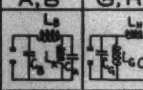
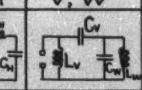
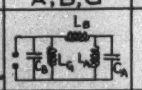
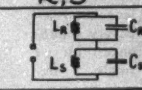
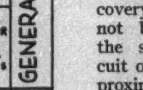
2. The frequencies of all the circuits may be determined by entering frequency curves (figure 5) with either n and m or n_o and m_o. When so used the following relations hold:

If entered with n and m:

$$\left.\begin{aligned}\omega_R &= \omega_m/K_B\\ \omega_B &= K_B \cdot \omega_n\end{aligned}\right\}\ \text{where}\ \begin{aligned}\omega_n &= \frac{1}{\sqrt{L_B C_n}}\\ \omega_m &= \frac{1}{\sqrt{L_m C_m}}\end{aligned}$$

If entered with n_o and m_o

$$\omega_R = \omega_B/K_B \qquad \omega_S = K_S \cdot \omega_A$$

A,B	G,H	V,W	A,B,G	R,S	GENERAL
					
$L_n = L_A$	L_G	L_W	$\left\{\frac{L_G(L_A+L_B)}{L_G+L_A+L_B}\right\}$	L_R or L_S *	L_n
$L_m = L_B$	L_H	L_V	$\left\{\frac{L_B(L_A+L_B)}{L_A}\right\}$	L_S or L_R	L_m
$C_m = C_B$	C_H	C_V	$\left\{\frac{C_A L_A^2}{(L_A+L_B)^2}\right\}$	C_S or C_R	C_m
$C_n = C_A$	C_G	C_W	C_B	C_R or C_S	C_n
$n = \frac{L_B}{L_A}$	$\frac{L_H}{L_G}$	$\frac{L_V}{L_W}$	$\left\{\frac{L_B(L_A+L_B+L_G)}{L_A L_G}\right\}$	$W_R = \frac{1}{\sqrt{L_R C_R}}$	$\frac{L_m}{L_n}$
$m = \frac{C_B}{C_A}$	$\frac{C_H}{C_G}$	$\frac{C_V}{C_W}$	$\frac{C_A}{C_B}\left(\frac{L_A}{L_A+L_B}\right)^2$	$W_S = \frac{1}{\sqrt{L_S C_S}}$	$\frac{C_m}{C_n}$
$n_o = \frac{L_B}{L_A}$	$\frac{L_H}{L_G}$	$\frac{L_W}{L_V}(1+\frac{C_W}{C_V})^2$	$\frac{L_B(L_A+L_B+L_G)}{L_A L_G}$	$\left\{\frac{\sqrt{L_R L_S}(C_R+C_S)}{L_R C_R - L_S C_S}\right\}^2$ *	$\frac{L_B}{L_A}$
$m_o = \frac{C_B}{C_A}$	$\frac{C_G}{C_H[1+n_o]^2}$	$\frac{C_W}{C_V}\left(\frac{1}{1+n_o}\right)^2$	$\frac{C_B}{C_A}\frac{(1+\frac{L_B}{L_A})^2}{(1+n_o)^2}$	$\left(\frac{\sqrt{C_R C_S}(L_R+L_S)}{L_R C_R - L_S C_S}\right)^2 \frac{1}{(1+n_o)^2}$	$\frac{C_B}{C_A}$
Conversion Equations: $L_A =$	$L_G\left(\frac{L_G}{L_H+L_G}\right)$	$L_V\left(\frac{1}{1+n_o}\right)$	$L_n\left(\frac{L_n}{L_n+L_m}\right)$	$(L_R+L_S)\left(\frac{1}{1+n_o}\right)$	L_A
$C_A =$	$C_H\left(\frac{L_H+L_G}{L_G}\right)^2$	$\frac{C_V^2}{C_V+C_W}(1+n_o)^2$	$C_m\left(\frac{L_n+L_m}{L_n}\right)^2$	$\frac{C_B}{m_o}$	C_A
$L_B =$	$L_H\left(\frac{L_G}{L_H+L_G}\right)$	$L_V\left(\frac{n_o}{1+n_o}\right)$	$L_m\left(\frac{L_n}{L_n+L_m}\right)$	$n_o L_A$	L_B
$C_B =$	C_G	$\left(\frac{C_V C_W}{C_V+C_W}\right)$	C_n	$\left(\frac{C_R C_S}{C_R+C_S}\right)$	C_B
$Z_A = \sqrt{\frac{L_A}{C_A}}$	$\sqrt{\frac{L_G}{C_H}\left(\frac{L_G}{L_H+L_G}\right)^3}$	$\sqrt{\frac{L_A}{C_A}}$	$\sqrt{\frac{L_n}{C_m}\left(\frac{L_n}{L_n+L_m}\right)^3}$	$\sqrt{\frac{L_A}{C_A}}$	$\sqrt{\frac{L_A}{C_A}}$
$Z_B = \sqrt{\frac{L_B}{C_B}}$	$\sqrt{\frac{L_H}{C_G}\left(\frac{L_G}{L_H+L_G}\right)}$	$\sqrt{\frac{L_B}{C_B}}$	$\sqrt{\frac{L_m}{C_n}\left(\frac{L_n}{L_n+L_m}\right)}$	$\sqrt{\frac{L_B}{C_B}}$	$\sqrt{\frac{L_B}{C_B}}$
$W_A = \frac{1}{\sqrt{L_A C_A}}$	$\frac{1}{\sqrt{C_H(L_H+L_G)}}$	$\sqrt{\frac{(C_V+C_W)}{L_V C_V^2(1+n_o)}}$	$\frac{1}{\sqrt{C_m(L_m+L_n)}}$	$\frac{1}{\sqrt{L_A C_A}} = \frac{1}{\sqrt{L_n C_n}}$ or	$\frac{1}{\sqrt{L_A C_A}}$
$W_B = \frac{1}{\sqrt{L_B C_B}}$	$\sqrt{\frac{(L_H+L_G)}{L_H \cdot L_G \cdot C_G}}$	$\frac{1}{\sqrt{L_B \cdot C_B}}$	$\sqrt{\frac{(L_n+L_m)}{L_m \cdot L_n \cdot C_n}}$	$\frac{1}{\sqrt{L_B C_B}} = \frac{1}{\sqrt{L_m C_m}}$ or	$\frac{1}{\sqrt{L_B C_B}}$

*Values so chosen that $L_R \cdot C_R$ is greater than $L_S \cdot C_S$. When $L_R C_R = L_S C_S$ use special equations in appendix.

Double Frequency Circuits

The vast majority of recovery circuits which cannot be approximated by the single frequency circuit of figure 1 can be approximated by 1 of the 4 double frequency circuits of figure 4. These equivalent circuits comprise all the possible 4-parameter double-frequency circuits (neglecting resistance) which will be encountered in the study of recovery rates. They comprise one class, all having in common a final through inductance path from the breaker terminals uninterrupted by capacitance necessary for the flow of current; as well as an initial through capacitance path from the breaker terminals uninterrupted by inductance which is imperative to the nature of the phenomena. Each of these circuits contain the simple coupled parameters of figure 1 (as shown in heavy lines) and for study these parameters in all circuits will be given the subscript *n*. Thus:

$$L_n = L_A, L_G, L_W, L_R \qquad (12)$$

$$C_n = C_A, C_G, C_W, C_R \qquad (13)$$

The 2 remaining parameters will be given the subscript *m*. Thus:

$$L_m = L_B, L_H, L_V, L_S \qquad (14)$$

$$C_m = C_B, C_H, C_V, C_S \qquad (15)$$

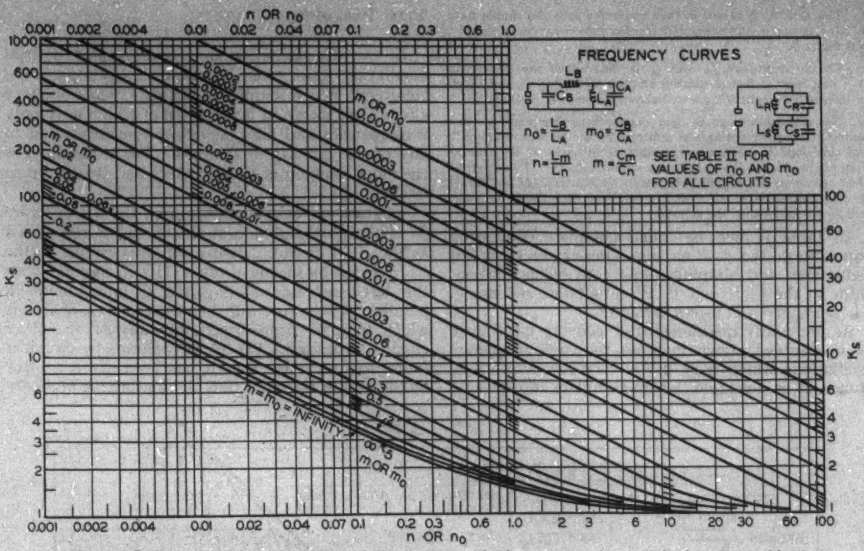


Fig. 5. Frequency curves for the purpose of determining the frequencies of any of the circuits of table II

If entered with n and m

$\omega_B = K_S\omega_n$

$\omega_R = \omega_m/K_S$

If entered with n_0 and m_0

$\omega_B = K_S\omega_A$

$\omega_R = \omega_B/K_S$

$$\omega_R = \frac{1}{\sqrt{L_RC_R}}\,;\ \omega_A = \frac{1}{\sqrt{L_AC_A}}\,;\ \omega_n = \frac{1}{\sqrt{L_nC_n}}$$

$$\omega_S = \frac{1}{\sqrt{L_SC_S}}\,;\ \omega_B = \frac{1}{\sqrt{L_BC_B}}\,;\ \omega_m = \frac{1}{\sqrt{L_mC_m}}$$

Now these 4 circuits, although all different, may be made equivalent to each or any of the other 3 circuits by the simple transformation of constants. (See reference 5, and appendix to present paper.) This fact is of great value, as they all may be transformed into the simple form R, S (figure 4*d*) which by inspection has the 2 frequencies isolated. It follows from equation 3 that the recovery voltage for this circuit will be:

$$V_r = k \cdot I \cdot \omega\{L_R(1 - \cos\omega_R t) + L_S(1 - \cos\omega_S t)\} \tag{16}$$

Here the frequencies and magnitude are both immediately available. They are:

$$f_R = \frac{1}{2\pi\sqrt{L_RC_R}} \qquad f_S = \frac{1}{2\pi\sqrt{L_SC_S}} \tag{17) (18}$$

Per unit amplitude of $f_R = L_R/L_R + L_S$ (19)

Per unit amplitude of $f_S = L_S/L_R + L_S$ (20)

It follows that due to the unrestricted equivalence of all of the circuits of figure 4, the above equations enable the determination of the frequencies and magnitudes, and hence the recovery impedance of each of the circuits provided they in turn are converted into the form of figure 4*d*. The labor of these conversions, however, has been considerably condensed in presenting table II. *Here in simple arithmetical form are all the relationships required to determine the frequencies, magnitudes, or recovery impedances for all of the circuits of figure 4.* The use of table II is perfectly straightforward and will be outlined here:

1. Having formed the particular circuit approximation suggested in figure 4;

2. Determine n_0 and m_0 from table II for the particular circuit chosen.

3. (*a*) To determine frequencies enter the curves of figure 5 with n_0 and m_0 determining K_S. Then:

$\omega_R = \omega_B/K_S$ and $\omega_S = K_S\omega_A$; where $\omega_N = 2\pi f_N$

(*b*) To determine the magnitudes of the above frequencies enter the curves of figure 6 with n_0 and m_0 determining J_R and J_S. Then:

$L_R = J_RL_A$ and $L_S = J_SL_A$ (Note: $J_R + J_S = n_0 + 1$)

(*c*) To determine recovery impedance Z_R directly, enter the curves of figure 7 with n_0 and m_0 determining W_T. Then:

$Z_R = W_TZ_B$ or ($Z_R = Z_A$ in some cases. See figure 7)

4. In all of which:

n_0, m_0, ω_B, ω_A, L_A, Z_B, and Z_A are determined from table II for the particular circuit under consideration.

Hence to determine the recovery impedance of any of the circuits of table II requires, at most, the arithmetical computation of n_0, m_0, and Z_B and reading one value, W_T, from the curves of figure 7. *In doing this actually the following operations are being performed automatically:*

1. The circuit chosen is converted by means of the conversion equations of table II into the form *A*, *B* of table II, chosen as the base circuit because of its frequent occurrence.

2. This new A, B circuit is then converted into the simple form R, S by means of the computed transformation curves of figure 5 and figure 6.

3. The 2 frequencies f_R and f_S so determined are plotted in $(1 - \cos)$ form at their respective amplitudes L_R and L_S and added as indicated by equation 16, and shown graphically in figure 7.

4. The maximum slope is then drawn from the origin to this composite recovery voltage, as indicated at the bottom of figure 7, and this slope is the recovery impedance in ohms Z_r determined from the product of W_T and Z_B as computed above. *A study of the above operations will suggest to the reader the possibility of performing the separate operations, all or any of which are made readily available here for the solutions of special cases.*

In table II will be found complete conversion equations to the A, B circuit. Quite often in circuit reductions and simplifications conversion relationships to the G, H and V, W circuits are necessary. These are given in tables III and IV.

As previously mentioned, the recovery impedance as determined above includes the high frequency oscillations which may be of very low amplitude. Hence, it is desirable, where complete information is desired, to check the relative amplitudes from figure 6. On these curves will be found a line drawn which is 40 per cent of the total amplitude of $(J_R + J_S)$. Amplitudes below this line indicate that the magnitude of that frequency is less than 80 per cent of the normal voltage crest, this value being tentatively set up as a dividing line. Special curve sheets can be made easily which give the recovery impedance automatically neglecting the high frequency oscillations below any desired percentage of the normal crest voltage. Space here does not permit this extension of the above curves.

Five Parameter Circuits

In the determination of recovery rates of field conditions, quite often 5 parameter circuits are encountered which require solution. Some of these circuits are shown in figure 8, all of which have only 2 frequencies and may be reduced on inspection to any of the circuits of figure 4. For example, a is the most common of these circuits and is reduced as follows:

Separate the circuit as shown on the left of figure 9. The right-hand side of this circuit is recognized as the A, B circuit. Transform this circuit to the G, H circuit by means of table III. Recombine with the left-hand side adding the 2 inductances in parallel. The result will then be a new G, H circuit which may be transformed into any of the other circuits as desired. The above 5 parameter circuit is found so frequently that it has been given a place on the master table, II, thus eliminating the necessity of the above transformations for this particular circuit. Frequencies, magnitudes, and recovery impedance can be determined rapidly for this circuit as outlined for all circuits of table II. In a similar way the other circuits of figure 8 may be reduced to simpler forms; their infrequent occurrence does not justify their development here.

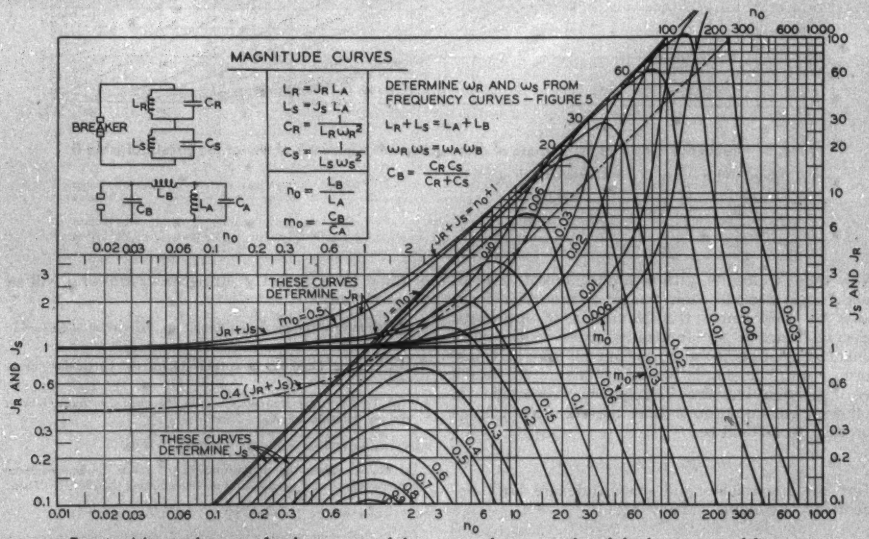


Fig. 6. Magnitude curves for the purpose of determining the magnitudes of the frequencies of figure 5

Reversibility

It will only be mentioned here that all of the above processes are quite reversible. That is, having

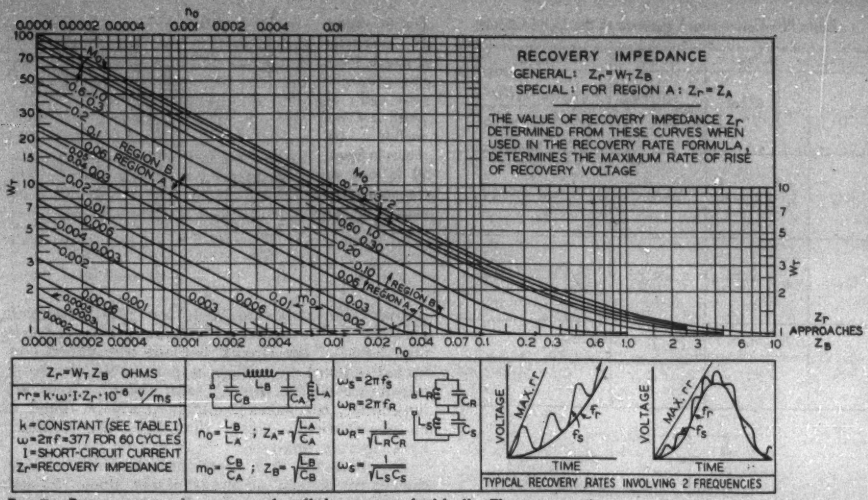


Fig. 7. Recovery impedance curves for all the circuits of table II. These curves determine Z_r of the recovery rate formula

a cathode ray oscillogram from which 2 frequencies and magnitudes can be determined, and knowing the circuit and power conditions under which the film was taken, the equivalent lumped circuits which will reproduce the film may be determined by means of the equations and curves given in this paper.

One of the practical uses of this reversibility is the development of lumped double frequency circuits to approximate the transformer. It is known that transformers when oscillating at their natural frequencies exhibit many frequencies. Quite often transformers may be represented, as far as recovery rates are concerned, by a single frequency. In the majority of cases, however, greater accuracy will be obtained by representing the transformer by one of the double frequency circuits of table II. Greater accuracy than this is not warranted because the rate of change of current in the recovery rate problem is usually not sufficient to excite higher transformer frequencies, and if excited their amplitude would be so low that they should be neglected. For general use, however, a knowledge only of the recovery impedance of a transformer or any apparatus is not sufficient because in the field setting the recovery circuit must be formed, including lines, cables, reactors, bushings, busses, transformers, etc., and hence each component element must be expressed in equivalent circuit form so that the approximate field circuit can be assembled as accurately as possible. (Recovery impedances cannot be added in series or in parallel except in very special cases.) The use of the double frequency circuit analysis in this paper will prove useful in the development of the equivalent circuits of the more complicated apparatus.

In general, the highest recovery rates are associated with transformers, not because the recovery impedances are highest, but because the power concentrations are high, combined with moderately high recovery impedances. In terms of equation 11, the product $I \cdot Z$, is maximum. Higher recovery impedances are associated with some of the current limiting devices, but inherently due to the restricted current, the product $I \cdot Z$, is smaller. The use of resistors shunting current limiting reactors, will considerably reduce the recovery impedance associated with reactors, especially when connected close to the breaker which must interrupt the circuit. The recovery impedances of shielded transformers will be found beneficially smaller due to the higher internal capacitance. Capacitors recommended for lightning protection also can be very effectively employed in reducing the recovery impedance of the circuit in which they are located. The electrostatic capacitance of metal clad bus structure, cables, and coupling capacitors are all beneficial to breaker performance especially when they provide the major capacitance paths close to the breaker terminals.

Transmission Lines and Machine Windings

When the only recovery circuit connected to a breaker is a long transmission line, the recovery impedance of the circuit is equal to the surge impedance of the line. This is the well-known $\sqrt{\frac{L}{C}}$ value of the line. The above is true provided the line is so long that the first or subsequent reflections do not affect the maximum recovery rate calculated on this basis. If the line is short, several

Table III—Conversion Equations to the G, H Circuit

G, H	A, B	V, W	R, S
L_H	$L_B\left\{\frac{L_A+L_B}{L_A}\right\}$	$L_W\left\{\frac{C_V+C_W}{C_V}\right\}^2$	$\frac{L_R L_S (L_R+L_S)(C_R+C_S)^2}{(L_R C_R - L_S C_S)^2}$
L_G	(L_A+L_B)	L_V	(L_R+L_S)
C_H	$C_A\left\{\frac{L_A}{L_A+L_B}\right\}^2$	$\frac{C_V^2}{C_V+C_W}$	$\frac{(L_R C_R - L_S C_S)^2}{(L_R+L_S)^2\cdot(C_R+C_S)}$
C_G	C_B	$\frac{C_V\cdot C_W}{C_V+C_W}$	$\frac{C_R\cdot C_S}{C_R+C_S}$

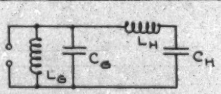
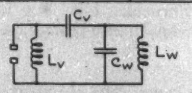


Table IV—Conversion Equations to the V, W Circuit

V, W	G, H	A, B	R, S
L_V	L_G	(L_A+L_B)	(L_R+L_S)
L_W	$L_H\left\{\frac{C_H}{C_G+C_H}\right\}^2$	$\frac{L_A^3 C_A^2 L_B L_V}{(L_A^2 C_A + L_V^2 C_B)^2}$	$\frac{L_{RS}\cdot C_R\cdot C_S}{C_V\cdot C_W}$ Where $L_{RS}=\left(\frac{L_R L_S}{L_R+L_S}\right)$
C_V	(C_H+C_G)	$\left\{\frac{C_A\cdot L_A^2}{L_V^2}\right\}+C_B$	$\frac{(L_R C_R+L_S C_S)-L_{RS}(C_R+C_S)}{(L_R+L_S)}$
C_W	$\frac{C_G}{C_H}(C_H+C_G)$	$C_B+\left(\frac{C_B^2 L_V^2}{C_A\cdot L_A^2}\right)$	$\frac{C_{RS}\cdot C_V}{C_V-C_{RS}}$ Where $C_{RS}=\left(\frac{C_R C_S}{C_R+C_S}\right)$



reflections must be included or approximated by using the π equivalent of a short line.

When, in addition to a single or a double frequency recovery circuit, there exists an additional long transmission line attached to the circuit at the breaker, the recovery circuit will be altered by having in parallel across the breaker terminals a resistance equal to the surge impedance of the appended line. The presence of a long line connected at the breaker will, in general, cause the

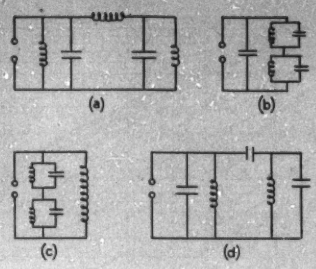


Fig. 8. Some 5-parameter double-frequency circuits all of which are reducible (as shown in figure 9) to one of the equivalent circuits of figure 4

recovery impedance to be so low that a complete analysis is unnecessary. Although the recovery impedance of the circuit, without the line so connected, cannot be added in parallel to the surge impedance of the line to form the final recovery impedance, the value so obtained will be found to be pessimistically higher than the value obtained by a rigorous analysis.

As generator and motor windings have been shown to behave as transmission lines to such transients,[7] their surge impedances determine their recovery impedances, subject to the same laws of reflections as mentioned above for short lines. If the machine windings have been made nonoscillatory[7] (no neutral reflections) by properly grounding through a neutral impedance they may be considered as long lines of the same surge impedance.

The lowest recovery impedances encountered are those of long cables connected to the breaker. Here the recovery impedance ranges from 30 to 70 ohms.

Summary

Circuit recovery impedance has been introduced as a true measure of circuit severity. It is an ohmic impedance Z_r dependent upon the external circuit, independent of the breaker. The maximum rate of change of current in amperes per microsecond at the moment of interruption of a short circuit at a normal current zero is dependent upon the type of fault, the steady-state short-circuit current and normal frequency $(k\cdot I\cdot\omega\cdot 10^{-6})$. From Ohm's law, the product of amperes per microsecond and recovery impedance in ohms is volts per microsecond, which is defined as recovery rate:

$$rr = k\cdot I\cdot\omega\cdot Z_r\cdot 10^{-6} \text{ volts per microsecond} \qquad (11)$$

For a single frequency circuit this ohmic recovery impedance is $\sqrt{\frac{L}{C}}$, but in more complicated double frequency circuits the recovery impedance, although still ohmic, is dependent upon 4 factors: the 2 frequencies and their corresponding magnitudes. The determination of these 4 factors as well as the direct determination of recovery impedance have been given in curve and table form for all the practical double frequency circuits which will be encountered in the field.

The flexibility of these circuits and their analysis have been indicated by extending their use to some 5 parameter double frequency circuits often found in recovery rate studies. Their use for the purpose of determining the approximate equivalent circuits of transformers, for recovery rate purposes, has been indicated.

It is felt that the introduction of the concept of recovery impedance as a single ohmic factor and the most important element in the recovery rate equation, together with a rapid means of its accurate determination will help the field engineer further to correlate recovery rate with breaker performance and to lead ultimately to its adoption as one of the factors which determine the rating of a circuit breaker.

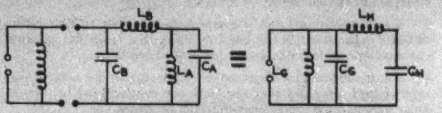


Fig. 9. Showing how figure 8(a) is reduced by means of table III to the 4 parameter, G, H circuit of figure 4

Appendix

It is the purpose of this appendix to present the basic equations which prove the equivalence of the circuits of figure 4 and suggest the method of calculation of the curves of figures 5, 6, and 7.

All the circuits of figure 4 contain one pure pair of coupled parameters as designated by the heavy lines. Giving these parameters the subscript n, there results:

$$L_n = L_A, L_G, L_W, L_R \tag{12}$$

$$C_n = C_A, C_G, C_W, C_R \tag{13}$$

The 2 remaining parameters take the subscript m, thus:

$$L_m = L_B, L_H, L_V, L_S \tag{14}$$

$$C_m = C_B, C_H, C_V, C_S \tag{15}$$

Now let:

$$n = \frac{L_m}{L_n} \quad \text{and} \quad m = \frac{C_m}{C_n} \qquad (21)\ (22)$$

$$M_{nm} = L_n \cdot L_m \cdot C_n \cdot C_m \tag{23}$$

$$N_{nm} = L_n \cdot C_n + L_m \cdot C_m + L_n \cdot C_m \tag{24}$$

(The product $L_n \cdot C_m$ occurs only when these parameters are coupled in any manner. Hence, as no coupling exists between L_R and C_S:

$$N_{RS} = L_R C_R + L_S C_S \tag{25}$$

$$Q_{nm} = \sqrt{N^2_{nm} - 4M_{nm}} \tag{26}$$

L_∞ = the impedance of the circuit if all the capacitances were removed (open circuited). Thus:

$$L_\infty = (L_A + L_B), L_G, L_V, (L_R + L_S) \tag{27}$$

C_0 = the impedance of the circuit if all the inductances were removed (open circuited). Thus:

$$C_0 = C_B, C_G, \left(\frac{C_V C_W}{C_V + C_W}\right), \left(\frac{C_R C_S}{C_R + C_S}\right) \tag{28}$$

$$C_{nm}' = \frac{M_{nm}}{C_0} \tag{29}$$

The differential equation of each of the circuits of figure 4 is similar in form and the solution of these equations shows that the operational impedance Z_p may be expressed by the following equation:

$$Z_{(p)} = \left(\frac{L_\infty p + C' p^3}{Mp^4 + Np^2 + 1}\right) 1 \tag{30}$$

The following relations are then obtained by equating the respective coefficients:

$$M = M_{AB} = M_{GH} = M_{VW} = M_{RS} \tag{31}$$

$$N = N_{AB} = N_{GH} = N_{VW} = N_{RS} \tag{32}$$

$$\therefore\ Q = Q_{AB} = Q_{GH} = Q_{VW} = Q_{RS} \tag{33}$$

$$L_\infty = (L_A + L_B) = L_G = L_V = (L_R + L_S) \tag{34}$$

$$C_0 = C_B = C_G = \left(\frac{C_V C_W}{C_V + C_W}\right) = \left(\frac{C_R C_S}{C_R + C_S}\right) \tag{35}$$

From these relations tables II, III, IV were compiled.

The curves of figures 5, 6, and 7 were determined from the following relations:

Let:

$$N_R = (N - Q), \tag{36}$$

$$N_S = (N + Q), \tag{37}$$

$$\omega_R^2 = \left(\frac{N_R}{2M}\right) \tag{38}$$

$$\omega_S^2 = \left(\frac{N_S}{2M}\right) \tag{39}$$

Then:

$$L_R = \left\{\frac{2L_\infty C_0 - N_R}{2C_0 Q \omega_R^2}\right\} = \frac{1}{C_R \omega_R^2} \tag{40}$$

$$L_S = \left\{\frac{N_S - 2L_\infty C_0}{2C_0 Q \omega_S^2}\right\} = \frac{1}{C_S \omega_S^2} \tag{41}$$

$$C_R = \left\{\frac{2C_0 Q}{2L_\infty C_0 - N_R}\right\} = \frac{1}{L_R \omega_R^2} \tag{42}$$

$$C_S = \left\{\frac{2C_0 Q}{N_S - 2L_\infty C_0}\right\} = \frac{1}{L_S \omega_S^2} \tag{43}$$

The above 4 equations are general for all of the circuits of figure 4. Their presentation in curve form was made possible by introducing the ratios n and m. Hence, for example:

$$K_S = \sqrt{\frac{q - \sqrt{q^2 - 4mn}}{2mn}} \qquad \text{(See figure 5)} \tag{44}$$

where

$$q = (1 + mn + m) \tag{45}$$

$$n = \left(\frac{L_m}{L_n}\right) \quad \text{and} \quad m = \left(\frac{C_m}{C_n}\right) \qquad (21)\ (22)$$

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Capacitive Excitation for Induction Generators

Up to the present, applications of induction generators have been limited, mainly because they must be paralleled with an existing synchronous system to determine their frequency and voltage and to obtain their necessary excitation. The tests described in this paper show that an induction machine may be operated as an independent or isolated generator at a predetermined voltage and frequency, with excellent wave form, by means of capacitive excitation. Further, proper choice and arrangement of the capacitors will result in a practically flat external load-voltage characteristic.

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THE DRIVING of an induction motor faster than synchronous speed causing it to generate alternating current power is quite well understood. Some installations of induction machines operated in this manner have been made, but as yet the practice of using induction generators has not been adopted to any appreciable extent. Probably the chief reason for this is that the induction machine must draw a lagging magnetizing current which up to this time has been supplied by the synchronous machinery of the system to which it is connected. This fact and the fact that the voltage and frequency of the induction generator are dependent entirely upon that of the connected system are the main disadvantages of the induction machine acting as a generator. Among the advantages may be listed the characteristic mechanical strength and ruggedness of the induction machine, decrease in station sustained short-circuit risk, the ability to run at high speeds, and relatively low initial and upkeep costs.

The purpose of this paper is to show that an induction machine can be made to operate as an isolated or independent generator, incorporating all the foregoing advantages and omitting most of the main disadvantages, by supplying the exciting or magnetizing current from static capacitance connected in shunt across the terminals of the machine. The following conclusions seem warranted:

1. The induction machine with capacitive excitation will build up its voltage exactly as does a d-c shunt generator, the final build-up value being determined by the saturation curve of the machine and by the value of reactance of the excitation capacitance.

2. Wave shape of the induction generator with capacitive excitation is sinusoidal.

3. Frequency of the output is directly proportional to the rotor speed minus the slip speed.

4. Machine constants can be compensated for quite well by means of series capacitance in the lines, resulting in a fairly flat external characteristic under unity power factor load conditions.

5. The induction generator can be made to handle almost any type of load, provided that the loads are compensated to present unity power factor characteristics to the generator.

6. Use of the induction generator with capacitive excitation may be made: (a) in laboratories where a source of sine wave power is desired; and (b) in installations of small capacity where single or 3 phase power is required, and where the cost of a synchronous generator and auxiliaries is prohibitive.

7. Present low cost of capacitors makes possible comparatively cheap installations, especially those of small capacity.

8. Small series capacitive reactances required for "compounding" can be obtained by means of series transformers with the capacitors connected to the high voltage sides of these transformers.

Build-Up of Generator Voltage

The build-up of voltage of the d-c shunt generator is known to depend upon residual magnetism in the field poles of the machine and upon the resistance of the field circuit, the final build-up voltage being determined by the field circuit resistance. It has been discovered that the induction generator with static capacitance connected in shunt across its terminals will build up its voltage in a manner similar to the build-up of the d-c shunt generator. Residual magnetism in the iron of the magnetic circuit sets up a small alternating voltage in the stator; this voltage applied to the capacitance causes a lagging magnetizing current to flow in the stator windings (machine applies leading quadrature current to the capacitance, or draws a lagging quadrature current). If the capacitance is of the proper value, the current that can flow will be large enough to increase the flux existing in the air gap. An increase of the air gap flux will result in a higher voltage, larger exciting current drawn by the capacitance, more air gap flux, and so on until the terminal voltage of the machine reaches its final build-up value. This value is determined by the saturation curve of the machine and by the capacitive reactance of the connected capacitance.

Following is an analysis of the build-up of the induction generator with capacitive excitation: If both the saturation curve (terminal no-load voltage versus exciting current) and a straight line through the origin, the slope of which is the capacitive reactance X_c, are plotted to the same scales, the point where the straight line intersects the saturation curve is the final build-up point. This corresponds identically to the behavior of the d-c shunt generator

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for which, if the saturation curve of the machine is known, the final build-up voltage for any particular field resistance can be predetermined by plotting on the same sheet and to the same scales the saturation curve and the field resistance, $R_f = E/I_f$. The point where the straight line, the slope of which is R_f, intersects the saturation curve is the point where the voltage will cease to build up. In like manner, if the saturation curve of the induction generator is known, the final build-up voltage for any particular capacitive reactance can be predetermined as shown in figure 1. The results given here as well as every point on the curve check almost perfectly with the measured values shown as encircled points on the saturation curve. This close agreement of measured and calculated values gives assurance that the theory of build-up as outlined is essentially correct. It may be seen also from the d-c analogy that the capacitive reactance of the induction generator corresponds to the field circuit resistance of the d-c shunt generator. The curve of figure 1 is for 3 phase operation. Similar results have been obtained for single phase operation where excitation is obtained from capacitance connected across 2 terminals of the machine.

An important part of the foregoing discussion centers around the saturation curve of the induction generator. This can be obtained in either of 2 ways: (1) by exciting the machine from a separate source of variable voltage of good wave form, keeping the power transfer zero between the machine and the source of excitation; or (2) by adjustment of the capacitive reactance, which gives a set of values on the workable portion of the curve. The results of these 2 widely different methods give practically the same saturation curve.

Frequency

The frequency of the induction generator is directly proportional to the actual speed of the rotor minus the slip speed. At no load, when the slip is practically negligible, the frequency is directly proportional to speed. Experimental results show this to be true. However, since the slip of the induction generator increases with increasing load, it is seen that in order to maintain constant frequency, the speed of the rotor must be increased by an amount equal to the slip speed. If constant frequency is desired—as it generally is—the induction generator must be driven by a prime mover the speed of which increases with load.

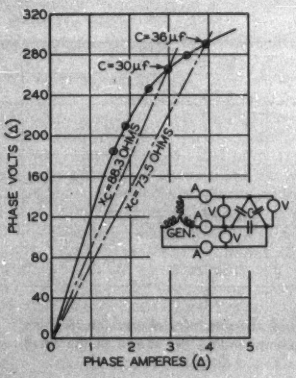

Fig. 1. No-load saturation curve and final build-up voltages of a 3-phase 60-cycle 220-volt 5-horsepower induction generator with capacitive excitation

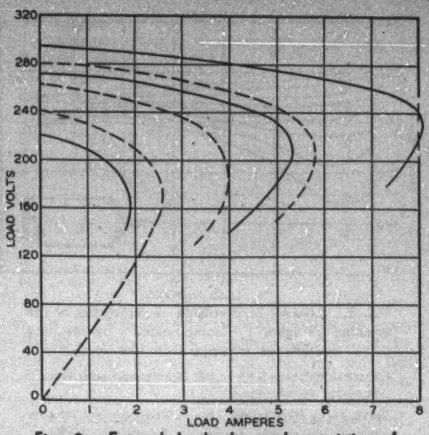

Fig. 2. External load-voltage characteristics of machine of figure 1 with unity power factor load

Solid lines are for 3 phase operation; dashed lines for single phase operation

Wave Shape of Induction Generator Voltage

In the calculation of X_c, the capacitive reactance used in the results of figure 1, the frequency was held constant at 60 cycles and it was assumed that the voltage wave was of sinusoidal form. The results obtained by these calculations checked very closely with the measured results, giving confirmation of the sine wave assumption. An oscillogram of the voltage wave gave conclusive proof that the assumption was correct and that the voltage wave was actually a sine wave. This fact is perhaps of considerable importance. Heretofore, a sine wave machine was obtained as a result of much arduous labor and the solution of many complicated design problems; now a sine wave voltage can be obtained easily from an ordinary induction motor by the use of capacitive excitation. This fact may open a new field for the induction machine, especially for laboratory use where a sine wave voltage sometimes is required, and where the cost of a synchronous machine of proper design is prohibitive.

Capacitive excitation was tried on 2 different induction machines: One was a General Electric 5-horsepower 3-phase induction motor having a squirrel-cage rotor with closed slots; the other was a Westinghouse 5-horsepower 3-phase motor, of older design having a regular squirrel-cage rotor with open slots. These machines built up their voltages

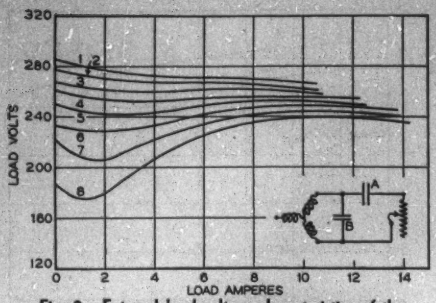

Fig. 3. External load-voltage characteristics of the machine of figure 1, "compounded" by inserting capacitance in series with the load

Capacitance A was fixed at 192 microfarads, capacitance B was varied as follows:

Curve	Microfarads	Curve	Microfarads
1	84	5	72
2	81	6	69
3	78	7	66
4	75	8	63

as already described, and gave a sine wave voltage when operated both as 3 phase and as single phase machines.

To determine the effect of capacitive excitation on the wave shape of a synchronous generator, a synchronous salient-pole 3-phase 6.3-kva generator, having a flat topped voltage wave was subjected to a capacitive load. With no d-c field on the generator, it was found that when the capacitive reactance was made low enough, the generator built up its voltage exactly as had the induction machine. The exciting current was naturally very high, as the reluctance of the magnetic path was considerably greater than that of the squirrel-cage machine. It is interesting to note that the voltage wave of the machine with capacitive excitation was a sine wave, whereas the voltage wave of the machine running as a synchronous generator was not. No appreciable difference in the wave shape was observed when the field circuit was open or short-circuited. Furthermore, it was discovered that with capacitive excitation the voltage wave held its sinusoidal form under load.

Loss and Restoration of Residual Magnetism

Operating as a shunt generator, a short circuit or too great a load will cause the induction generator to lose its voltage, and the residual magnetism of the rotor is destroyed, preventing the machine from again building up. Any method that gives temporary excitation to the iron will restore the residual magnetism. A few methods that have been found are: (1) running the machine as a motor from an existing a-c system; (2) discharging a charged condenser through the stator windings while the machine is in operation; and (3) connecting a 6 volt storage battery across 2 terminals of the machine for a few moments while the machine is at rest. All 3 of these methods have been proved successful in restoring the residual magnetism, thus enabling the machine to build up its voltage; but the third method, that of using a storage battery, is by far the most practical when dealing with an isolated generator where power from an existing system cannot be obtained.

Loading

Having determined thus far that the induction machine under the influence of capacitive excitation will build up a voltage of sine-wave form and maintain this voltage with stability, the next consideration that naturally comes to mind is that of loading the machine. Can this machine be made to supply power to a load and at the same time have reasonable voltage regulation characteristics? The answer to this question follows.

Shunt Loading. The first load test consisted in placing a unity power factor load directly across the terminals of the machine with the capacitance connected as shown in the diagram of figure 1. Results of the preliminary test are shown in figure 2. Here it may be seen that the voltage falls off quite rapidly with increased load, thus further bearing out the resemblance of this machine to the d-c shunt generator. The voltage holds up better as the machine is operated at higher degrees of saturation, as might be expected.

Loads of different power factors were tried in this connection. It was found that lagging loads caused the voltage to fall more rapidly, whereas leading loads held up the voltage. The effect of these loads was the same as that of an equivalent unity power factor load with the shunt capacitance increased or decreased according to whether the load in question was leading or lagging.

Compounding. The fact that leading power factor loads tend to hold up the voltage leads to the possibility of compounding the machine, that is, causing all loads to be effectively leading by placing series capacitance in the line wires as a permanent feature. This was tried and found effective in varying degrees depending on the initial voltage or saturation. A

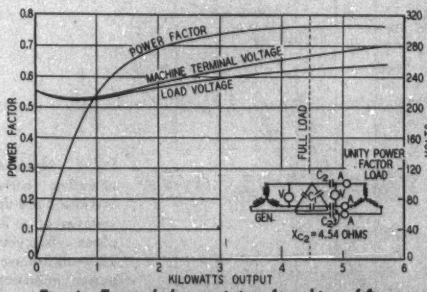

Fig. 4. External characteristics of machine of figure 1 with "flat compounding" as shown in the small diagram

family of such curves is shown in figure 3. The magnitude of the series capacitance used in this test was chosen after some experimenting, which revealed that there is some optimum value of reactance that produces the best characteristics under all degrees of saturation. A check indicated that the capacitive reactance needed corresponds quite closely to the effective inductive reactance offered by the machine windings. Further discussion of this point will be taken up later.

As to the general shape of the "compounded" curves, it may be noted that those taken at low saturation exhibit a pronounced dip initially, whereas at the higher saturations the dip practically disappears. For an explanation of this phenomenon, consider what occurs in the part of the circuit external to the machine. The external circuit then is composed of a constant capacitive reactance in series with a variable resistance (the load). When the load is light, that is, when it has high resistance, the effect of the small capacitive reactance in series with it is practically negligible. Hence, initially, all curves of the family tend to follow the straight shunt form. As the load resistance decreases, the effect of the capacitance becomes more prominent and finally governs, bringing the voltage up again. If the normal shunt characteristic will carry over this dip and hold up the voltage until the series capacitance becomes effective, there will result an approximation of "flat compounding." This reasoning is borne out by the appearance of the curves of figure 3. Figure 4 shows a typical external characteristic with load and terminal voltage plotted together with the power factor measured at the machine terminals.

Short-Circuit Conditions

The effect of sustained overloads and sudden short circuits on any piece of electrical apparatus is of considerable importance. The investigation along this line for the induction generator with capacitive excitation was carried out in 4 sections: with both suddenly and gradually applied short circuits for the pure shunt connection and for the so-called "compound" connection.

With the shunt connection, the application of a load causes a drop in terminal voltage which also decreases the current taken by the exciting condensers. The effect is thus cumulative, and the terminal voltage drops to a point of stable equilibrium, providing that the load applied be not too great. As the load is increased further, the terminal voltage, of course, decreases more and more rapidly, receding along the saturation curve until the straight portion is reached. At this point the machine becomes unstable, and the terminal voltage and current drop rapidly to zero. This phenomenon is shown plainly by the extended curve of figure 2. Under these conditions, there is no possibility for any abnormal voltage or current; beyond an unavoidable loss of residual magnetism there are no consequences.

When the terminals of the machine with shunt connection suddenly were short-circuited, the final result was the same. There was a sudden rush of

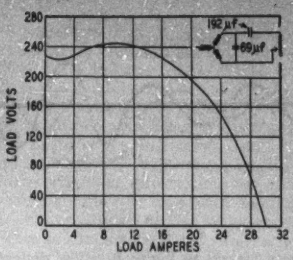

Fig. 5. External load - voltage characteristic of machine of figure 1 compounded and connected for single phase operation as shown in diagram

current of extremely short duration through the short circuit, the magnitude of which depended upon the voltage existing at the capacitor terminals at the instant of application of the fault together with the resistance presented by the fault. This is what happens whenever a capacitance is discharged through a resistance; there are no abnormal voltages, and the current does not enter the machine. The machine current decayed in a matter of 3 or 4 cycles, depending on the time constants of the machine windings. This current never can be greater than that flowing in the windings at the time of application of the fault. All these facts were brought out by repeated oscillograms taken of current and voltage through the period of short circuit.

Short circuits applied to the compound connection present a somewhat different aspect. Series capacitance is placed in the line wires to cause the load current to lead the terminal voltage, thereby providing added excitation as the load is increased. As the load current is increased beyond a certain point, the drop in the series capacitive reactance exceeds the rise in terminal voltage afforded by the added excitation, and the load voltage falls, finally to zero, as shown by the curve of figure 5. The machine terminal voltage, however, has been rising during this progressive decrease in load resistance. The final value to which this terminal voltage will rise may be determined graphically from the saturation curve of the machine, using for a value of X_s the equivalent series value obtained from the combination of the shunt and series capacitances. This reasoning may be fitted easily to either the single or 3 phase short circuit. For the circuit shown in figure 5, the terminal voltage rose to 415 volts, this being applied to the series as well as the shunt capacitors. When this short circuit was applied suddenly, the same final results prevailed as for the gradually decreased load resistance. Short-circuiting the load merely amounts to suddenly increasing the shunt capacitance to an amount equal to the sum of the shunt and series capacitances. There may be a sudden, brief rush of current to the series capacitors at the instant of application of the fault as they become charged to, and begin to operate under, a higher voltage. However, there will be no voltage surges to damage the capacitors.

An oscillogram, selected from several taken, showing the voltage and current in the series capacitors through the period of the short circuit is

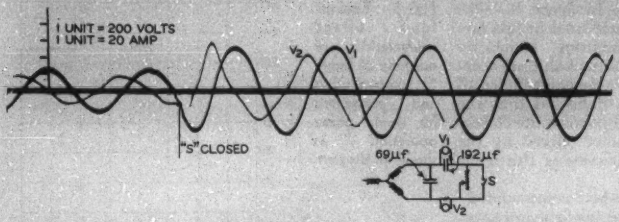

Fig. 6. Oscillogram showing voltage and current in series capacitance of compounded machine during short circuit

Conditions before switch S was closed: voltage (V_1) 175 volts; current (V_2) 12.7 amperes; load volts 238. Conditions after switch S was closed: voltage (V_1) 415 volts; current (V_2) 30.0 amperes. (All current and voltage values are effective)

reproduced in figure 6. The departure of the current from true sinusoidal form is, no doubt, a result of the abnormally high degree of saturation existing in the iron of the machine with the high terminal voltage. There is no possibility of a voltage surge, and the final steady-state voltage probably will not be in excess of twice the terminal voltage under normal conditions. Furthermore, the current will not be greater than 3 times its normal value. If series transformers are used in connection with the series capacitors, even these abnormalities are eliminated. Consequently, for the compound connection no detrimental effect on the equipment will result from a short circuit, if the series capacitors either are capable of withstanding roughly double the rated terminal voltage or are operated in connection with series transformers properly selected. The machine will be unaffected if the short circuit is removed before serious overheating occurs.

From this discussion, it may be seen that no serious effects will result from the gradual or sudden short circuit of an induction generator operating with capacitive excitation. In the shunt connection, short circuits can do no harm under any condition. In the compound connection, there need be no difficulty.

Compensation

A consideration of the familiar equivalent diagram of the induction machine, shown in figure 7, reveals that the various reactances of the machine are grouped in a T section. If these reactances remain reasonably constant, it should be possible to compensate for them completely with a suitable T or Π section of capacitance, neglecting for the moment, all voltage drops resulting from copper and iron losses. This assumption seemed reasonable from the fact that the best compounding results were obtained with a series capacitance corresponding in reactance to the appropriate value of inductive reactance to be placed on such a diagram. This general scheme was tried, but was found not to give sufficient advantage over the former method to warrant the added capacitance required.

It might be supposed that with proper compounding an induction generator could be compensated to carry loads of all power factors, but such is not the case. The behavior of the voltage under different load conditions always follows the same trend as was exhibited by the shunt machine. In justification of this (assuming the validity of the equivalent circuit) it should be remembered that the resistance shown at the left of the diagram in figure 7 multiplied by I_2^2 represents the internal load of the machine. The magnitude of this resistance is given as $R = r_2\,(1-s)/s$, where r_2 is the rotor resistance referred to the stator, and s is the slip. If the slip becomes negative (machine generating) this resistance becomes negative and may be replaced by an equivalent generator, but this generator can furnish power only at unity power factor. Hence, with the machine compensated, the reactive component of the load current cannot be fed from this hypothetical generator, but must circulate through the part of the circuit that furnishes excitation. Thus, the reactive components of the load currents add or subtract from the machine excitation as before.

Capacitive Networks

Various connections of the shunt and series capacitances may be used to obtain essentially the same results as are shown in figure 3. Besides the method of placing the shunt capacitance directly across the terminals and the series capacitance in the line wires, as first tried, the idea may be reversed, placing the series capacitance inside the shunt—that is, a "long shunt" connection.

A comparison of the "long" and "short" shunt connections brings out the following facts: In the short shunt connection the voltage applied to the shunt capacitors rises with the terminal voltage; hence, more exciting current is obtained automatically in a cumulative manner. The difference between the machine and load voltages is only the drop in the series capacitors, which is small. In the long shunt connection the voltage applied to the shunt capacitors drops with the load voltage. Further, the load voltage in effect is tapped out of a capacitive potentiometer connection, resulting in a low ratio of load to terminal voltage, which is not to be desired. Since any other network is necessarily a compromise between the 2 simple short and long shunt connections, not much work was done in this direction. The short shunt connection was found to give results equal to any of the others, and, being

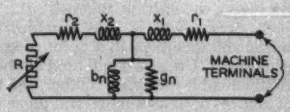

Fig. 7. Equivalent diagram of a single phase induction machine

the most economical of capacitors, it was adopted as a standard.

Single or 3 Phase Operation?

Early investigations were conducted with the machine operating as a 3 phase generator with delta connected capacitors. To simplify the work an attempt was made later to operate the machine as a single phase generator. Experimentation and comparison showed that the characteristics for either are identical. This fact is brought out clearly by the curves of figure 2 where both the 3 phase and single phase curves correspond exactly as to shape. Furthermore, the bottom curve of figure 2 is for both 3 phase and single phase operation. It was discovered further that the constants or values of capacitance for either case could be translated quite easily to the other. In the single phase method, the wye connected machine was operated with 2 of the phases in series. As a result, in compensating, the series capacitive reactance must be approximately twice the 3 phase value, since it must balance out the inductive reactance of 2 of the phases. In regard to the shunt capacitance, remembering that to operate at the same voltage (either single or 3 phase) the iron of the machine must be at the same saturation, it might be supposed that the same kilovolt-ampere value of capacitance would be required for either single or 3 phase operation. This relation checked quite closely experimentally.

To obtain large values of capacitance for series use, series transformers may be used with small-capacitance high-voltage capacitors. The operation of a capacitor through a transformer gives the capacitor an effective reactance equal to its actual reactance multiplied by the square of the transformation ratio. Operation in this manner is satisfactory so long as the transformers are operated well below the knee of their saturation curves.

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Effects of Saturation on Machine Reactances

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The effects of magnetic saturation on the various types of reactances used in calculations on synchronous machines are considered in this paper. Saturation factors for the important constants used in transient and unbalanced load calculations are presented in curve form. These data are taken from short-circuit tests on a large number of machines. The saturation factor for transient reactance under conditions encountered in stability calculations is difficult to test directly so the test data are supplemented by theoretical calculations.

THE new methods of analyzing synchronous machine performance under transient or unbalanced load conditions have introduced a large number of new constants.[4,5] The method of symmetrical components requires negative and zero sequence reactances (x_2 and x_0) and an accurate analysis of transients requires transient and subtransient reactances (x_d' and x_d'') and transient and subtransient time constants (T_d' and T_d'') as well as the synchronous reactance (x_d).

These new theories were developed either on the assumption of no saturation or of fixed permeability. In 1929, the company with which the writer is associated started a series of tests to determine the effects of saturation and to check methods of calculation. Several parts of these data were presented in an A.I.E.E. paper,[6] by S. H. Wright, in 1931.

An A.I.E.E. committee report[3] on "Proposed Definitions of Terms Used in Power System Studies," by H. K. Sels, lists the constants which are effected by saturation but gives no quantitative data on saturation nor does it state which value of the constant is to be understood when the degree of saturation is not specified. It may not be desirable in a list of formal definitions to limit the value of the constant to any particular degree of saturation. However, for practical purpose it would be very useful to have standard curves showing the effects of saturation on the constants of typical machines and also to have an accepted value (either saturated or

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5. For all numbered references see list at end of paper.

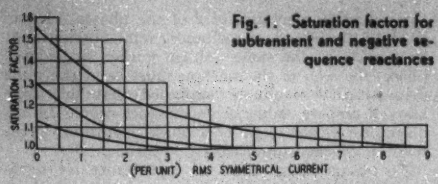


Fig. 1. Saturation factors for subtransient and negative sequence reactances

Factor is ratio of partially saturated to saturated value
Curve A—For 2 pole turbine generators with solid rotors
Curve B—For 4 pole turbine generators with solid rotors
Curve C—For salient pole machines without damper windings
For salient pole machines with damper windings no correction is necessary

unsaturated) for each constant which is to be understood when the degree of saturation is not specified. In this paper curves showing the effects of saturation on the more important constants are given. These curves are based upon the test data, except in the case of transient reactance where the test data are supplemented by calculations, since tests under conditions encountered in transient stability studies are difficult to obtain.

It is concluded that one value of each constant is all that is needed for most cases. A choice of saturated or unsaturated values for each constant as the value to be understood unless otherwise qualified is recommended in this paper. This choice is based upon the most common use of the quantities and the value which gives the least error for most applications.

Methods of Dealing With Saturation

It is generally agreed that the reactances of turbine generators are affected by saturation, and the test data of table I show that the transient reactance of salient pole machines is also affected. In using these constants for different applications it is necessary to apply correction factors if very accurate results are to be obtained. There has been considerable discussion as to which value (saturated or unsaturated) should be used as a reference.

Theoretically it would be more simple to define all the constants as unsaturated values and then apply reduction factors to obtain the saturated or partially saturated values. This method has the practical objection that if the unsaturated value of subtransient and negative sequence reactance of turbine generators were used in the calculation of short circuits, the currents obtained might be too low by as much as 35 per cent. The most common use of these 2 constants is in the calculation of short-circuit currents and those who make such calculations often do not have time, or are not sufficiently familiar with the refinements, to apply saturation factors. If the saturated values (that is, values which would be obtained by sudden short circuit from full voltage) are used, the results are correct for sudden short circuits near the machine and the errors are small for short circuits through considerable external reactance, since the machine reactance is then only a part of the total. Furthermore, if standard saturation factors are applied to these constants for turbine generators, the errors due to variations in individual machines will be greater if the saturation factors are applied to the unsaturated values, than if the saturated value is used as a base.

With these practical considerations in mind, it is suggested that the *one value which can be used in most calculations and which should be understood, unless otherwise specified, be the saturated value* for the following constants: (1) the transient reactance x_d'; (2) the direct axis subtransient reactance x_d''; (3) the quadrature axis subtransient reactance x_q''; (4) the negative phase sequence reactance x_2; (5) the zero phase sequence reactance x_0; (6) the transient time constant T_d'; (7) the subtransient time constant T_d''; and (8) the armature time constant T_a.

In using the synchronous reactance, saturation must ordinarily be considered but saturation may be dealt with by using the saturation curves of the machine; hence, it is best to define the synchronous reactance x_d as the unsaturated value. The other quadrature axis reactances and time constants of turbine generators and the quadrature axis synchronous reactance of all machines are affected by saturation. Since these constants are less commonly used and sufficient test data have not yet been obtained to determine these saturation factors definitely, it seems best to suggest that, unless otherwise qualified, the unsaturated values of these constants are to be understood.

There has been some objection to using the saturated values as a reference on the grounds that short-circuit tests at full voltage are required. However, short-circuit tests of some type[3,4] must be employed to obtain the time constants of all machines, and the transient reactance of all, except salient pole machines without damper windings. If standard saturation factors similar to those given here were adopted, the unsaturated values could be tested for by locked tests and short circuits at reduced voltage, and the correction factors applied.

Tests show that certain of the constants are not

Table I—Results of Sudden Short-Circuit Tests at Several Voltages for Salient Pole Machines

Rated Kva	Speed	Per Unit Voltage	Per Unit Transient React. x_d'	Transient Constant Time T_d'	Ratio of Value of x_d' at 100% and 50% E	Ratio of T_d' at 100% and 50% E
31,250	300	0.50	0.277			
		1.00	0.244		0.88	
30,000	720	0.48	0.40	3.45		
		0.99	0.37	2.74	0.92	0.79
1,500	900	0.50	0.40			
		1.00	0.34		0.85	0.85
7,500	360	0.51	0.565	1.9		
		0.75	0.54	1.79		
		1.04	0.54	1.70	0.95	0.89
5,000	900	0.51	0.251	1.28		
		0.514	0.261	1.35		
		1.00	0.22	0.89	0.85	0.68
		0.995	0.23	1.07	0.90	0.77
730	1,200	0.50	0.332	0.765		
		0.74	0.321	0.713		
		1.01	0.295	0.573	0.89	0.75
330	1,200	0.50	0.28			
		1.00	0.22		0.79	

appreciably affected by saturation and for these locked tests or other tests giving the unsaturated values are at all times applicable. The tests made show the following reactances to be effected to such a slight extent that for practical purposes saturation may be neglected: the subtransient and negative phase sequence reactances (x_d'', x_q'' and x_2) of salient pole machines with damper windings, the subtransient time constant T_d and zero sequence reactance x_0 of all machines. Test on one large 25 cycle single phase machine showed a reduction of subtransient reactance of 0.83 so that this type of machine should be considered an exception to the above rule. It is suggested that the same ratio of saturated to unsaturated value of x_d'', x_q'', and x_2 of large 25 cycle machines be taken as the same as that for transient reactance as shown by curve B, figure 2.

Saturation Factors

Subtransient and Negative Sequence Reactance. The average variation in the subtransient reactance of solid rotor turbine generators is plotted in curves A and B, figure 1. These data with the exception of one additional test are taken from the data given in figure 23 of S. H. Wright's paper.[6] The term solid rotor includes plate rotors but not those made of thin laminations. The test data for values of current less than 1.5 times rated current were determined by locked tests and those above this value were determined by sudden short-circuit currents.

For these same machines where line to line short circuits were also made the negative phase sequence reactance was determined from the single phase subtransient $x_1''\phi$ as:

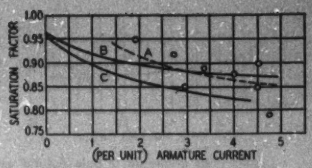
$$x_2 = \sqrt{3}(x''_{1\phi}) - x_d''$$

These results, although less consistent than the values of x_d'' showed that the same saturation factors

Table II—Results of Sudden Short-Circuit Tests at Several Voltages for Turbine Generators

Rated Kva	Speed	Per Unit Voltage	Per Unit Transient React. x_d'	Transient Time Constant T_d'	Subtransient Time Constant T_d''	Ratio of Value of x_d'' at 100% and 50% E	Ratio of T_d at 100% and 50 % E
75,000	1,800	0.335	0.268	1.57	0.037		
		0.667	0.37	1.53	0.020		
		1.00	0.238	1.53	0.035	0.89	0.97
43,750	1,800	0.50	0.27	1.15	0.016		
		0.75	0.245	1.11	0.020		
		1.00	0.245	1.00	0.020	0.91	0.87
18,750	3,600	0.50	0.161	0.65			
		0.767	0.152	0.593			
		1.00	0.140	0.59		0.87	0.87
		0.53	0.162				
		0.78	0.147				
		1.00	0.14			0.87	
12,500	3,600	0.50	0.155	0.55	0.097		
		1.00	0.135	0.54	0.047	0.87	0.98
9,375	3,600	0.51	0.155	0.555	0.040		
		0.515	0.150	0.55	0.030		
		1.06	0.135	0.44	0.037	0.87	0.825
8,575	3,600	0.47	0.133	0.455	0.038		
		0.75	0.117	0.438	0.036		
		1.00	0.120	0.433	0.052	0.90	0.95

Fig. 2. Saturation factors for transient reactance of salient pole machines



Curve A—Short circuit test from rated voltage, no load
Curve B—Normal operation as a motor or generator
Curve C—Condenser under load
Circles—Test points from short circuits at no load

(curves A and B, figure 1) determined for the subtransient reactance could be used. A complete analytical calculation of transients in turbine generators is impossible since the number of damping circuits formed by the solid iron of the rotor is infinite. An approximate analysis does indicate, however, that for the same root mean square symmetrical current, the depth of penetration in the iron of the flux on 60 cycle locked test is about the same as that on short circuit at the end of the first half cycle. Since the peak at about one-half cycle is the first point on the oscillogram which influences the determinations of x_d'', it would seem that the locked test should give about the same reactance as sudden short circuit for the same currents. The test curves (figure 23 of S. H. Wright's paper[6]) do not show any locked and sudden short-circuit values at the same current, but the points from both tests seem to be on the same general curve. In several tests load was dropped suddenly and the initial rise in voltage measured to give the subtransient reactance at lower currents. These values agree quite well with the values obtained by locked test at the same current.

The subtransient and negative sequence reactances of salient pole machines as determined by locked tests, sudden short circuit, or other tests[6] agree quite well and show a negligible amount of saturation. Theoretically, one would expect an appreciable saturation in the tips of the partially closed damper slots, but this generally constitutes only about 0.10 or 0.15 of the total, hence, the reduction in the total reactance is negligible.

Saturation Factors for Transient Reactance. The transient reactance for a number of turbine generators and salient pole machines was determined by short circuits at full voltage and at one or more lower voltages. The results of these tests are shown in tables I and II. There are a number of inconsistencies in the several values determined for some of the machines, indicating a maximum test error of about ±8 per cent. However, these tests do indicate definitely that for the machines tested the average ratio of the transient reactances determined by short circuits at full voltage and half voltage is 0.88. These test ratios for salient pole machines are shown by the points on figure 2. Curve A, figure 2, gives the calculated reduction of the transient reactance as determined for a typical salient pole machine by the method developed in appendix A and seems to agree within the limits of error with the test results.

Curve B shows the reduction factor for a typical

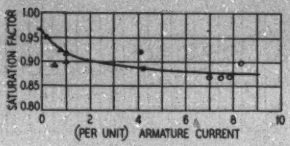


Fig. 3. Saturation factors for transient reactance of turbine generators

Circles—Test points on 2 pole turbine generators, short circuit from full voltage
Dots—Test points on 4 pole turbine generators, short circuit from full voltage
Triangles—Test values obtained by suddenly applied loads, measuring transient change in voltage

salient pole machine under conditions similar to those encountered in transient stability problems. In the calculation of curve B, the machine was assumed to be operating with $(E_d' + E_s) = 1.30$ and $x_d = 1.15$ (see appendix B for symbols) which would correspond to an initial condition of unity power factor with the saturation ampere turns equal to 0.3 of the gap ampere turns. It was also assumed that the quadrature axis current was equal to the direct axis current, although the quadrature axis current can vary quite widely without greatly affecting the result, since it adds to the saturation on one pole tip and subtracts on the other. The range of current encountered in transient stability problems is generally from 1 to 3 times rated current and the average reduction between these points, indicated by curve B, for these currents is 0.895.

Curve C is calculated by the same method for a synchronous condenser which may be swinging about the mean position. $(E_d' + E_s) = 1.45$, which corresponds to a saturation ampere turns equal to 0.25 of gap ampere turns for $x_d' = 0.20$ and $x_d = 1.40$. The range of currents encountered in calculating the swings of a condenser in a stability problem is generally from 1 to 2 for which the average reduction factor, from curve C, is 0.87.

For turbine generators the tested transient reactances (table II and figure 3) show similar ratios of values measured by short circuit at full and at half voltage. The effects of saturation on the transient reactance of turbine generators cannot be calculated by any relatively simple manner, such as that used for salient pole machines. The calculation of the reduction factor k_{sm} for the saturation of the main magnetic circuit is the same as for salient pole machines. This fixes the reduction in transient reactance when operating at full voltage with low currents as about 0.97. The remainder of the curve is drawn from the test points in figure 3.

Saturation Factors for Time Constants. Tests[6] show that the open circuit transient time constant T_{d0}' is not appreciably affected, nor is the subtransient time constant T_d'' of either turbine generators or salient pole machines.

The test data of tables I and II show that on the average the transient time constant T_d' varies in the same manner as the transient reactance. If the variation is assumed to be exactly the same, the relation $T_d' = \frac{x_d'}{x_d} T_{d0}'$ is still maintained.

Summary

From the data presented here, it is concluded that there is one value of each of the important constants of a synchronous machine which can be used for most purposes and which should be understood unless the value is otherwise qualified. The one value to be used for most purposes is the saturated value for the following constants:

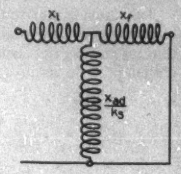
Transient reactance	$= x_d'$
Direct subtransient reactance	$= x_d''$
Negative sequence reactance	$= x_2$
Zero sequence reactance	$= x_0$
Quadrature axis subtransient reactance	$= x_q''$
Transient time constant	$= T_d'$

The synchronous reactance x_d should be understood to be the unsaturated value as now defined by the A.I.E.E. Data have been presented in the curves of figures 1, 2, and 3 from which the relations between saturated, unsaturated, or partially saturated values can be obtained.

Table III gives the average ratios between the saturated and the unsaturated values of the constants.

The term "saturated value" as used here means the value which would be determined by a sudden short circuit from full voltage. This does not mean that it would be necessary to make sudden short-circuit tests at full voltage in every case to establish the value of the constants, since some of the simpler

Fig. 4. Equivalent circuit for transient reactance



tests can be made for the unsaturated values and the saturation factors given here applied to determine the saturated value.

The curves of figures 1, 2, and 3 may be used to determine the saturation factors to be applied to either saturated or unsaturated values of normal machines. Although individual machines will vary somewhat from these average factors based upon typical machines, the application of such factors does give an increase in the accuracy over that which could be obtained by using a single value.

Appendix A—Effect of Saturation of the Main Magnetic Circuit

The total reduction of transient reactance due to saturation may be considered in 2 parts, first, due to saturation of the main magnetic circuit, and second, due to saturation of the leakage paths. These will be calculated separately as 2 separate factors which may be multiplied to give the total reduction factor. This method is not rigorously correct, since saturation in the one part affects the other but these secondary effects are small and will be neglected.

The reduction factor k_{sm} due to the saturation of the main magnetic circuit is very readily calculated if the transient reactance is

resolved into its components: armature leakage x_l, field leakage x_p, and magnetizing reactance x_{ad} as shown in the equivalent circuit of figure 4.

The reduction in permeability of the parts of the main magnetic circuit has an effect equivalent to increasing the air gap or of directly reducing x_{ad}. If the total ampere turns required to take care of saturation is $F_t = E_s F_g$ where F_g = the no-load gap ampere turns, and E_s = per unit excitation required for saturation; the gap ampere turns for the given flux is $E_g F_g$, where E_g = per unit air gap voltage. Then the factor by which x_{ad} is divided is: $k_s = \frac{E_g + E_s}{E_g}$

The unsaturated transient reactance x_{du} may be calculated as

$$x_{du}' = x_l + \frac{x_p \cdot x_{ad}}{x_p + x_{ad}} \tag{1}$$

The saturated value x_d' may be calculated as:

$$x_d' = k_{sm} x_{du} = x_l + \frac{x_p \cdot x_{ad}}{k_s x_p + x_{ad}} \tag{2}$$

From this relation k_{sm} may be calculated as:

$$k_{sm} = \left[\frac{x_l}{x_{du}} + \frac{x_p}{x_{du}} \left(\frac{x_{ad}}{k_s x_p + x_{ad}} \right) \right] \tag{3}$$

For a normal relation between the reactances: k_{sm} = 0.98 for k_s = 1.15, which is typical of no load; and for k_s = 1.30, which is a typical full load value, k_{sm} = 0.957.

Appendix B—Effect of Saturation of the Pole Tips on Transient Reactance of Salient Pole Machines

The effects of pole tip saturation were studied originally by calculating the densities throughout the pole tip for various values of armature and field currents. Out of this study the following simplified method was developed based upon the assumption that the ampere turn drop in the pole tip is the same as if the density at every point was the same as at a point A, $^1/_3$ the way from the body to the end of the pole tip.

The pole tip leakage flux per inch of length $\phi_{pl} = \lambda_{pl} F$ where F is the total field ampere turns per pole and λ_{pl} is 3.19 times the ratio of effective width to length of path for the pole tip flux up to the point C. See figure 5. The point C was chosen so the pole tip flux up to this point includes the differential leakage of the field which was caused by harmonics of the field form. The differential leakage is assumed to vary with saturation in the same manner as the pole tip leakage.

The air gap flux per inch ϕ_{pt} which enters the pole tip up to the point A (which is $^1/_3$ the way from the pole body out to the end of the pole tip; see figure 5) may be calculated by assuming that the net magnetomotive force acting across the gap at the center of this section (point B, figure 5) is the field ampere turns F minus the armature magnetomotive force at this point. The point B is normally about 60 degrees from the pole center and the ampere turns acting across the gap may be taken as $F_A \left(\frac{I_d}{2} \pm 0.866 I_q \right)$ where F_A = the maximum armature magnetomotive force. The assumption that the ampere turn drop is the same as if the density were the same as at point A throughout the pole tip, leads to a simple method of

Table III—Average Ratios Between Saturated and Unsaturated Values of Constants

Constant	Salient Pole Machine: With dampers	Salient Pole Machine: Without dampers	Turbine Generators (Solid rotor): 2 pole	Turbine Generators (Solid rotor): 4 pole
Transient reactance	0.88	0.88	0.88	0.88
Subtransient reactance	1.0	0.88	0.65*	0.77*
Negative sequence reactance	1.0	0.88	0.65*	0.77*
Zero sequence reactance	1.0	1.0	1.0	1.0
Transient time constant	0.88	0.88	0.88	0.88

* The ratio of the saturated value to the rated current value of subtransient and negative sequence reactance of 2 pole turbine generators is 0.73, and the same ratio for 4 pole turbine generators is 0.87.

For large 25 cycle single phase machines the ratio of saturated to unsaturated value of subtransient and negative sequence reactances is 0.88.

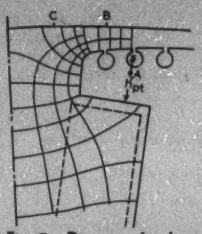


Fig. 5. Diagram of pole tip flux at no load, no saturation

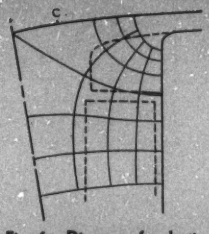


Fig. 6. Diagram of pole tip flux at no load assuming unit permeability in the pole tip

calculating the saturation effects. The saturation curve of the iron will be approximated by assuming that for densities below 125,000, negligible saturation exists and any flux above this value requires the same ampere turns as if it were in air. The pole tip leakage field assuming unit permeability for the pole tip is shown in figure 6; the pole tip and belt leakage for this condition is about 0.2, the value which would be obtained with no saturation; and I_d and I_q are the per unit direct and quadrature axis components of current. The + sign is used for one pole tip and − for the other. It can be shown that, approximately:

$$\phi_{pt} = \lambda_{pt} \left[F - F_A \left(\frac{I_d}{2} \pm 0.866 I_q \right) \right]$$

The density B_{Pt} which would exist at the point A if no saturation existed would be:

$$B_{pt} = \frac{\phi_{pt} + \phi_{pl}}{h_{pt}'} = F \frac{(\lambda_{pl} + \lambda_{pt})}{h_{pt}'} - F_A \left[\frac{I_d}{2} \pm 0.866 I_q \right] \frac{\lambda_{pt}}{h_{pt}'}$$

where h_{Pt}' = depth of pole tip at point A, as shown by figure 5; subtract $^1/_2$ the depth of the damper bar to give effective depth.

As a reference it is convenient to calculate the pole tip density at no load (B_0)

$$B_0 = F_g \left(\frac{\lambda_{pl} + \lambda_{pt}}{h_{pt}'} \right)$$

where F_g = the gap ampere turns at rated voltage.

$$\left[B_{pt} = B_0 \left\{ \frac{F}{F_g} - \left(\frac{\lambda_{pl}}{\lambda_{pl} + \lambda_{pt}} \right) \frac{F_A}{F_g} \left[\frac{I_d}{2} \pm 0.866 I_q \right] \right.$$

Hence, this part of the reactance is reduced by the factor:

$$\left[\frac{125{,}000}{B_{pt}} + 0.2 \left(1 - \frac{125{,}000}{B_{pt}} \right) \right]$$

For the purpose of obtaining a simple result applying to normal machines, certain typical relations will be assumed:

$$\frac{\lambda_{pl}}{\lambda_{pl} + \lambda_{pt}} = 0.65; \quad \frac{F_A}{F_g} = 0.845 X_{ad} I_d$$

then:

$$\frac{F}{F_g} = [E_d' + E_s + I_d(X_d - X_d')]$$

and assuming:

$$X_{ad} = 0.9 X_d \text{ and } X_d - X_d' = 0.78 X_{ad}$$

then

$$B_{pt} = B_0 [E_d' + E_s + 0.375 X_d (I_d \pm 2 I_q)]$$

The value of B_0 varies quite a little so that some variation in saturation may be expected, but a typical value of B_0 = 83,000 will be used. It will also be assumed that $^1/_3$ of the total reactance is effected by pole tip saturation:

$$k_{sl} = 0.735 + \frac{0.40}{E_d' + E_s + 0.375 X_d (I_d \pm 2 I_q)} \tag{4}$$

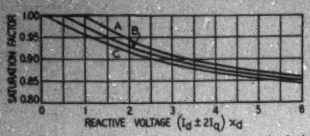


Fig. 7. Reduction factor k_d as a function of $(I_d \pm 2I_q) \times_d$

Curve A—$(E_d' + E_a) = 1.15$; typical of short circuit from no load

Curve B—$(E_d' + E_a) = 1.30$; typical of machine at 1.0 to 0.8 power factor

Curve C—$(E_d' + E_a) = 1.45$; typical condenser

From equation 4 the curves of figure 7 are calculated. They give k_d as a function of $(I_d \pm 2I_q)$ for different values of $(E_d' + E_a)$. The factor is to be calculated using both signs for I_q and the 2 results averaged. The net factor k_d times k_{sm} gives the total reduction factor for transient reactance of salient pole machines.

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Complex Hyperbolic Function Charts

Complex hyperbolic function charts covering the range ordinarily found in problems dealing with long electric power transmission lines are presented herewith. By restricting the charts to this range, it has been possible to draw them to a large scale so that good accuracy can be obtained from these comparatively small charts.

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THE important pioneer work of Dr. A. E. Kennelly in developing the use of complex hyperbolic functions for the solution of alternating current problems is well known. His tables and charts of complex hyperbolic functions have been of great service, but they cover a range so broad that the power transmission engineer finds difficulty in obtaining from them precise values. The purpose of the small set of charts presented herewith is to make possible more rapid, accurate, and convenient solutions of problems dealing with long electric power transmission lines. Only the portion of the complex plane lying in the range of power transmission problems has been mapped. This makes possible the use of a large scale. The range covered is from 0 to 290 miles at 60 cycles per second, and from 0 to 700 miles at 25 cycles.

The independent variable used in mapping is ZY, or θ^2, rather than θ. This obviates the necessity of taking the square root of ZY to find θ, which has been the common practice. It has the further advantage of causing adjacent curves of constant size of the independent variable to be nearly equidistant, which is a considerable advantage in legible mapping and accurate reading.

By careful use of the charts, with visual interpolation, a precision of 1 part in 10,000 may be obtained. If only slide rule accuracy is desired, it may be obtained by reading only to the nearest divisions of the function scales.

It has been customary to use the following formulas for solving steady-state long-line problems:

$$E_G = E_L \cosh \theta + I_L Z_0 \sinh \theta \qquad \text{vector volts} \qquad (1)$$

$$I_G = I_L \cosh \theta + \frac{E_L}{Z_0} \sinh \theta \qquad \text{vector amperes} \qquad (2)$$

or

$$E_L = E_G \cosh \theta - I_G Z_0 \sinh \theta \qquad \text{vector volts} \qquad (3)$$

$$I_L = I_G \cosh \theta - \frac{E_G}{Z_0} \sinh \theta \qquad \text{vector amperes} \qquad (4)$$

in which $\theta = \sqrt{ZY}$, $Z_0 = \sqrt{Z/Y}$, and Z and Y are respectively the total series impedance and the total shunt admittance per phase; E_G, E_L, I_G, and I_L are the voltages and currents at the generator and load ends, respectively, of the line.

The following formulas are equivalent to formulas 1, 2, 3, and 4 and less laborious to use:

$$E_G = E_L \cosh \theta + I_L Z \frac{\sinh \theta}{\theta} \qquad \text{vector volts} \qquad (5)$$

$$I_G = I_L \cosh \theta + E_L Y \frac{\sinh \theta}{\theta} \qquad \text{vector amperes} \qquad (6)$$

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or

$$E_L = E_0 \cosh \theta - I_0 Z \frac{\sinh \theta}{\theta} \quad \text{vector volts} \qquad (7)$$

$$I_L = I_0 \cosh \theta - E_0 Y \frac{\sinh \theta}{\theta} \quad \text{vector amperes} \qquad (8)$$

The necessity of calculating Z_0 is eliminated. Also, the necessity of having a chart of sinh θ is eliminated, and 3 charts are sufficient, whether the solution is to be carried out by formulas 5 to 8, or by an equivalent π or T circuit. In the equivalent π, the architrave or top impedance Z' and the pillars or upright admittances $Y'/2$ have values equal respectively to:

$$Z' = Z \frac{\sinh \theta}{\theta} \text{ and } \frac{Y'}{2} = \frac{Y}{2} \frac{\tanh \theta/2}{\theta/2}$$

In the equivalent T line the arm impedances $Z''/2$ and the upright admittance Y'' are:

$$\frac{Z''}{2} = \frac{Z}{2} \frac{\tanh \theta/2}{\theta/2} \text{ and } Y'' = Y \frac{\sinh \theta}{\theta}$$

The original drawings for the charts were made to a large scale on heavy art board and have been reduced photographically to approximately $^1/_4$ size. The points for drawing the lines on the charts were located graphically by adding vectors representing the individual terms in the series expansion for each function, as given in a succeeding paragraph. Several hundred points on each chart also were checked against values given in Kennelly's tables or computed independently. In all cases the accuracy was within $^1/_{100}$ of 1 per cent.

The series expansions of the 3 functions follow:

$$\cosh \theta = 1 + \frac{ZY}{2} + \frac{(ZY)^2}{24} + \frac{(ZY)^3}{720} + \ldots$$

$$\frac{\sinh \theta}{\theta} = 1 + \frac{ZY}{6} + \frac{(ZY)^2}{120} + \frac{(ZY)^3}{5040} + \ldots$$

$$\frac{\tanh \theta/2}{\theta/2} = 1 - \frac{ZY}{12} + \frac{(ZY)^2}{120} - \frac{17(ZY)^3}{20{,}160} + \ldots$$

One advantage of using the 3 functions chosen is that each of them remains nearly equal to unity for small values of its argument. Consequently, the range that must be covered in the variation of the function is reduced to such an extent that great precision is easily possible in the charts.

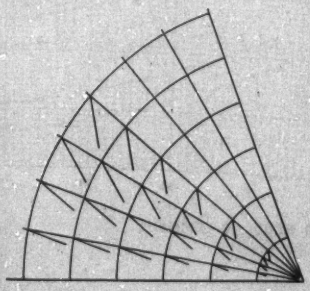


Fig. 1. A partially constructed chart

The first term of the series is the horizontal unit vector. Second term vectors have been drawn, and some of the third term angle lines

In drawing the charts, the origin of co-ordinates was allowed to fall far to the left of the drawing paper. The horizontal unit vector was shown only near its terminal point. From the terminal point, angle lines were drawn for each degree of ZY, and arcs of circles were struck about this point for each hundredth in the argument size. The points of intersection of

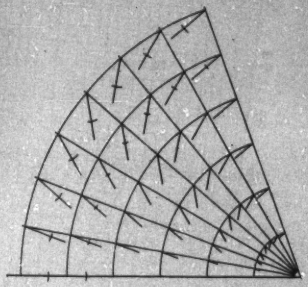


Fig. 2. Chart of figure 1 in a further stage of completion

All the third term angle lines have been drawn, and 2 sets of third term sizes have been laid off with compass

these arcs and angle lines represent the sum of the first 2 terms of the series. The third term is representable by a vector drawn at an angle double that of the second term and was added by drawing a series of lines from the intersection points at the appropriate angles. A drafting machine was used and after setting it at the correct angle, all third-term angle lines having that angle could be drawn rapidly. Figure 1 shows this stage of construction. After the entire set of angle lines had been drawn, a pair of dividers was set for the length of the third term corresponding to a definite size of the argument, and this length was laid off along all angle lines corresponding to that size. This construction is indicated in figure 2. Fourth and succeeding terms were added in a similar manner.

The basic co-ordinate scales necessarily had to be in polar form, since the size and angle were the basic co-ordinates and graphic construction used. The range is such, however, that the curvature and convergence of the lines are hardly noticeable. Precise geometric methods were used to lay out the main points, and large railroad curves were used in the inking of the final lines.

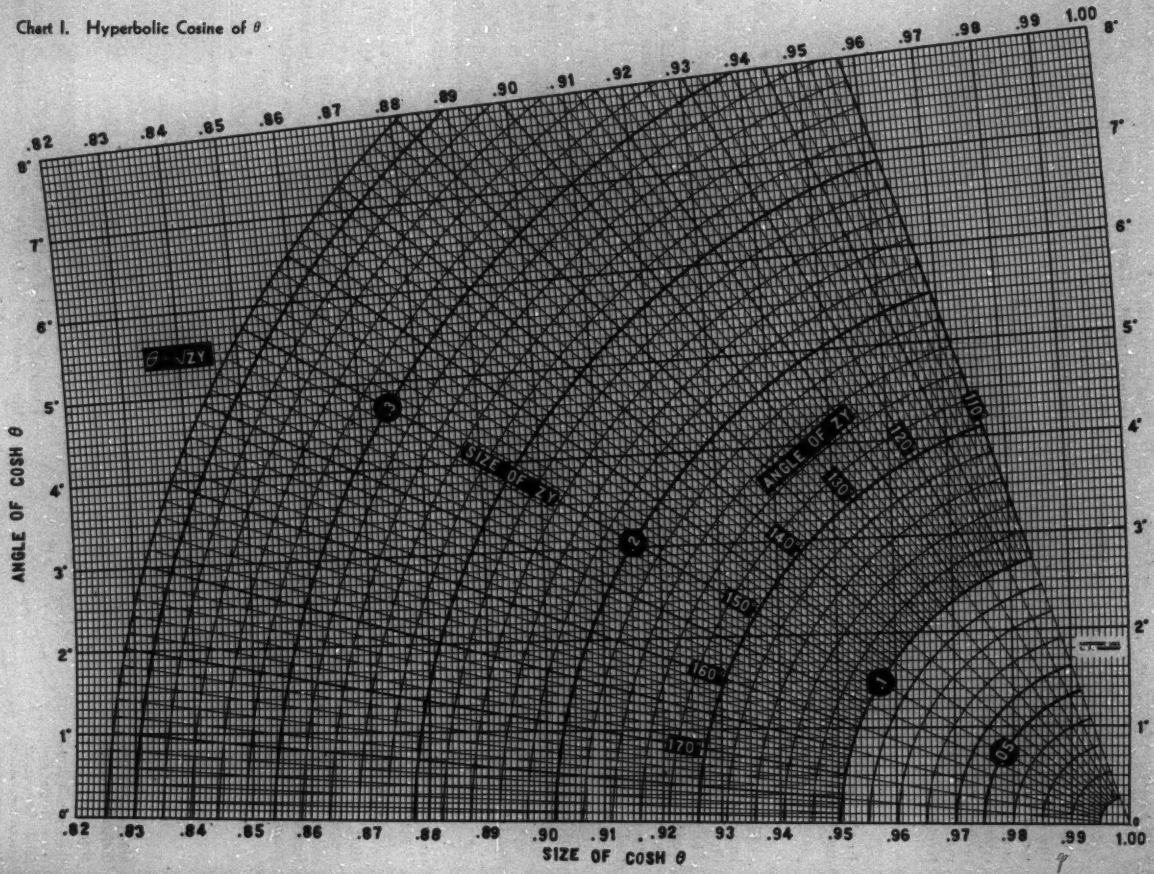
Example of Use

A transmission line has total series impedance per phase, Z, of 200.0 $\underline{/80.00°}$ vector ohms, and total shunt admittance, Y, of 0.00130 $\underline{/90.00°}$ vector mho per phase to neutral. Find cosh θ and $\frac{\sinh \theta}{\theta}$.

$$ZY = 200.0 \underline{/80.00°} \times 0.00130 \underline{/90.00°} = 0.260 \underline{/170.00°}$$

Entering chart I with this value of ZY, it is found that cosh θ = 0.8750 $\underline{/1.41°}$. Similarly, from chart II, $\frac{\sinh \theta}{\theta}$ = 0.9578 $\underline{/0.44°}$.

Chart I. Hyperbolic Cosine of θ



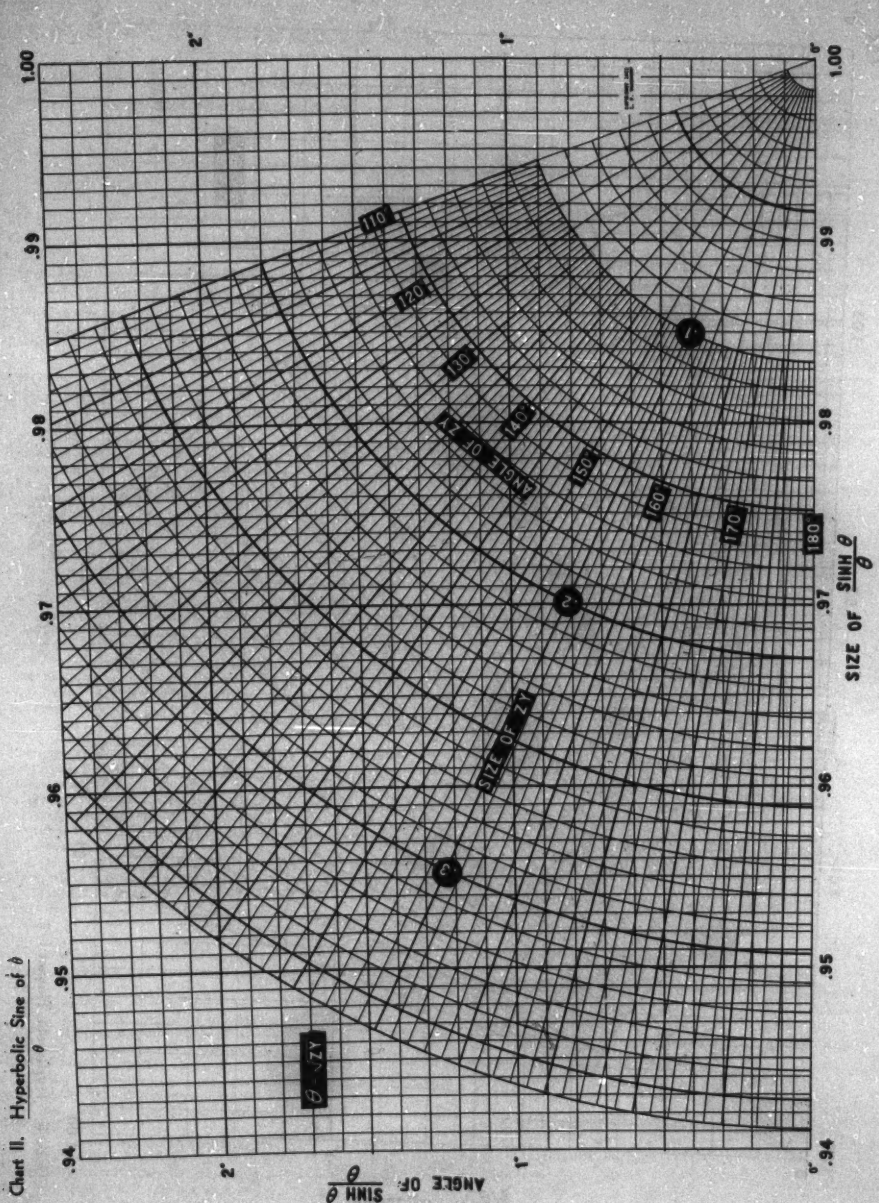


Chart II. Hyperbolic Sine of θ / θ

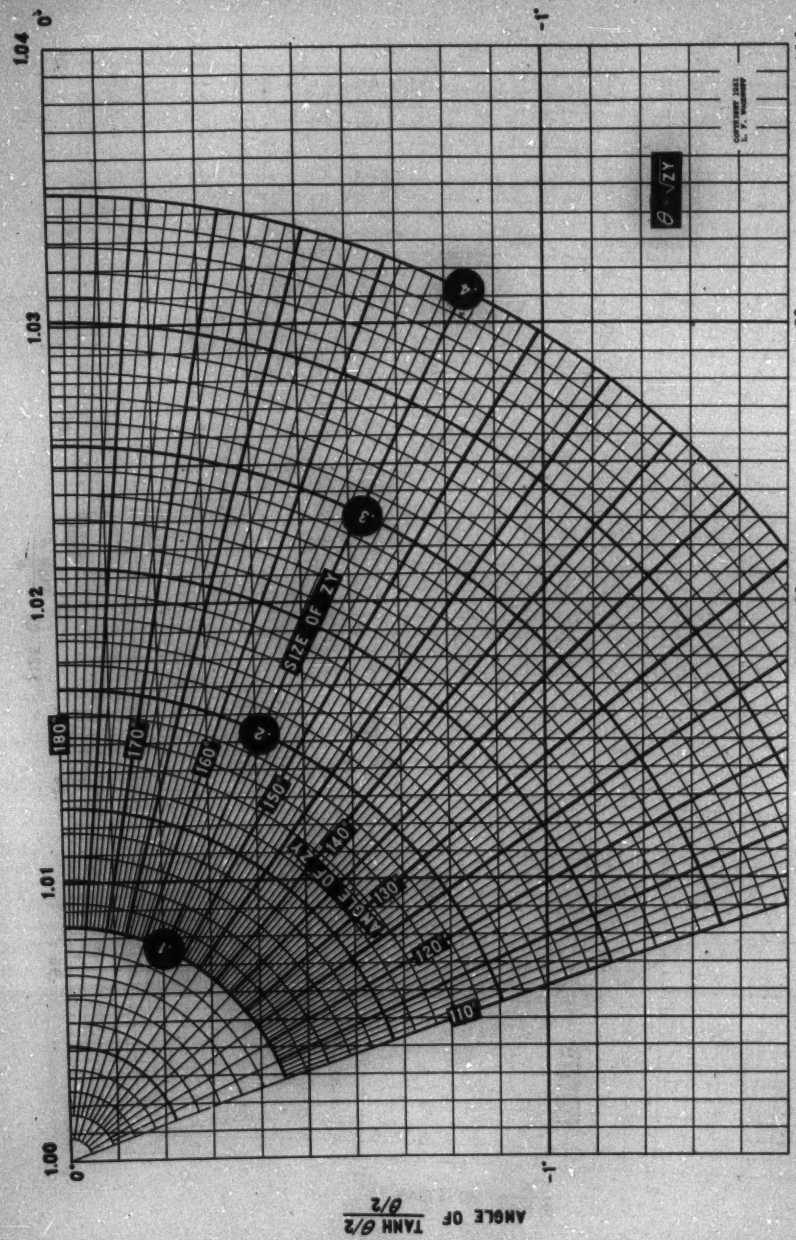


Chart III. Hyperbolic Tangent $\frac{\theta/2}{\theta/2}$

Discussions

Of A.I.E.E. Papers—as Recommended for Publication by Technical Committees

IN order to provide additional space for the publication of summer convention papers in this issue the discussion has been limited to a total of 5 pages, in which appear the discussion of a paper presented at the 1934 A.I.E.E. North Eastern District meeting, Worcester, Mass., May 16–18, and several discussions and one authors' closure of papers presented at the 1935 A.I.E.E. winter convention, New York, N. Y., January 22–25, 1935. Other discussions of winter convention papers appear in ELECTRICAL ENGINEERING for March 1935, pages 322–35, and April 1935, pages 431–9; further discussions and authors' closures will be published in later issues.

Heat Flow in Turbine Generator Rotors

Discussion of a paper by C. E. Peck published in the October 1934 issue, pages 1359–65, and presented for oral discussion at the electrical machinery session of the winter convention, New York, N. Y., January 22, 1935.

D. S. Snell (General Electric Co., Schenectady, N. Y.): In the past few years several attempts have been made, chiefly by French and German investigators, to obtain a rational solution to the problem of heat flow in a turbine generator rotor. For the most part, however, the solutions obtained have been somewhat too involved to be of practical value to the designer and also have been based upon certain simplifying assumptions which, for many types of rotor construction, are not justifiable. This paper, I believe, represents a distinct advance over the work that has been previously done in this field in that the solution neglects no important factors, and also is not too involved for use in practical design calculations. The purpose of this discussion is to suggest a method for obtaining the overall temperature rise constant of the rotor body, using the equations developed in the paper, which takes account of the difference in the cooling conditions at different parts of the body.

With the type of rotor ventilation considered in the paper the internal cooling conditions vary considerably throughout the rotor, so that the use of an average surface heat transfer coefficient for the internal ducts and an average temperature rise for the internal cooling air in calculating the temperature rise constant of the body may not always lead to accurate results. I would consider it more accurate, in calculating this constant, to assume the different sections of the rotor which have dissimilar cooling conditions as thermally insulated from each other, and to calculate the temperature rise constant for each section separately. A weighted average of these constants could then be taken to represent the temperature rise constant of the body.

In figure 1 of this discussion is shown a representative section of a rotor body divided into sections for which the cooling conditions are dissimilar. There are indicated, for the rotor considered, 21 sections for which different temperature rise constants could be calculated. It can be shown however, that the cooling conditions for sections 11–15 do not differ greatly from the conditions for sections 16–21, also that the effect on the total temperature rise constant of the body of the inferior cooling conditions for sections 1–10 as compared with sections 11–21 can be allowed for through a correction factor. It should be possible, therefore, to determine a satisfactory temperature rise constant for the rotor body by calculating the temperature rise constants for sections 11–15 only and applying a correction factor to the resultant weighted mean constant.

To take account of the elevation of the temperature of the cooling air in passing through the body, the ambient air temperature rise θ_a in the equations for the copper and iron temperature rises inside the surface of division should be taken as the rise of the air up to the rotor section under consideration, and the surface heat transfer coefficients for the axial and radial ducts should be referred to this temperature. A convenient equation for calculating the heat transfer coefficient on this basis is given by Richter in his book "Elektrische Machinen," volume I, page 324, and is as follows:

$$h = \frac{scv}{2L}(1-e^{-m}) \text{ watts per square centimeter per degree centigrade}$$

where

$$m = 0.1448\,\frac{L^{0.946}}{(2r)^{1.16}}\left(\frac{h}{scv}\right)^{0.316}$$

L and r are the duct length and hydraulic radius, respectively, in centimeters; v the air velocity in centimeters per second; h

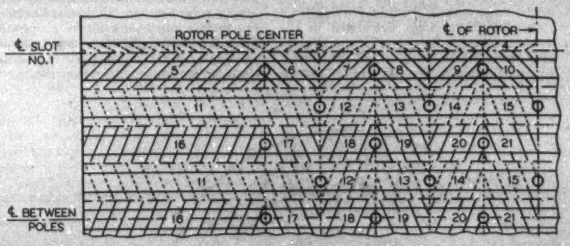


Fig. 1 (above). Development of rotor surface showing division of body into sections having dissimilar cooling conditions

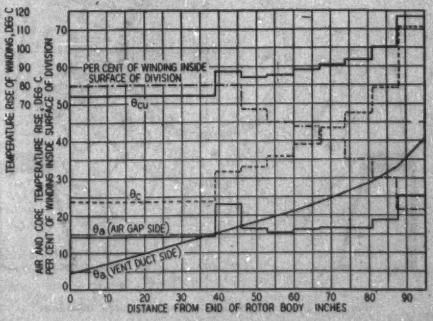
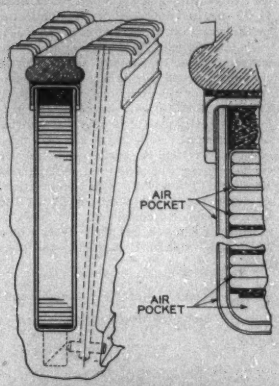


Fig. 2. Calculation of temperature rise of a turbine generator rotor winding

the thermal conductivity in watts per degree centigrade per centimeter; s the specific weight in grams per cubic centimeter; and c the specific heat in joules per degree centigrade per gram for air at the temperature $\frac{t_0 + t_3}{2}$, where t_0 is the temperature of the air entering the duct and t_3 the mean temperature of the duct walls.

In figure 2 is shown the temperature rise



Figs. 3 and 4. Rotor slot ideal for heat flow, and same slot with such air pockets as may form

of the body part of the field winding for a rotor 190 inches long, calculated in the above manner for the generator operating at zero power factor, overexcited. This rotor was provided with 40 axial ducts, and an average of 9.5 radial ducts per tooth, spaced 14 inches apart. The calculation shown in figure 2 is for a tooth remote from the pole center, such as number 2 or 4 in figure 1, and assumes the tooth to be divided into 9 sections thermally insulated from each other, the first section from the end of the body including the distance to the first radial duct, the other sections including $^1/_3$ the distance between adjacent ducts. From this calculation, the mean temperature rise constant of the body, referred to the average of the air temperatures in the axial ducts and air gap, was found to be 3.18 degrees centigrade per watt per inch of coil. For the ventilated end winding the calculated temperature rise constant was 4.86 degrees per watt per inch. Combining these 2 constants in accordance with equation 8 of the paper, the mean temperature rise of the winding θ_{rem} for the load considered was calculated to be 92.8 degrees centigrade. The measured temperature rise for this load was 86.5 degrees centigrade. The agreement between calculation and test is thus within 7 per cent, which, for this type of calculation can be regarded as very good, and indicates the general reliability of Peck's solution to the heat flow problem for turbine generator rotors.

S. H. Mortensen (Allis-Chalmers Mfg. Co., Milwaukee, Wis.): Progress in electrical machine design has been achieved through improvements in available construction materials combined with a better understanding of factors affecting machine operation. This paper is a valuable contribution to the latter. To those who have been active in the development of high speed turbine generators it is most interesting to see a comprehensive analytical method for predetermining rotor heating. It is an achievement to have put into a workable form a problem involving heat generation, flow, and dissipation in more than one plane in a body of irregular configuration and heat conductivities. As the agreement between the calculated rotor heating and test values depends upon the choice of constants derived from tests, a few remarks bearing upon the latter may be of interest. Types of ventilation mentioned in the following discussion pertain to machines made by the Allis-Chalmers company.

Briefly, the main constants needed for predetermining rotor temperature rise must take into consideration its heat losses and the thermal resistivity of its materials and contact surfaces, combined with the coefficient of heat transfer between its radiating surfaces and ventilating air.

Of these factors the magnitude and distribution of rotor heat losses are easy to predetermine, except in cases involving single phase or unbalanced polyphase operation. In modern machines with balanced loads, rotor stray losses are negligible and the main rotor heat loss is the I^2R of excitation.

Factors for thermal conductivity of the rotor materials can also be predetermined with accuracy. It is a more difficult problem to arrive at the proper constants for thermal resistances of the surfaces between the heated copper and the rotor iron. Inconsistencies in heating results on duplicate machines frequently can be attributed to air pockets resulting from inaccuracies in the dimensions of the rotor insulation, copper, and slots. This condition is brought out in figures 3 and 4 of this discussion, of which figure 3 depicts a rotor slot ideal for heat flow, because of the absence of air pockets. Figure 4 shows the same slot with such air pockets as may result from inaccuracies in winding, slot machining, and shrinkage of insulation materials. The effect of the air pockets upon the temperature gradients between copper and iron could be predetermined, if the magnitude of the air pockets were known.

The constant, taking into consideration the coefficient of heat transfer between the respective rotor radiating surfaces and the ventilating air, varies considerably with different types of stator and rotor ventilation and must, for that reason, be derived by experimentation. Figure 5 shows the type of ventilation used on Allis-Chalmers' larger machines. A great many schemes for increasing rotor output by improved heat

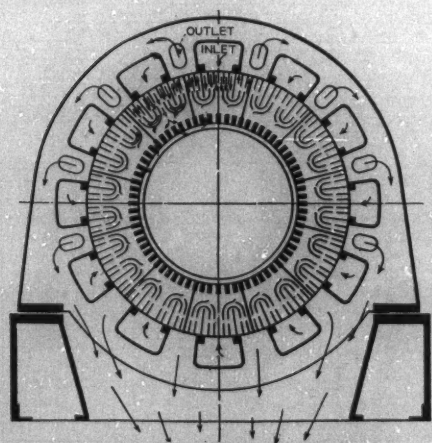


Fig. 5. Type of ventilation used on large machines

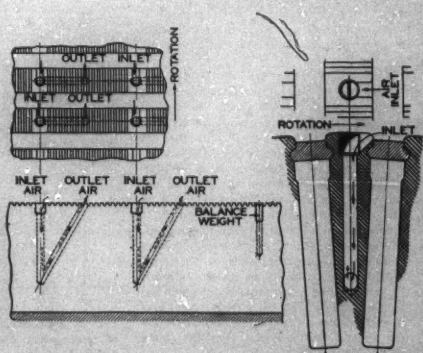


Fig. 6. Type of ventilation used on long rotors

dissipating capacities have been tested out at various times, frequently giving disappointing results which could have been foreseen with the aid of an analytical investigation. The rotor tooth ventilating scheme shown in figure 3 is used on rotors of short and medium lengths. Rotors of great axial length are ventilated as indicated in figure 6. With this scheme, the cylindrical radiating surface of the rotor is augmented with radial vent ducts in the rotor body. By special design, the entrance side of the duct produces an impact head, which forces air from the air gap through the ducts back into the air gap, from which it passes through the ventilating paths as indicated in figure 5. This type of ventilation has been satisfactory on rotors of lengths up to 283 inches and with peripheral velocities up to 26,000 feet per minute.

The importance of ventilating rotor coil ends has been recognized since the early days of turbogenerator construction. On present designs it is taken care of by means of ventilating ducts in the rotor coil support rings as well as in the portion of the rotor body adjoining the coil ends. The ventilating openings are located with the idea of obtaining high air velocities over the exposed coil ends and eliminating dead air pockets.

In conclusion I wish to reiterate that Peck's work is of practical value, not only in analyzing test results but also as a contribution to the further advances of the art of rotor design.

Transients in Magnetic Systems

Discussion of a paper by C. F. Wagner published in the March 1934 issue, pages 418–25, and presented for oral discussion at the electrical machinery session of the winter convention, New York, N. Y., January 22, 1935.

Ernst Weber (Brooklyn Polytechnic Institute, Brooklyn, N. Y.): This paper represents a valuable extension of the original treatise ("Field Transients in Magnetic Systems," Ernst Weber, A.I.E.E. TRANSACTIONS, volume 50, 1931, pages 1234–46) to cases where the relative amount of magnetomotive force expended on the solid section of the magnetic path is a large fraction of the total magnetic motive force in the magnetic circuit. This ratio is defined as

$$\mu = \frac{b}{a + b}$$

where $b = \frac{l_s}{\mu_s}$ and $a = \delta + \frac{l_l}{\mu_l}$ with l the length, μ the relative permeability, δ the length of the air gap, and subscripts s and l indicating the solid and laminated parts, respectively. Obviously μ will be large if a is much less than b, as when the air gap δ is very small and when μ_s is very small.

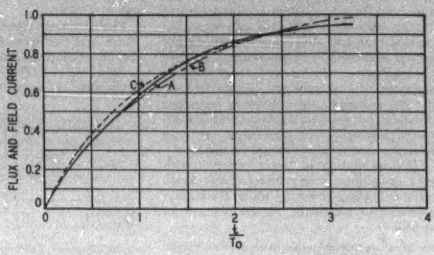
In the case of small air gaps, however, the fundamental assumption of Wagner, that the readjustment of the distorted magnetic flux, as present in the solid part, to uniform distribution in the laminated part shall occur in an infinitely thin layer of infinite permeability, cannot be true. It seems reasonable to assume that the transition to uniform distribution will be gradual and might occupy the whole air gap length so that, in fact, the true problem should include the solution of the magnetic field distribution in the air gap with given boundary distributions on either side of the air gap. A vigorous solution of this problem would hardly be justified and from the small correction to be applied one can infer that the complete solution of the problem would give results somewhere between the values presented in the 2 papers. Large d-c machines, certain relay circuits, and possibly galvanometers might present magnetic circuits requiring the more involved treatment as given by Wagner, whereas the synchronous machine problems are, in general, adequately covered by the original theory.

Fig. 1. Variation of total flux and field current as a function of t/T_0

A. Magnetic field flux ϕ from oscillogram

B. Exciting current I from oscillogram

C. Computed field transient



To give an example, oscillograms have been taken on a smaller synchronous generator in the electrical laboratory of the Polytechnic Institute of Brooklyn. The 3-phase generator rated 7.5 kva at 110 volts per phase was driven by a d-c motor at synchronous speed with the field circuit switch open. At the instant of closing this switch the current induced in one of the stator phases, short circuited through a large resistance, and the current in the exciting winding were oscillographed simultaneously (see figure 1 of this discussion). From the curves a true time constant of the magnetic field could be evaluated as $T_\phi = 0.1486$ second. Computations from the known data of the generator lead to the following values: $T_0 = \frac{L_0}{R} = 0.144$ second, $T_s = 0.942$ second, and $\mu = 0.0341$. The small value of μ tends to indicate a very small deviation from the exponential curve for the magnetic field and a comparison with the computed curves in the paper by Wagner confirms this.

It is interesting now to contrast the value of the field time constant as given by equation 59 in the original paper with the experimental value given here. According to definition, $\theta = \mu T_s = 0.0353$ second and $\frac{\theta}{T_0} = 0.218$ so it follows that

$$T_\phi = T_0 + 0.12\theta = 0.144 + 0.0042 = 0.1482 \text{ second}$$

which is in very close agreement with the test. It seems, therefore, that it is quite possible to predict the time constant of complex magnetic circuits with fair accuracy if the air gap is comparatively large. Unfortunately Wagner does not arrive at a similar simple formula for the total magnetic time constant valid for small air gaps and showing the dependence on the ratio μ. This would be valuable for quick-excitation problems in large reversible d-c machines such as are used in mining and milling plants. (See "Wissenschaft Veroeff a. d. Siemens Konzern," E. Weber and H. Hess, 1930, volume 9, part 1, page 115.)

Expulsion Protective Gaps on 132 Kv Lines

Discussion of a paper by Philip Sporn and I. W. Gross published in the January 1935 issue, pages 66–73, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935. Other discussions of this paper were published in the March 1935 issue, pages 329–32.

C. M. Foust (General Electric Co., Schenectady, N. Y.): The performance of the expulsion protective gaps is very interesting, and highly gratifying to those who have taken part in this forward looking experiment. As I have had the opportunity to follow closely the tower structure current measurements, such as given in table V, I am very interested in the use made of these measurements in arriving at tube currents such as given in column 4 of this table. I note that the authors have used the laws of traveling waves, assuming that the stroke current travels to the tower where it seeks various paths, in the line conductor, ground wire, and through the tower to ground. On this basis tube currents arrived at range from 11,000 to 37,000 amperes. The cases considered include only those wherein tower leg currents above 25,000 amperes were recorded. I also note the authors' opinion that the true tube currents may be only $^1/_2$ the values given in the table.

Values of tube current may be arrived at by another method, as follows:

1. Calculate tower structure potential from tower footing resistance and tower leg current.
2. Take a conductor surge impedance in both directions such as 250 ohms and calculate tube current by dividing tower potential by this impedance.

I have worked out values using this method for all cases wherein the tower leg currents indicated direct strokes to towers.

The current values for the tubes obtained ranged from 450 amperes to 9,000 amperes, which range is about $^1/_4$ that given in table V. The average tower potential for single tube operation was 710 kilovolts, for 2 tube operation 970 kilovolts, and for all 3 tubes, top, middle, and bottom, 1,100 kilovolts. In the cases considered it is, of course, not certain that the stroke terminated on the tower; undoubtedly in some cases it reached the conductor. Such cases detract from the accuracy of this analysis. Again the use of the ordinary tower footing resistance measured at low voltage undoubtedly introduces errors. The true surge resistance at high current values should be used.

The correlation of tower currents with tube operations is very interesting. Again using only those towers at which the strokes appeared to terminate, current values ran as follows:

For top phase tube operation, tower currents ranged from 13,000 to 35,000 amperes, averaging 28,000 amperes.

For middle phase operation, tower currents ranged from 15,000 to 44,000 amperes, averaging 31,000 amperes.

For bottom phase operation, tower currents ranged from 23,000 to 49,000 amperes, averaging 36,000 amperes.

For top and middle phase operation, tower currents ranged from 30,000 amperes to 68,000 amperes, averaging 45,000 amperes.

For top and bottom phase operation, tower currents ranged from 28,000 to 30,000 amperes, averaging 29,000 amperes.

For middle and bottom phase operation, tower currents ranged from 38,500 to 52,000 amperes, averaging 45,000 amperes.

For top, middle, and bottom phase operation the tower currents ranged from 17,000 to 100,000 amperes, averaging 60,000 amperes.

The average tower current for single tube operation was 32,000 amperes; for 2 tube operation, 38,000 amperes; and for 3 tube operation 60,000 amperes.

More current measurements are required, particularly such measurements as might help to determine the correct method for determination of the tube currents.

P. L. Bellaschi (Westinghouse Elec. and Mfg. Co., Sharon, Pa.): The part lightning plays as a disturbing factor in the transmission and distribution of power is well known. To mitigate its effect has been the problem. In this respect field records of strokes of lightning near and at distribution transformers protected with deion gaps have furnished data. The electrodes of the deion gaps discharging the lightning current are marked with a surface figure which when compared with similar figures on deion gaps tested in the laboratory with known lightning currents, enables us to evaluate the lightning current discharged through the deion gap in service.

A record of lightning strokes near and at distribution transformers during 1932–33 is shown by the heavy line in figure 1 of this discussion. A direct stroke to the terminals of a transformer, which was recorded in 1934, indicated a current somewhat greater than 100,000 amperes. The dash-dot extension to 150,000 amperes in the figure is intended to represent the maximum current hereto recorded; however, this maximum value does not preclude the possibility of even 200,000 amperes in the more infrequent case of a very severe lightning stroke.

The lightning stroke current has also been evaluated from other physical effects manifested with the discharge, such as the fusion and crushing of conductors, the explosive action produced, etc. The currents evaluated in this way are well in accord with the values in figure 1.

The lightning stroke currents reported by Sporn and Gross in table V of their paper are interesting indeed. They are plotted in figure 2 of this discussion. It will be noted that the magnitude of the lightning

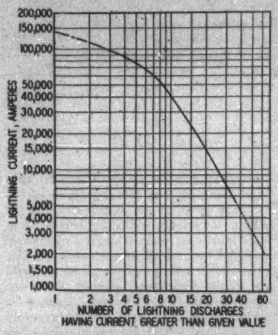


Fig. 1. Record of lightning strokes near and at distribution transformers during 1932–33

Transformer years = 4,000

stroke currents as established by the 2 sets of independent data in figures 1 and 2 are substantially the same. Furthermore, data on lightning currents presented at the A.I.E.E. Pacific Coast convention, September 1934, show similar distribution curves. Another interesting observation is the confirmation between the recent field data and the lightning stroke currents that have been calculated by C. L. Fortescue.

The data on lightning presented by the authors are distinct contributions to the art of lightning protection. From the

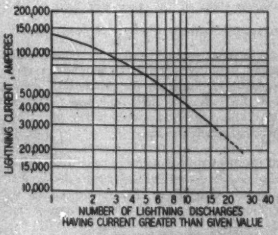


Fig. 2. Record of direct strokes of lightning to 132 kv transmission line

standpoint of the electrical engineer, perhaps the most important future work in the domain of lightning is to establish directly with the cathode ray oscillograph the amplitude and duration of the lightning stroke potential developed on electrical circuits. In all events, field experience will undoubtedly remain a most valuable source of information and in fact it alone can be the ultimate confirmation of the adequacy of the protective apparatus used.

A Carrier Current Relay Installation

Authors' closing discussion of a paper published in the January 1935 issue, pages 109–15, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935. Other discussions of this paper were published in the March 1935 issue, pages 333–4, and in the April 1935 issue, pages 445–6.

O. A. Browne and **W. L. Vest, Jr.** (both of Western Massachusetts Companies, Turners Falls and Springfield, respectively): A brief review of some of the existing conditions on this system will answer some of the questions raised in the discussion.

The lines on which the carrier controlled relays were installed were constructed between the years 1913–1918 inclusive, using double circuit steel towers. The spacing of the conductors is 8 and 9 feet, vertical. The insulation on approximately 80 per cent of the lines protected with the new relays is 4 and 5 standard 10 inch units, protected by arcing horns set with gaps of approximately 15 inches at suspension towers. One ground wire is used on all the towers. The insulation level is low enough to allow simultaneous flashover of both circuits from heavy induced lightning surges. From observations of relays and other equipment, the double circuit faults are generally simultaneous.

As a result of the location of these lines with respect to the large interconnected systems to the north and south, disturbances external to the system frequently caused unnecessary operations, thereby splitting the system. In order that these operations be kept at a minimum, high current and long time settings were required.

The new relay scheme was installed in May and June 1933, during the lightning season. This relay scheme was not tested with any artificial faults, as such a procedure was not practical on this system. The relays were expected to operate, and where incorrect relay operations occurred, the analysis of these operations would serve as a guide in correcting any troubles. Although this method is not conducive to the best operating record, it does have certain obvious advantages.

An analysis of the incorrect operations is shown in table I of this discussion. Generally, several incorrect operations would occur from the same cause before corrective measures could be made. It is quite common for the same section of line to trip out 3 to 5 times within an hour or so.

With the previous arrangement, surging and out-of-step conditions with the Connecticut system frequently occurred. During these occurrences the trouble would be cleared with the operation of the relays on the Hartford-Agawam lines, at either one

end or the other. These operations usually resulted in a drop in frequency on one of the 2 systems, dependent upon direction of load in the lines, and consequently some delay occurred before the systems could again be paralleled.

In the design of this relay scheme, no provision was made for controlled separation during out-of-step conditions, as it was believed that this situation would be vastly improved with the faster relays.

No change to a series or loop connection was made at any of the tap stations, as it was not considered desirable to transmit power across certain of the station busses. At stations such as Cobble Mountain there would be considerable line and voltage loss if the station were looped, particularly with the generators in service. However, cutting Amherst and Westfield into just one line as a loop station has been considered, as it will reduce outages to these stations when double circuit line faults occur in these sections.

The type *IAC* tripping relays were selected for use at the various sectionalizing stations as it would be possible to accurately predetermine the time and current values at which the relays would trip. At the tap stations, the *IDP* relays were chosen as being more sensitive both in current and time, although the values would be more difficult to predetermine, since the voltage restraint would be the deciding factor.

On the several tapped lines, it was considered desirable to allow 8 cycles time on the tripping relays at the ends of the line, and a somewhat lower setting at the tap stations, until some operating experience was obtained. The results obtained have been so good that, although the tripping time of the relays might be reduced somewhat, it is not absolutely necessary, and it does add somewhat to the hazard of incorrect operations.

Carrier current equipment was preferred over leased lines of the communications companies as it was considered desirable to have complete control of the pilot channel at all times. Also, many of the trunk communication lines in this area are of open wire construction. This is in no way any reflection on the quality of service now furnished us by the communication companies.

The dynamotor operating from the station battery was selected as the source of a constant supply alternating potential which could be used with a step-up transformer and rectifier to obtain the necessary direct potential. Alternating potential from the station service supply would be suitable, based on a voltage regulation standpoint, but would be subject to interruptions. In 2 years of operation, one failure of a dynamotor occurred, and this was not serious.

Although continuous carrier current systems are faster than those schemes used for blocking purposes only, the failure of the continuous system for any reason would result in unnecessary tripping.

All of the stations are protected with bus overload and ground protection. In addition, the phase overload relays act as transformer overload protection, and sufficient time is allowed to select with secondary feeders. The ground relay is set for a minimum current and time, dependent upon the type of relay used.

Table I—Analysis of Incorrect Relay Operations

Number of Incorrect Operations	Number of Failures to Operate	Cause
During 1933		
	6	Too sensitive a setting on *RCC* receiver relay
7	3	Incorrect connection of *ICC* and *ICP* ground relays
2		Improper co-ordination of the *ICC* relays at Cabot station with the *ICP* relays on the remainder of the system
1		Faulty relay adjustment
During 1934, to October 1		
9		Incorrect connection of a relay due to a panel change
9		Ground in current transformer
2		Improper co-ordination of the *ICC* relays at Cobble Mountain station with the *ICP* relays on the remainder of the system
2		Receiver relay failed to block tripping; cause unknown
	2	Cobble Mountain station shut down, no polarizing current in ground relays

The relays originally used for single circuit and double circuit protection at the sectionalized stations were left in service as back-up protection for the carrier relays. In some cases, the current settings were as high as 400 amperes (66 kv) each, per pair of circuits, or 800 amperes on the remaining circuit with one out of service and with time settings of 140 cycles at 10 times the above current settings.

Any relay scheme that the authors are familiar with requires the correct operation of all the relays on the system, for complete and successful protection. Of course, one must remember that "correct relay operation" often means no operation at all for a particular relay.

The M.I.T. Power Factor Bridge and Oil Cell

Discussion of a paper by J. C. Balsbaugh, N. D. Kenney, and Alfred Herzenberg published in the March 1935 issue, pages 272–9, and presented for oral discussion at the selected subjects session of the North Eastern District meeting, Worcester, Mass., May 16, 1934.

W. S. Baird (nonmember): The authors of this and the companion paper (Franklin Institute *Journal*, volume 49, 1934, page 218) have brought the Schering bridge to a degree of perfection, both in analysis and design, made necessary by the demand for precision in this most important field of research. The design of the component parts, the high voltage capacitors, and the cells, shows that due consideration has been given to all the factors recognized to be of influence when working in the specified range of power factor.

The change in the power factor of the oil cell as shown in figure 6 of their paper is not explained and the reason for such behavior is conducive to speculation. The fact that temperature error cannot be the cause, and the fact also that the power factor returned approximately to its original value seem to indicate that the cause lies in thermal expansion and subsequent cell deformation concurrent with such a heat cycle. That such may be the case and may cause considerable error if not taken into account has been shown recently in the paper by Whitehead and Greenfield (ELECTRICAL ENGINEERING, October 1934, pages 1389–96, and November 1934, pages 1498–1503). While measuring the specific resistance of mercury in "pyrex" glass tubes and over the identical temperature range covered by the authors of the paper under discussion, the writer found looped curves and ascribed them to dimensional changes in the glass. After successive runs, it was found that the variation with increasing and decreasing temperatures became smaller, as is shown also by the curves of figure 6. This can be explained as a result of successive annealing cycles. From curve *D* of the figure and the authors' discussion, it is not clear whether the experimental points represent increasing or decreasing temperatures, or both. If curve *D* represents both the results of increasing and decreasing temperatures after heating by induction, an interesting light is thrown upon the mechanism which gives rise to power factors for air capacitors in the region 10^{-4} for which a satisfactory explanation has not yet been given.

In previous papers and indeed in the present paper, the authors have indicated that they believe power factors of air condensers in the region 10^{-4} are caused by films of oxide on the measuring surfaces. Such an oxide film would have to be of considerable thickness to give rise to a resistance sufficient to account for a power factor of this order of magnitude, since the loss must result from the flow of the displacement current over the film and the resistance of that film. It is the opinion of the writer that the power factor can be accounted for by the fact that the surface of the metal used to form the capacitors is not smooth, even though care is taken to clean it. Such a roughened surface would have innumerable points giving occasion for local regions of high stress, and a subsequent Joule heating through the point itself, i. e., from the tip, or point of high stress, to the base, or region of lower stress. This is equivalent to saying that the surface density of charge is not uniform with the consequences resulting therefrom. The only evidence at present available to substantiate this theory is taken from a curve of the authors in the Franklin Institute paper, which shows that after wetting the surface of a capacitor, the power factor showed a decrease; the wetting gave at first a surface smoother than that of the metal. In the present instance, heating by induction may have smoothed the surface in several ways. This suggestion is offered for what it may be worth.

Toward the end of the paper the statement is made, ". . . prevents the oil test sample from being injected into a vacuum." Is one to infer from this that the authors consider the injecting of oil into a vacuum a bad practice?

News

Of Institute and Related Activities

Program of the A.I.E.E. Summer Convention at Cornell University

A PROGRAM replete with activities of interest to the profession has been arranged for the 51st annual summer convention of the Institute to be held on the campus of Cornell University, Ithaca, N. Y., June 24–28, 1935. The annual business meeting, conference of officers, delegates, and members, board of directors' meeting, 10 technical sessions, and a number of technical conferences assure a busy and profitable week for those who wish to keep pace with Institute affairs and the progress of the art. Also, sports, trips, and recreation, as well as entertainment for the visiting women, have not been overlooked. The evenings will be devoted mainly to social functions. All these activities are offered to members and guests at a very reasonable cost, made possible by the splendid facilities which Cornell University affords in a beautiful scenic setting. A large attendance is expected.

Of interest to some members of the Institute is the fact that during the latter part of the week immediately preceding the convention at Ithaca, the semi-annual meeting of The American Society of Mechanical Engineers will be held in Cincinnati, Ohio, June 19–21, 1935. Technical papers on a variety of subjects will be presented at the A.S.M.E. meeting, and a side trip to Norris Dam is scheduled by the A.S.M.E. for June 22. Members making this inspection trip should be able to arrive at Ithaca in time for the beginning of the A.I.E.E. meeting.

The general schedule of events for the A.I.E.E. convention is given below. Details of technical sessions, technical conferences, entertainment, inspection trips, sports, and other features are given in other parts of this article.

Summarized Schedule of Events

Eastern standard time is used in Ithaca throughout the year.

Monday, June 24

8:30 a.m.—Registration
10:00 a.m.—Opening of Convention
Address of welcome: Dr. A. R. Mann, provost, Cornell University
Annual Business Meeting of the Institute
Annual report of board of directors, in abstract, by H. H. Henline, national secretary
Report of committee of tellers on: (*a*) election of officers; (*b*) constitutional amendments
Introduction of and response from president-elect
Presentation of prizes for papers
Presentation of Lamme medal to Henry E. Warren
President's address: J. Allen Johnson
11:30 a.m. Conference of Officers, Delegates, and Members
1:00 p.m.—Lunch
2:00 p.m.—Conference of Officers, Delegates, and Members (continued)
2:00 p.m.—Technical Conferences
8:00 p.m.—President's Reception

Tuesday, June 25

9:00 a.m.—Instruments and Measurements Session
Power Generation Session
11:30 a.m.—Lecture
1:00 p.m.—Lunch
2:00 p.m.—Conference of Officers, Delegates, and Members (continued)
Technical Conferences
2:00–4:30 p.m.—Cars will leave campus for an outing to Taughannock State Park
5:30 p.m.—Shore Dinner at Taughannock
8:30 p.m.—Lecture

Wednesday, June 26

9:00 a.m.—Start of womens' trip to Corning Glass Works. Luncheon either in Corning or Watkins, followed by bridge or other entertainment
9:00 a.m.—Electrical Machinery Session—I
Protective Devices Session
Education Session
11:30 a.m.—Directors' luncheon meeting
9:00–2:30 p.m.—Cars will leave the campus for an inspection trip to the Corning Glass Works
Buffet supper at Corning

Thursday, June 27

9:00 a.m.—Electrical Machinery Session—II
Applications to Iron and Steel Production Session
Selected Subjects Session
11:30 a.m.—Lecture
2:00 p.m.—Technical Conferences
7:00 p.m.—Convention banquet; dancing

Friday, June 28

9:00 a.m.—Electrochemistry and Electrometallurgy Session
Power Transmission Session
12:00 Noon—Windup luncheon

Technical Sessions

A number of timely technical papers which have to do with some of the most recent developments will be presented in an enlarged program comprised of 10 technical sessions. The Boulder Canyon project will be quite thoroughly described by a series of papers to be presented in the sessions on power generation, power transmission, and protective devices. The hydroelectric construction will be given in a paper by L. C. McClellan, chief electrical engineer, U.S. Bureau of Reclamation, Denver, Colo. Some general features as well as the engineering features of the project and of the transmission system from Boulder Dam to the City of Los Angeles, will be given in 2 papers by E. F. Scattergood, Bureau of Power and Light, Los Angeles, Calif. Still another paper by D. C. Prince, General Electric Company, Philadelphia, Pa., will treat the theory, construction, and testing of the large 287 kv circuit breakers for this line. In addition, 7 other technical sessions embrace many valuable papers which will present the latest theories, designs, and researches in the following fields: instruments and measurements, electrical machinery (2 sessions), applications to iron and steel production, electrochemistry and electrometallurgy, education, and selected subjects.

In the technical program which follows, it may be noted that for the papers which already have been published, reference is given after the title to the issue and page of ELECTRICAL ENGINEERING publication. Remaining papers are scheduled for publication in the June issue. The availability of many of the papers considerably in advance of the convention will permit the careful preparation of discussion. Thus those who attend the sessions will be assured of hearing many pertinent discussions by engineers who are well known in their respective fields of endeavor.

RULES ON PRESENTING AND DISCUSSING PAPERS

At some of the technical sessions, a few papers may be presented only by title. This will permit the devotion of more time to discussion. At other sessions, papers will be presented in abstract, 10 minutes being allowed for each paper unless otherwise arranged, or the presiding officer meets with the authors preceding the session to arrange the order of presentation and allotment of time for papers and discussion. Authors will be notified officially in each case about one month in advance.

Any member is free to discuss any paper when the meeting is thrown open for general discussion. Usually 5 minutes are allowed

Technical Program

Tuesday, June 25

9:00 a.m.—Instruments and Measurements, W. B. Kouwenhoven, *chairman*

Precise Speed Control for D-C Machines, R. H. Frazier and J. Eisler, Massachusetts Institute of Technology, and W. F. Frantz, Curtis Publishing Company. March issue, p. 307–12

Definitions of Power and Related Quantities, H. L. Curtis and F. B. Silsbee, Bureau of Standards. April issue, p. 394–404

Direct Measurement of Surge Currents, C. M. Foust and J. T. Henderson, General Electric Co. April issue, p. 373–78

An Improved Electrothermic Instrument, P. M. Lincoln, Cornell University. May issue, p. 474–81

Lubrication Increases Life of Metre Bearings, T. A. Abbott and J. H. Goss, General Electric Co. April issue, p. 428–31

9:00 a.m.—Power Generation, H. W. Leitch, *chairman*

Engineering Features of Boulder Dam and Power Plant, L. N. McClellan, U. S. Bureau of Reclamation. Scheduled for June issue

Design and Operation of Huntley Station No. 2, H. M. Cushing, Buffalo General Electric Co. Scheduled for June issue

Rehabilitation of the Connors Creek Power Plant, R. E. Greene, Detroit Edison Co. Scheduled for June issue

Wednesday, June 26

9:00 a.m.—Electrical Machinery—I, V. M. Montsinger, *chairman*

An Analysis of the Induction Motor, S. J. Levine, General Electric Co. May issue, p. 526–9

Capacitive Excitation for Induction Generators, E. D. Bassett, F. W. Sickles Co., and F. M. Potter, General Electric Co. May issue, p. 540–5

Sparking Under Brushes of Commutator Machines, R. E. Hellmund and L. R. Ludwig, Westinghouse Electric and Mfg. Co. March issue, p. 315–21

Time-Temperature Tests to Determine Machine Losses, M. D. Ross, Westinghouse Electric and Mfg. Co. May issue, p. 512–5

9:00 a.m.—Protective Devices, H. P. Sleeper, *chairman*

Oil Circuit Breaker and Voltage Recovery Tests, E. J. Poitras, Ford Instrument Co., H. P. Kuehni and W. F. Skeats, General Electric Co. Feb. issue, p. 170–8

Breaker Performance Studied by Cathode Ray Oscillograms, R. C. Van Sickle, Westinghouse Electric and Mfg. Co. Feb. issue, p. 178–84

Circuit Breakers for Boulder Dam Line, D. C. Prince, General Electric Co. April issue, p. 366–72

The Determination of Circuit Recovery Rates, B. W. Boehne, General Electric Co. May issue, p. 530–9

Surge Currents in Protective Devices, A. M. Opshal, Westinghouse Electric and Mfg. Co. Feb. issue, p. 200–4

Fault and Out-of-Step Protection of Lines, H. D. Braley, The New York Edison Co., and J. L. Harvey, New York Power and Light Co. Feb. issue, p. 189–200

9:00 a.m.—Education, L. A. Doggett, *chairman*

An Advanced Course in Engineering, A. R. Stevenson, Jr., and Alan Howard, General Electric Co. March issue, p. 265–8

Possibly another paper.

Thursday, June 27

9:00 a.m.—Electrical Machinery—II, V. M. Montsinger, *chairman*

A Stroboscopic Power-Angle Recorder H. B. Edgerton, Massachusetts Institute of Technology. May issue, p. 485–8

Armature Leakage Reactance of Synchronous Machines, L. A. March and S. B. Crary, General Electric Co. April issue, p. 378–81

Transient Voltages in Rotating Machines, E. M. Hunter, General Electric Co. Scheduled for June issue

Saturated Synchronous Reactance, Charles Kingsley, Jr., Massachusetts Institute of Technology. March issue, p. 300–5

Insulation for High Voltage Alternators, C. M. Laffoon and J. F. Calvert, Westinghouse Electric and Mfg. Co. Scheduled for June issue

Effects of Saturation on Machine Reactances, L. A. Kilgore, Westinghouse Electric and Mfg. Co. May issue, p. 545–50

9:00 a.m.—Applications to Iron and Steel Production, R. W. Graham, *chairman*

D-C Braking of Induction Motors, F. E. Harrell and W. R. Hough, The Reliance Electric and Engineering Co. May issue, p. 488–93

Speed Transients of D-C Rolling Mill Motors, L. A. Umansky and T. M. Linville, General Electric Co. April issue, p. 387–4

Electric Power Equipment for Steel Plants, R. H. Wright, Westinghouse Electric and Mfg. Co. May issue, p. 481–5

D-C Circuit Breakers in Steel Mill Services, William Deans, I-T-E Circuit Breaker Co. Scheduled for June issue

9:00 a.m.—Selected Subjects, H. M. Turner, *chairman*

Protective Signaling, P. M. Farmer, American District Telegraph Co. Scheduled for June issue

D-C Clean-Up-In Insulating Oils, J. B. Whitehead and S. H. Shevki, The Johns Hopkins University. Scheduled for June issue

The Sparkless Sphere Gap Voltmeter, R. W. Sorensen, J. E. Hopson, and Simon Ramo, California Institute of Technology. Scheduled for June issue

Friday, June 28

9:00 a.m.—Electrochemistry and Electrometallurgy, N. R. Stansel, *chairman*

Opening Address.

Calculations for Coreless Induction Furnaces, H. B. Dwight, Massachusetts Institute of Technology, and M. M. Eagal, Ampere, N. J. March issue, p. 312–5

Storage Battery Charging, J. L. Woodbridge, The Electric Storage Battery Co. May issue, p. 516–25

Photoelectric Control of Resistance Type Metal Heaters, E. H. Vedder, Westinghouse Electric and Mfg. Co., and M. S. Evans, American Car and Foundry Co. Scheduled for June issue

Address: The Electrochemical and Electrometallurgical Industries in Japan, D. Takei, Tokyo University of Engineering.

9:00 a.m.—Power Transmission, D. M. Simmons, *chairman*

Some Features of the Boulder Canyon Project, E. F. Scattergood, Bureau of Power and Light, City of Los Angeles. April issue, p. 361–5

Engineering Features of the Boulder Dam Transmission System, E. F. Scattergood, Bureau of Power and Light, City of Los Angeles. May issue, p. 494–512

A Criterion of Quality of Cable Insulation, K. S. Wyatt and E. W. Spring, The Detroit Edison Co. April issue, p. 417–21

to each discusser for the discussion of a single paper or of several papers on the same general subject. When a member signifies his desire to discuss several papers not dealing with the same general subject, he may be permitted a somewhat longer time.

It is preferable that a member who wishes to discuss a paper give his name in advance to the presiding officer of the session at which the paper is to be presented. Each discusser is to step to the front of the room and announce, so that all may hear, his name and professional affiliations. Three typewritten copies of discussion prepared in advance should be left with the presiding officer.

Other discussion to be considered for publication must be submitted, typed double spaced, in triplicate to C. S. Rich, secretary of the technical program committee, A.I.E.E. headquarters, 33 West 39th St., New York, N. Y., on or before July 12, 1935. Discussion received after this date will not be accepted.

Technical Conferences

A number of technical conferences or informal round table meetings on various subjects have been scheduled for the benefit of specialists and the younger members. At some of these meetings leaders in specialized fields will speak informally pointing out the lines of future progress as they see them, after which those attending should feel free to discuss subjects on the agenda informally. It is hoped that these talks will direct some of the work of the Institute committees into new and pertinent channels. No provision will be made for printing of talks, papers, discussions, or conclusions reached at these conferences.

The objectives and agenda for several of the technical conferences are described in the paragraphs which follow the "Schedule of Technical Conferences" given below.

Schedule of Technical Conferences

Monday, June 24, 2:00 p.m.

Problems of the Student and Cadet Engineer, M. G. Malti, *chairman*.

D-C Test Code, R. W. Owens, *chairman*.

Transformers, J. E. Clem, *chairman*.

Research on Insulating Oils, K. S. Wyatt, *chairman*.

Tuesday, June 25, 2:00 p.m.

Noise, P. L. Alger, *chairman*.

Mercury Arc Rectifiers, O. K. Marti, *chairman*.

Dielectric Theories, H. H. Race, *chairman*.

Circuit Breaker Standards, H. P. Sleeper, *chairman*.

Reactance Coefficients of Synchronous Machines, C. M. Laffoon, *chairman*.

Thursday, June 27, 2:00 p.m.

Electrical Engineering Curricula and Educational Methods, H. W. Bibber, *chairman*.

Research in Engineering Schools, Vladimir Karapetoff, *chairman*.

Distribution Transformer Protection, K. B. McEachron, *chairman*.

Tensor Analysis, E. E. Dreese, *chairman*.

Conductor Vibration, D. M. Simmons, *chairman*.

In some cases members are invited to submit discussions to the respective chairmen in advance of the meetings. In general, the conferences have been sponsored by the subcommittees of technical committees and they afford an opportunity for the committees to obtain assistance from individuals, not members of the committees, but interested in the particular subjects under discussion. In this way both the individuals and the committees will profit.

Problems of the Student and Cadet Engineer

Of interest to students, educators, and personnel directors is the technical conference devoted particularly to the problems of the student and cadet engineer. Professor Malti has, for the past 2 months, been sounding educational and professional opinion as to how this round table discussion may be made most beneficial to students. He promises to give those who attend a cross section of the views regarding problems of students and cadet engineers. There will be short 10 minute talks by men in the industry and in the universities as well as by the students themselves. The purpose of these talks is to stimulate discussion rather than express dogmatic opinions. The speakers and subjects for this meeting will be announced in the June issue of Electrical Engineering. Watch for it!

Baker chemical laboratory on the campus of Cornell University, Ithaca, N. Y., where many of the technical sessions and round table discussions during the Institute's 1935 summer convention June 24–28, will be held

D-C Test Code

The meeting will be opened by the chairman who will give a brief statement as to the history and purpose of the test code. Members of the subcommittee will discuss assigned topics as follows: judging of commutation, running-light losses, shaft currents, temperature test, brush setting insulation resistance, and stray load losses.

Noise

The discussion at this meeting will bring out available information on the levels of noise now existing under different living conditions in different places and psychological data on the desirable or "comfort" levels of noise which may reasonably be sought for in the future.

The availability of improved noise meters and measurement standards now enables noise levels to be determined and described accurately. This fact, together with the growing public demand for quieter apparatus, has greatly stimulated interest among electrical engineers in the subject of noise control. From the ideas developed at this meeting, it is hoped that designers will secure an improved understanding of what will constitute satisfactory noise levels in the future, and engineers generally will learn much about the practical aspects of noise measurement.

Informal talks will be given by 4 men who are noted for their leadership in the field of acoustics and noise measurements. Dr. Donald A. Laird, of Colgate University, will speak on the psychological aspects of noise; Dr. E. E. Free, of the E. E. Free Laboratories, New York, N. Y., will present the results of his experience in conducting over 100 noise surveys; John S. Parkinson, of the Johns-Manville Research Laboratory, will give his experiences in regard to the establishment of satisfactory levels of noise; and H. B. Marvin, of the General Electric Company, will speak on noise measurements with particular reference to electrical apparatus. Advance information may be secured by addressing the subcommittee chairman, P. L. Alger, General Electric Company, Schenectady, N. Y., or any one of the speakers.

Mercury Arc Rectifiers and Inverters

At this conference prominent engineers will express their views on various subjects now being actively studied regarding this type of equipment. Among the topics to be discussed are: (1) water cooling, with its attendant phenomena of corrosion, and remedies for the latter; (2) interference with communication circuits due to harmonics produced in the a-c supply circuits, and means for their suppression or elimination; (3) voltage control by means of control grids, inversion, and regeneration; (4) consideration of terms such as thyratron, ignitron, and mutator, in view of the widening field of application of grid-controlled mercury arc rectifiers as inverters, frequency changers, commutators, etc.; and (5) the proposed A.I.E.E. Standards for dielectric tests, with particular reference to the recent use of mercury arc rectifiers for high voltage applications. It is felt that such a discussion will prove of benefit to all engineers taking part in it, who are interested in this increasingly important field.

Reactance Coefficients of Synchronous Machines

The discussion at this conference will cover definitions, effects of saturation, application, and methods of measuring reactances. Interested engineers are invited to submit discussions of this subject in advance of the meeting to C. M. Laffoon, chairman, synchronous machinery subcommittee, Westinghouse Electric and Manufacturing Company, E. Pittsburgh, Pa.

Electrical Engineering Curricula and Educational Methods

The list of speakers introducing the topics to be considered at this conference will be brief, in order that those attending may have an opportunity to express their personal views. An endeavor will be made to hold the discussion within the field of curricula and methods. It is hoped that the absence of any printed papers or reports of the discussion will result in speakers omitting many of the qualifying phases which frequently take the life out of a printed paper, so that bold and vigorous statements of views will be the rule. There has been no dearth of recent periodical literature dealing with questions of curricula and methods, and Dr. W. E. Wickenden's final report on the S.P.E.E. investigation of engineering education provides much interesting material for discussion.

Circuit Breaker Standards

This conference will consist of a discussion of the effect of recovery voltage and whether it should be included in the standard definition of interrupting rating, also a discussion of the differences between American and European circuit breaker standards.

Distribution Transformer Protection

This conference will consider the methods of protection of distribution transformers with particular reference to those in rural service, covering such items as interconnection of primary and secondary neutrals, grounding of transformer tanks, use of protective gaps, etc.

Tensor Analysis

Those interested in new theoretical developments should find this conference of unusual interest. Tensor analysis, as a branch of mathematics, has long been known to mathematicians. In late years this mathematical tool has been extensively employed by the physicists, particularly in dealing with relativity. Only recently has tensor analysis been applied with any vigor and success to electrical engineering. It now appears that the methods of tensor analysis give promise to the electrical engineer of simplicity of expression and generalization of heretofore divergent sub-

jects. This theoretical contribution appears to those electrical engineers familiar with it, to be important and significant in the treatment of circuits, electrical machinery, and the electron tube. It is the purpose of this conference to sound out not only these theoretical possibilities of simplification and generalization, but also to appraise, as well as can be done at this time, the practical significance and advantages of this new analysis in electrical engineering problems.

The application of tensor analysis to electrical engineering problems has nothing to do with relativity or relativity dynamics. It has simply been discovered that when the electrical engineer attacks the electrical machine using tensor analysis as a tool, he reaches a generalized equation which is of the same *form* as the equation reached by Doctor Einstein when he attacked the problem of relativity by the use of tensor analysis. This leads those versed in the subject to conclude that there is in the electrical machine a concrete physical analogue of the electron in motion.

Other Features

Entertainment

The entertainment features will consist of the President's reception and dance on Monday evening, an outing and picnic at Taughannock State Park on Tuesday afternoon, an inspection trip to the Corning Glass Works and buffet supper at Corning on Wednesday, an annual banquet and entertainment on Thursday, and a get-together luncheon on Friday.

In addition to the above, for the women there will be a drive about the Cornell campus, an inspection of the Home Economics College and laboratories, a drive to Enfield State Park, and a bridge luncheon. There will also be a musicale on Wednesday evening, at which Professor Karapetoff will be one of the entertainers. The committee is also making arrangements for 3 lectures by well known leaders in their respective fields.

Notice of Annual Meeting

The annual meeting of the American Institute of Electrical Engineers will be held at Cornell University, Ithaca, N. Y., at 10 a.m. on Monday, June 24, 1935. This will constitute one session of the annual summer convention which is to be held this year in Ithaca, N. Y.

At this meeting, the annual report of the board of directors, and the reports of the committee of tellers on the ballots cast for the election of officers and for constitutional amendments will be presented.

Such other business, if any, as properly may come before the annual business meeting may be considered.

(Signed) H. H. Henline
National Secretary

It will be necessary to charge moderate fees for certain entertainment events but the total amount of the fees for all events will not exceed $6 per person.

Taughannock State Park

There will be a picnic for all members of the A.I.E.E. and their guests on Tuesday afternoon, June 24. Taughannock Boulevard, skirting the western shore of Cayuga Lake, northward, 11 miles from Ithaca, leads to Taughannock State Park, where plunges Taughannock Falls, 215 feet high, the highest straight falls east of the Rocky Mountains. The park contains a bathhouse, shelter pavilion, excellent bathing beach, trails, baseball diamond, children's playground apparatus, bowling green, tennis courts, quoits, and horseshoe pitching courts, camping and picnic facilities, as well as large parking areas, sight-seeing boulevards, outlooks, bridges, and other advantages. The cool breezes across Cayuga Lake constantly fan the 400 acres in the preserve.

Program

2:00–4:30 p.m.—Cars will leave campus at convenience of guests. Transportation will be provided for those who do not drive their own cars.

Entertainment at the Park—Trip through gorge to main falls; about one mile of scenic paths easy to travel. About one hour should be allowed for return trip. No guides necessary. Form your own party and take your time.

Sports on playground near the lake—Baseball (soft ball); Horseshoe pitching; Bowling.

Swimming—Dressing rooms at State Park Pavilion may be used.

5:30 p.m.—Picnic supper served along lake front.

7:00–7:30 p.m.—Return to Ithaca in time for lecture at Bailey Hall.

Corning Glass Works

The main plants of the Corning Glass Works, the world's largest manufacturers of technical glassware, are located in Corning, N. Y., about 40 miles from Ithaca. Here was poured the famous 200 inch astronomical mirror for the California Institute of Technology, the production equipment for which may be inspected, as well as the manufacture of many products for scientific and general use. The company specializes in the manufacture of well-known brands of borosilicate and other technical glasses. Some of the products which may be in the course of manufacture during the inspection trips are: insulators; ovenware; chemical and laboratory ware; and railroad, marine and aviation signal glassware. Processes to be witnessed include the drawing of thermometer tubing, hand and machine drawing of tubing for neon signs, electric light bulbs, automobile fuses, gage glasses, etc., and also the manufacture of miscellaneous industrial wares. Of interest to the women will be the hand production of the famous "Steuben" art glass, such as vases, goblets, bowls, etc. A showroom is maintained for the display of some of the many thousands of items manufactured by this company.

At Wellsboro, Pa., about 40 miles from Corning, is another plant which will be open for inspection, where the high speed machine production of electric light bulbs and radio tube bulbs may be observed.

Principally for the women, the trip will start at 9:00 a.m. from Willard Straight Hall on Wednesday, June 26, and transportation will be available for the men attending the sessions from 9:00 a.m. to 2:30 p.m. in groups of 4 or 5 persons.

Future AIEE Meetings

Summer Convention,
Ithaca, N. Y., June 24–28, 1935

Pacific Coast Convention,
Seattle, Wash., Aug. 27–30, 1935

Great Lakes District Meeting,
West Lafayette, Ind., Oct. 24–25, 1935

Winter Convention,
New York, N. Y., Jan. 28–31, 1936

North Eastern District Meeting,
New Haven, Conn., May 1936

Summer Convention,
Los Angeles, Calif., June 22–26, 1936

Middle Eastern District Meeting,
Akron, Ohio (date to be determined)

Sports

Golf, tennis, and swimming may be enjoyed at any time during the convention.

Golf—The Ithaca Golf Course, overlooking Cayuga Lake, is located just outside the campus and is one of the best courses in the Finger Lakes region. Arrangements have been made so that all guests can use this course on the payment of green fees of $1 per day. Other courses in this region will also be available.

The usual competition for the Mershon and Lee golf trophies will be held. The Mershon trophy is competed for on a match play handicap basis. The qualifying round for the Mershon trophy must be played on Monday, June 24; the second round, best 16, match play, will be played on Tuesday, followed by the third round on Wednesday, and the semi-final and final rounds on Thursday.

The Lee trophy is awarded annually for the lowest net score for 36 holes, of which the first 18 may be the qualifying round and the other 18 must be played not later than Thursday afternoon.

Other contests, including a putting contest for the women, will be held.

Tennis—The contests will center, as usual, about the Mershon tennis trophy which, beginning this year, is to be on a new basis. Instead of becoming the property of one who wins twice, it is to remain permanently in the possession of the Institute. The name of the winner will be engraved on it each year. The first contests in men's singles will be started on Monday, June 24.

Contests in men's doubles, women's singles, and mixed doubles will also be arranged if there is sufficient registration for them. Prizes for the winners will be awarded for these contests. There are plenty of courts available on the campus for all who desire to play whether competing for prizes or not.

Swimming—There are many natural outdoor swimming places about Ithaca, one of which is located in Fall Creek Gorge

Membership—

Mr. Institute Member:

Shortly after the time this message is placed in your hands you will receive a letter in the interest of membership activities asking that you send in the name of one person who, you feel, should be invited to join the Institute. Your helpfulness in this regard in the past has been the means of receiving many applications for membership and we know you will want to continue to help in this regard as in the past.

Chairman National Membership Committee

only a few minutes walk from the dormitories.

Walking and Driving—Ithaca is noted for its many gorges and beautiful walks. There are 2 gorges on the campus in which the outdoor enthusiast can spend many hours. There are also within a short driving distance many other beauty spots including: Buttermilk Falls and Gorge, 2 miles; Enfield Park and Gorge, 6 miles; Watkins Glen and Gorge, 30 miles. Directions to reach these will be available at the registration desk.

Housing

Living accommodations will be largely confined to the university dormitories located on the Campus. These are modern in all respects and while they do not have rooms with private baths, the accommodations are very comfortable. The rates charged at university dormitories are:

$2.00 per day per person for first 2 days
$1.00 per day per person after first 2 days

Dormitory reservations should be made in advance with L. A. Burckmyer, Cornell University, Ithaca, N. Y., chairman of the housing committee.

During the convention, good meals may be obtained economically in the cafeteria and dining rooms of Willard Straight Hall.

Private rooming houses adjoining the campus offer accommodations as follows:

$1.00 to $1.50 per day per person

Reservations also can be obtained at the hotels. Rates, European plan, are as follows:

Ithaca Hotel; 125 rooms, 75 with bath

	Per Day
Single rooms without bath	$2.00
Double rooms without bath	3.00 and $4.00
Single rooms with bath	2.50 and $3.00
Double rooms with bath	5.00 and $6.00

Clinton House; 60 rooms

	Per Day
Single room without bath	$2.00
Double room without bath	4.00
Single room with bath	2.50 and $3.00
Double room with bath	5.00 and $6.00

These hotels are at the foot of the hill about one mile from campus headquarters.

Glenwood Hotel on Cayuga Lake, about 4 miles from campus headquarters, will accommodate 75 people in the hotel and cottages. There is a good road along the lake shore to Glenwood. Reasonable rates may be obtained on either the American plan or the European plan.

Members and guests should make their hotel reservations by writing directly to the hotel of their preference.

Camping facilities may be found in a number of places, but the most desirable is at Taughannock State Park about 11 miles from Ithaca, and can be reached by good roads.

Reduced Railroad Rates

Fare and one-third for the round trip over the same route will be available to members and guests, provided 100 certificates are validated at the registration desk. Consult your local ticket agent regarding the territory and dates applicable. Obtain your certificate authorized by the railroad passenger associations.

Campus Headquarters and Registration

The campus headquarters will be Willard Straight Hall, which is located on Central Avenue on the Cornell campus. The Cornell campus, one of the most beautiful in America, is situated on a hill overlooking the City of Ithaca and Cayuga Lake and may be reached from the depots by street car or bus (fare 10 cents), or by taxi (fare generally 50 cents). The registration bureau will open at 8:30 Monday morning and those in attendance should register promptly. A registration fee of $2.00 will be charged all nonmembers, except Enrolled Students and the immediate families of members.

Committee

The general convention committee for the 1935 summer convention consists of the following members: R. F. Chamberlain, *chairman;* W. H. Timbie, *vice-chairman;* A. C. Stevens, *secretary-treasurer;* P. L. Alger, C. H. Bissell, R. N. Conwell, E. P. Harder, V. Karepetoff, P. M. Lincoln, True McLean, W. E. Meserve, A. C. Stallman, I. Melville Stein, J. O. West, and J. P. Wood; also the following subcommittee chairmen: registration, E. M. Strong; housing, L. A. Burckmyer, Jr.; publicity, M. G. Malti; transportation, B. K. Northrop; inspection trips, J. T. Littleton; entertainment, W. C. Ballard, Jr.; and women's committee, Mrs. R. F. Chamberlain.

South West District Meeting Well Attended

Reports of the opening day of the A.I.E.E. South West District meeting held in Oklahoma City, Okla., April 24–26, received in time for inclusion in this issue, indicate a successful meeting. Registration for the first day exceeded 350 members, Students, and guests, and was drawn from 13 states. Attendance at the first 2 technical sessions averaged more than 300 persons each, and the wide discussion of the papers presented at these sessions reflects active interest.

A full report of this meeting is scheduled for publication in the June issue of Electrical Engineering.

A.I.E.E. Executive Committee Meets

In accordance with action of the board of directors in October 1934, a meeting of the executive committee of the A.I.E.E. was held at Institute headquarters, New York, N. Y., on March 29, 1935.

In the absence of President Johnson, due to illness, Vice-President R. H. Tapscott presided, and the other members of the committee present were H. P. Charlesworth, F. Malcolm Farmer, Everett S. Lee, W. I. Slichter; also present were L. W. W. Morrow, a member of the board of directors, and National Secretary H. H. Henline.

A resolution in memory of Dr. Michael I. Pupin, Honorary Member and past president of the Institute, who died on March 12, was adopted, as printed elsewhere in this issue.

Reports were presented and approved of meetings of the board of examiners held February 19 and March 21, 1935; and upon the recommendation of the board of examiners, the following actions were taken: 2 applicants were transferred to the grade of Member; 12 applicants were elected and 13 transferred to the grade of Member; 76 applicants were elected to the grade of Associate; 205 Students were enrolled.

The finance committee reported monthly disbursements amounting to $24,089.39 in February and $17,009.87 in March. Report approved.

Upon request of the Southern Virginia

Section, the name of that Section was changed to "Virginia Section," inasmuch as its territory includes a large part of the state.

Upon the recommendation of the standards committee and subject to concurrence by the American Standards Association, the Association de Ingenieros del I.C.A.I. was granted permission to reprint A.I.E.E. Standards in Spanish.

Report was made of the following appointments made upon the recommendation of the standards committee: E. F. Beck as one of the Institute's representatives upon the Sectional Committee on Safety Code for Lightning Protection, and W. M. Dann as an alternate representative upon the Sectional Committee on Transformers.

The president's appointment of the following committee of tellers to canvass and report upon the ballots cast for the 1935 election of Institute officers and for the proposed constitutional amendments was confirmed: R. H. Twiss, *chairman*, J. T. Binford, W. E. Coover, K. B. Hoffman, Henry Kurz, H. F. Marples, and R. B. Shanck.

F. M. Farmer, chairman of the Institute's committee on research, was nominated for election as a representative of the Institute upon the Engineering Foundation board for the 4 year term beginning in October 1935, succeeding Dr. C. E. Skinner, whose term will expire at that time.

Dr. J. B. Whitehead was nominated for appointment as a representative of the Institute upon the division of engineering and industrial research, National Research Council, for the 3 year term beginning July 1, 1935, to succeed Chester W. Rice, whose term expires at that time.

Approval was given to the disbanding of the American Committee on Electrolysis after distribution of its assets among the organizations comprising the committee.

Announcement was made of a joint dinner meeting to be held at the Engineers' Club, New York, N. Y., on May 20, 1935, of the members of the governing bodies of the founder societies, United Engineering Trustees, Inc., and all joint organizations of these societies, for a comprehensive discussion of all joint activities.

Other matters were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.

Pacific Coast Convention Now Being Planned

Plans are taking form for the A.I.E.E. 1935 Pacific Coast convention, which will be held in Seattle, Wash., August 27–30. The Olympic Hotel will be convention headquarters. The tentative plans call for 5 technical sessions and 2 student sessions with social activities scheduled in the evenings.

The personnel of the Pacific Coast convention committee was announced in ELECTRICAL ENGINEERING for April 1935, page 451. The names of the chairmen of the District committees on Student activities, E. O. Osburn and F. C. Lindvall, have been added to the convention committee. J. H. Kelly, chairman of the subcommittee on publicity, is unable to serve and in his place R. E. Kistler has been appointed.

Fundamental Research in Electric Welding

The following self-explanatory item has been submitted by the Institute's committee on research:

"What can be done in the way of getting research investigators sufficiently interested to volunteer to take up research investigations is illustrated by the success of the efforts of the fundamental research committee of the American Bureau of Welding, with H. M. Hobart (A'94, F'12 and member for life) of the General Electric Company, chairman. As practically all of these projects have to do with electric welding, the research committee of the Institute feels that this accomplishment should be brought to the attention of the members of the Institute.

"A total of 87 projects have been initiated. Some of these are duplicates, that is, the same project is being worked on by more than one investigator but there are over 60 different subjects in the list. A total of 71 individuals are doing the work in 29 colleges and universities, and 11 industrial and Government laboratories. As all of this work is being done quite voluntarily without any financial support other than the negligible amount that may be involved in supplying weld specimens that are required. The majority of the men are busy professors and it is very much to their credit that they undertake these research projects "on the side." It is also evident that there is plenty of the research spirit in our technical schools which will respond to inspirational leadership.

"The Institute's committee on research

A Cornell Residential Hall to Be Used During the Summer Convention

BALCH Hall, one of a group of residential halls available for housing guests at the Institute's annual summer convention to be held this year on the campus of Cornell University, Ithaca, N. Y., June 24–28. The exterior of this hall is shown here, together with an interior view of one of the students' rooms.

has been advised that anyone interested in the details of this program can obtain a copy of a complete list of the projects, the men carrying them out, their affiliation, etc., together with any other details upon application to H. M. Hobart, chairman, fundamental research committee, American Bureau of Welding, Engineering Societies Building, 29 West 39th Street, New York, N. Y."

Suggestions for Section Activities

FOR the purpose of improving the quality of the meetings of the Institute's numerous Sections, and increasing the interest of members in them, the circulation of ideas among the Sections is desirable. I. Melville Stein, chairman of the A.I.E.E. Sections committee, has summarized the practices of a few of the Sections which depart somewhat from customary procedure, and for the benefit of other Sections, these items are presented herewith:

A Suggestion From Our Canadian District

Vice President A. H. Hull, of the Canadian District (number 10) recently called to the attention of the Sections in his District an additional Institute activity which might be undertaken by the Sections.

Specifically, Vice President Hull called attention to the interesting news items appearing in Electrical Engineering, such as "Message from the President," "Letters to the Editor," and other items appearing under "News of the Institute and Related Activities," and suggested that the membership could be kept better informed on such matters if important news items, such as these, were reviewed briefly at Section meetings. It was Vice President Hull's suggestion that the executive committees of the Sections appoint individuals to review such news items and to provide 10 minutes or so at each Section meeting for the reviewer or reviewers to present briefly the ideas contained in these news items.

Judging from the comments of the Sections' officers in District number 10, the suggestion was received enthusiastically and is being tried out in a number of the Canadian Sections. It is too early to report definite results, but the operation of this plan in the Canadian District will certainly be well worth watching.

It has been suggested that this same general idea might be successful in connection with strictly technical papers appearing in Electrical Engineering. Specifically, it has been suggested that the Section executive committees might appoint individuals known to be familiar with particular technical articles appearing in Electrical Engineering, to present, briefly, before Section meetings, the high-lights of these articles, so that those members not expert in a particular field could be kept informed in a general way.

Section Meeting Notices

There is a great diversity in the type of notices sent out by various Institute Sections. Many of these notices are in such excellent form that it is obvious that considerable time and thought have been given to their preparation. A discussion of all of the excellent forms used would be too lengthy to be included here.

The Cincinnati, Ohio, Section has recently adopted a form of notice, which, not only is excellent in form, but includes a distinct feature that deserves specific mention, that is, the inclusion on each meeting notice of a photograph of the speaker. The notice is arranged in a dignified form on standard $8^1/_2$ by 11 inch paper and reproduced from the original typing and the original photograph by the offset printing process.

Forum Meetings

The Toledo, Ohio, Section has adopted a form of meeting which it calls "forum meetings," to satisfy the desire of its members for meetings in which general current topics can be discussed. The forum meetings are additional to the regular technical meetings and are held on days which not only do not conflict with the regular Section meetings, but are sufficiently spaced from the regular meetings to avoid having the members choose between one or the other type of meeting rather than attending both. At the forum meetings, men of real ability are obtained for speakers, to assure that the topic under discussion is well presented.

The popularity of the forum meetings is attested by the fact that when they were discontinued for a time because of economic reasons, the Section received many requests for their continuance and they have been resumed during the current year.

15 Minute Talks

Another local activity being conducted by the Toledo Section is a series of 15 minute talks on fundamental electrical theory, one of these talks preceding each regular meeting of the Section. All the speakers for these 15 minute talks are chosen from the Section membership and experience with these meetings over a period of several years has shown to have the following advantages:

1. The bringing to light of latent local talent which otherwise might not have been revealed.
2. The re-establishment in the minds of the audience of certain phases of fundamental theory, which, because of lack of use, had almost been forgotten.
3. An increase in attendance at meetings.

At first the speakers were allowed to choose their own subjects for these 15 minute talks, but later the subjects of the talks were selected according to a program. In neither case was any attempt made to relate the subject of the 15 minute talk to the main subject of the evening.

Views of the Boulder Dam Project

Various phases of the Boulder Dam project on the Colorado River between Arizona and Nevada, and of the 275 kv transmission line connecting it with Los Angeles, Calif., are illustrated in these reproductions of 16 recently taken photographs. Photograph 1, showing Boulder Dam, was taken on March 20, 1935. Photographs 2 to 9, inclusive, showing other views of the Boulder Dam project, were taken on March 13; final height of the dam is shown, although the roadway across the top of the dam was not quite completed at that time. Photographs 10 to 16, inclusive, showing the transmission line, were taken on March 19. All were taken by D. M. Simmons, chairman of the Institute's committee on power transmission and distribution. The Boulder Dam project is being constructed by the U.S. Bureau of Reclamation, and that transmission line which is illustrated here is being erected by the Bureau of Power and Light of the City of Los Angeles.

(1) View of Boulder Dam and the intake towers, looking downstream

(2) Passenger launch on the lake being created above the dam

(3) Spillway on the Nevada side of the river

(4) Boulder Dam, looking upstream, and showing the Nevada wing of the power house

(5) View from Lookout Point, near the dam, showing the water forming some 6 miles upstream

(6) Top of Boulder Dam, intake towers, and the spillway on the Arizona side of the river

(7) The dam and a section of 30-foot penstock. To get the scale, note the people standing to the right of the penstock

(8) Downstream face of the dam, and the 2 wings of the power house; the Nevada wing is on the left, Arizona wing on the right

(9) Bottom of the excavation, showing the Arizona wing of the power house

(10) Connecting a dead end insulator string on a tower near Jean camp, about 70 miles west of Boulder Dam

(11) A dead end insulator string being raised to a tower at Jean camp

(12) Assembling a suspension insulator string near Kingston camp, about 40 miles west of Boulder Dam

(13) A dead end tower near Kingston camp; in this photograph and in numbers 10 and 11, note the men on the tower

(14) Dead end assembly at Jean camp for exhibition purposes; this assembly, including an I-beam for stiffening it during handling, weighs almost 700 pounds

(15) A supply of reels at Jean camp, each reel containing one mile of 1.4 inch diameter hollow copper cable for the transmission line. This conductor, and other features of the line, are described in a paper on pages 494–512 of this issue. (Among other papers discussing the line and dam project are 2 in the April 1935 issue and 2 scheduled for issues in the near future)

(16) A transposition tower east of Jean camp

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E.C.P.D. Reports on Plans to Guide Students, Accredit Schools, and Promote Professional Status

DEVELOPMENTS in the co-operative program of engineering societies, educators, and representatives of state licensing boards looking toward the improvement of the engineering profession and the enhancement of the status of its members are recorded in the second annual report of the Engineers' Council for Professional Development, published on April 15, 1935.

The report, copies of which may be obtained at the headquarters of the E.C.P.D., secretary, 29 West 39th Street, New York, N. Y., is a pamphlet of 44 pages and includes 4 individual reports of the E.C.P.D.'s principal committees on student selection and guidance, engineering schools, professional training, and professional recognition.

Dr. C. F. Hirshfeld (A'05), director of research, Detroit (Mich.) Edison Company, and C. E. Davies, secretary, The American Society of Mechanical Engineers, acting, respectively, as chairman and secretary of the E.C.P.D. for 1934, call attention in the main report to the progress made during the year. The 7 participating bodies approved the recommendation that E.C.P.D. be established as an accrediting agency for schools of engineering. Two of the participating societies, the American Society of Civil Engineers, and The American Society of Mechanical Engineers, approved in principle a definition of an engineer, proposed by the E.C.P.D., and standard grades of membership in engineering societies, a recommendation of the E.C.P.D. Another participating body, the National Council of State Boards of Engineering Examiners, approved the definition.

Aided by a grant of $2,800 from the Engineering Foundation for publications and for the work being conducted in student selection and guidance, in post-college training and development, and in professional recognition, E.C.P.D. was able, during 1934, to supplement and extend the voluntary efforts of its numerous committee members. As a result, substantial progress is noted in the reports of the Council's 4 major committees.

R. L. Sackett, dean, college of engineering, Pennsylvania State College, in the report of the committee on student selection and guidance, of which he is chairman, says that during 1934 the committee concerned itself with 3 major problems:

1. The selection of a suitable booklet for informing high-school and secondary-school students about engineering.
2. Consideration of ways and means whereby this booklet could be used to the best advantage by students in secondary schools.
3. The development of some means whereby boys qualified to take up engineering could be selected from among those who apply for entrance to engineering schools.

The report describes 3 experiments in guidance conferences for secondary-school students.

Setting up a procedure by means of which the accrediting of schools of engineering may be undertaken by E.C.P.D. is described by Dr. Karl T. Compton (F'31), president, Massachusetts Institute of Technology, Cambridge, in the report of the committee on engineering schools, of which he is chairman. Supplementing the report is the complete questionnaire to be used by the committee in securing the basic facts with respect to the engineering school seeking to be accredited by E.C.P.D.

For the year's activities of the committee on professional training, its chairman, Gen. Robert I. Rees, assistant vice president, American Telephone and Telegraph Company, New York, N. Y., reports a comprehensive method by which junior engineers may make a personal appraisal of themselves. Searching questions to be answered by the individual cover his occupation and his personal and professional status and provide the basis of formulating a general and an immediate program for his own development. Another accomplishment of the committee is the revision of an annotated reading list of more than 100 carefully selected books covering a broad range of nonengineering subjects. Sections of this list are being published month-by-month in current issues of ELECTRICAL ENGINEERING.

Two major efforts of the committee on professional recognition, whose chairman is Conrad N. Lauer, president, Philadelphia Gas Works, Philadelphia, Pa., were devoted to the adoption of a tentative draft of a program of certification into the engineering profession, and the explanation of the committee's proposed definition of the term "engineer" and of its suggested standard grades of membership in engineering societies. The committee's program of certification into the profession is given in detail.

In addition to the reports of the 4 major committees, the main report also includes the charter and rules of procedure of E.C.P.D., the verbatim statement of 5 policies previously adopted by E.C.P.D., and the complete personnel of the Council and all of its committees. The report is thus a complete and authoritative source of information on the work and organization of this body.

The Engineers Council for Professional Development is a conference of engineering bodies organized to enhance the professional status of the engineer through the co-operative support of the national organizations directly representing the professional,

In Memoriam

MICHAEL I. PUPIN

DR. Michael Idvorsky Pupin, an Honorary Member of the Institute, and its thirty-eighth President, died on March 12, 1935, in his seventy-seventh year.

Coming to the United States alone at the age of 15, he devoted all possible time to studies while earning his living at various types of work. His unusual ability and his determination to secure a good education enabled him to enter Columbia University in 1879 and to graduate in 1883. After pursuing advanced study in mathematics and physics at the University of Cambridge and in thermodynamics at the University of Berlin, he received the degree of doctor of philosophy from the latter in 1889.

Upon returning to the United States, he became a member of the faculty of Columbia University, entering upon a long career which was to bring him worldwide fame as educator, scientist, engineer, inventor, and author, and many high honors from governments, universities, and scientific bodies.

Gifted with a thorough understanding of human nature, he ever stood firmly in opposition to those who tried to create a breach in the relations of science and religion.

Doctor Pupin joined the Institute in 1890, was transferred to the grade of Fellow in 1915, and was elected an Honorary Member in 1928. He served on various committees, as director 1892–95, as vice president 1895–97 and 1901–03, and as president 1925–26. He received the Edison Medal in 1920, the Washington Award in 1928, the John Fritz Medal in 1932, and other medals.

BE IT THEREFORE RESOLVED: That, upon behalf of the membership of the American Institute of Electrical Engineers, the executive committee hereby expresses its sincere regret at the death of Doctor Pupin and its appreciation of the important contributions he made to the development of the Institute and of the fields of engineering and science; and be it further

RESOLVED: That these resolutions be entered in the minutes and transmitted to the members of Doctor Pupin's family.

—A.I.E.E. Executive Committee, March 29, 1935

technical, educational, and legislative phases of an engineer's life. The participating bodies are: American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, The American Society of Mechanical Engineers, American Institute of Electrical Engineers, Society for the Promotion of Engineering Education, American Institute of Chemical Engineers, and National Council of State Boards of Engineering Examiners.

The executive committee is composed of C. F. Hirshfeld (A'05), *chairman*, J. Vipond Davies, F. M. Becket, W. E. Wickenden (A'07, M'13), C. F. Scott (A'92, M'93, F'25, HM'29, member for life, and past-president), H. C. Parmelee, R. I. Rees,

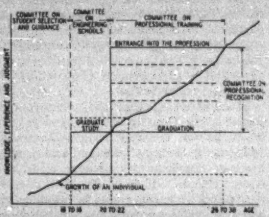


Chart illustrating the fields of activity of the 4 committees of the Engineers Council for Professional Development

D. B. Steinman, and the secretary is George T. Seabury, 29 West 39th Street, New York, N. Y. A list of the officers, representatives, and committee members of E.C.P.D. was given in ELECTRICAL ENGINEERING for February 1935, pages 249–50.

The activities of the 4 major committees are organized to cover the educational and professional needs of the engineer from the time he is a student in the secondary school, faced with the problem of entering upon a college education leading to a professional career, to the time he has developed in the practice of his chosen branch of the engineering profession to such an extent that he is eligible for membership in one of the professional engineering societies and for registration for license to practice engineering under the laws of his state. The accompanying diagram indicates the areas of influence in the engineer's life to which the activities of these 4 committees are related.

Other articles on the activities of E.C.P.D. are given in the 3 preceding issues of ELECTRICAL ENGINEERING.

A Reading List for Junior Engineers

A LIST of books recommended for reading by junior engineers has been prepared by a number of eminent men, many of them distinguished in the engineering profession. Previous sections of this list have been published in ELECTRICAL ENGINEERING for December 1934, page 1667, January 1935, page 133, March 1935, page 345, and April 1935, page 456. Two additional sections are published herewith, and others are scheduled to follow in subsequent issues. The complete list includes more than 100 titles.

Systematic reading of worth while books adds breadth and vision to the background of an engineer and should be considered a part of the intellectual development designed to fit the young engineer for full professional recognition. It is suggested that over a period of about 4 years a minimum of about 25 of these books might be selected and read, with the limiting recommendation that the selection made will include at least one book in each classification, preferably in accord with the individual engineer's most vital interests.

Biography and Travel

Abraham Lincoln, Lord Godfrey Charnwood. Henry Holt, 1916.

Two Years Before the Mast, R. H. Dana. Macmillan, 1923.

Great Men of Science, Philipp Lenard. Macmillan, 1933. Biographical sketches of about 10 pages each, of more than 50 outstanding scientists from ancient times to the World War.

Alexander Graham Bell, C. D. Mackenzie. Houghton, Mifflin, 1928.

Romance of Leonardo da Vinci, D. S. Mereshkovskii. Translated by Herbert Trench. Putnam.

Travels of Marco Polo, edited by G. B. Parks.

Life of George Westinghouse, Henry G. Prout. Scribner, 1922.

Immigrant to Inventor, Michael Pupin. Scribner, 1923.

Northward Course of Empire, Vilhjalmur Stefansson. Macmillan, 1924.

Autobiography of Lincoln Steffens, Lincoln Steffens. Harcourt, Brace, 1931.

Life and Letters of John Hay, W. R. Thayer. 2 volumes. Houghton, Mifflin, 1915.

Fine Arts

Scope of Music, Percy Buck. Oxford University Press, 1924. A series of 10 lectures on physics of sound, origin and place of music as an art, the nature of beauty, melody, form, and psychology of music.

Simple Guide to Pictures and Painting, M. H. Bulley. Dutton, 1928. Deals with principles of construction—design, personality, craft, tradition and ways in which a painter works. Outlines the development of painting from Byzantine to modern French.

Art Through the Ages, Helen Gardner. Harcourt, Brace, 1926. World survey of history of art—architecture, painting, sculpture, and the minor arts from earliest times to the present.

Enjoyment of Architecture, T. F. Hamlin. Scribner, 1921. Fine explanations for laymen of basic principles of architectural design and construction, ancient and modern structures, with special attention to American buildings.

Theatre, edited by E. J. R. Isaacs. Little, Brown, 1927. A collection of 30 essays on the art of the theatre.

Listening to Music, Douglas Moore. W. W. Norton, 1932. Analysis, interpretation, and appreciation through intelligent listening. No previous training in music required.

Photoprints Service Available From Engineering Library

The Service Bureau of the Engineering Societies Library has supplied almost 200,000 photoprints of material in the library to individual engineers, engineering corporations, and libraries throughout the world, in a 5 year period. This service makes it possible for an engineer, who is far from library service or whose local library cannot provide the great wealth of engineering information housed in the Engineering Societies Library, to obtain copies of articles or of books that he needs in his work.

By this method is it possible for the service bureau to supply exact copies of printed or manuscript data, graphs, charts, maps, and illustrations at a minimum cost. Pages may be photographed just as they appear in the book, or, in the case of small print, they may be enlarged for increased clarity and ease in reading.

Photostats are sent either in negative (with white print on a black background) or in positive form (with black print on a white background). However, the cost of the positive print is double that of the negative print because a negative print must be made first.

Photoprinting, as well as searching, abstracting, preparation of bibliographies and translations, and all other work of the service bureau is done at cost. For further information or quotations, write, telephone, or telegraph the Engineering Societies Library, 29 West 39th Street, New York, N. Y.

(Articles on other services available from the Engineering Societies Library were given in ELECTRICAL ENGINEERING for December 1934, pages 1668–9, January 1935, pages 130–1, and March 1935, page 341.)

Physical Society Meetings. The summer meeting on the Pacific Coast of the American Physical Society will be held in affiliation with the Pacific division of the American Association for the Advancement of Science in Los Angeles, Calif., during the week of June 24–28, 1935; it is planned to hold one session at California Institute of Technology, Pasadena. Another meeting of the American Physical Society will be held in Minneapolis, Minn., June 21–22, 1935.

E.E.I. to Meet in Washington. The third annual convention of the Edison Electric Institute will be held at The Mayflower Hotel, Washington, D. C., June 3–6, 1935. Subjects to be discussed are: building good will, rural electrification, government in business, rates, and sales programs.

"Scientific Education—What Is Wrong With It?"

A highly informative meeting at which many critical and original ideas were expressed regarding the education of engineers and scientists, was sponsored by the New York Electrical Society, Inc., and held Wednesday evening, March 27, 1935, in the auditorium of the Engineering Societies Building, New York, N. Y. This "Science Forum" had for its subject "Scientific Education—What Is Wrong With It?"

The speakers who addressed the audience were Dr. William E. Wickenden (A'07, M'13) president of Case School of Applied Science, Cleveland, Ohio; Dr. Colin G. Fink, head of the electrochemistry department of Columbia University, New York, N. Y.; Dr. Alan Gregg, director of medical sciences for the Rockefeller Foundation, New York, N. Y.; and Dr. Harry Woodburn Chase, chancellor of New York University, New York, N. Y. Discussion from the floor was led by Gano Dunn (A'99, M'94, F'13, and Life Member) president, J. G. White Engineering Corporation, New York, N. Y., and past president of the Institute as well as of the New York Electrical Society; J. W. Barker (M'26, F'30) dean of engineering, Columbia University, New York, N. Y.; Dr. Frank L. Babbott, Jr., president, Long Island (N. Y.) College of Medicine; H. C. Rentschler, director of research, Westinghouse Lamp Company, Bloomfield, N. J.; Dr. E. E. Free, consulting engineer, New York, N. Y.; and Gen. R. I. Rees, assistant vice president, American Telephone and Telegraph Company, New York, N. Y.

Doctor Wickenden's address, being particularly pertinent to the education of electrical engineers, is presented in full in this issue of ELECTRICAL ENGINEERING, pages 471–3.

Doctor Fink, in his address, spoke primarily in terms of high school graduates, and complained that natural sciences today are in general taught to children in primary and secondary schools "in a manner so uninteresting that it tends to destroy for life an interest in science." In urging the importance in modern life of an understanding of the basic principles of the fundamental sciences he said "it might be argued that not every child needs to be acquainted with scientific matters, but such argument would hold true only perhaps 50 years ago. It certainly does not apply today. Every high school graduate today, whether he goes to college later or not, should be trained in the most essential principles of the various sciences, notably biology, chemistry, and physics. Today it is just as important to be schooled in the sciences as it was formerly to be schooled in the '3 R's.' A knowledge of the properties of the gas in the kitchen oven, or the gasoline in the automobile, or of the composition of the basic foods, is more important to high school graduates today than is a knowledge of the dates of the wars of Napoleon, the ability to compose poetry, or to recite Vergil." Doctor Fink recommended that science should be taught in the high schools more through the laboratory and less through the library and blackboard; that the best teachers available in science should be employed in the high schools; and that the ground covered be reduced rather than increased, so that the basic principles may be brought home in such a way as to arouse the interest of the child in matters scientific, and to encourage the development of such interest.

Doctor Gregg spoke of educational procedures in terms of the distinction between tactics and strategy, stating his belief that education at present is too largely tactical and that entirely too little attention is given to strategy. He defined tactics as the ability to use one's forces to meet conditions already decided upon, or outlined, and strategy as the vital art of choosing the circumstances under which one's known strength or ability could be developed or applied to the best advantage. He deplored overemphasis of systemized routine curricula except perhaps as groundwork, pleading for a more general realization that when a mature student has "finished the business of giving proof that he is competent in assigned tasks he should be given a wider freedom and a more generalized responsibility and experience in choosing his own field of work." In this connection he criticized particularly such practices as the assignment of thesis subjects. With particular reference to the pursuit of the fundamental research that is essential to scientific advancement, Doctor Gregg emphasized the great importance of liberal and long-term fellowships that would provide for terms of research ranging from 2 to 10 years or more according to requirements, instead of the present tendency to provide one year fellowships which unduly restrict the extent of the work that can be carried on.

Editor Appointed by A.S.C.E

Beginning with the May 1935 issue the editorial work for *Civil Engineering*, monthly publication of the American Society of Civil Engineers, is in charge of P. H. Carlin, an associate member of that society. Mr. Carlin succeeds Walter E. Jessup, who, as announced in ELECTRICAL ENGINEERING for April 1935, page 455, has been appointed field secretary of the society.

To his new work Mr. Carlin brings excellent technical training, considerable engineering experience, and a knowledge of society affairs and editorial practice. A native of Philadelphia, Pa., he is a graduate of the University of Pennsylvania with the degrees of bachelor of science in civil engineering in 1922, and civil engineer in 1930, has studied law at Temple University, and is a registered professional engineer in Pennsylvania.

Much of his experience has been with the Philadelphia Department of City Transit, where he was engaged from 1924 through 1932 on the design of subways and in writing specifications for subways and their appurtenances. He has also filled a number of shorter engagements in building and highway design and construction. Following his work on Philadelphia subways, Mr. Carlin was for some time with C. E. Myers, consulting engineer, Philadelphia. His latest engagement before taking up the duties of editor of *Civil Engineering* was with the

Near the Scene of a Future A.I.E.E. Convention

THE beautiful setting of Paradise Inn at Paradise Valley with Mount Rainier in the background towering 14,408 feet above sea level. This point is a 2 hour drive from Seattle, where the 1935 Pacific Coast convention of the Institute will be held August 27–30. Excellent highways lead from Seattle to this famous playground in Rainier National Park.

Pennsylvania State Emergency Relief Board as assistant director, Luzerne County Work Division, with headquarters at Wilkes-Barre.

He has for some time been active in the society's Philadelphia section, having been since 1931 editor of that section's monthly publication, *The News*, which he has expanded into an attractive 8 page form.

"Science Series" Reprint Demand Exceeds Supply

An expression of regret is offered to the many Institute members who entered orders for the "Science Series" reprint too late to be filled. In an effort to guard against just such an eventuality, the notices published in the November and December 1934 issues of ELECTRICAL ENGINEERING urged all interested members to file advance orders not later than January 7, 1935, the date on which the reprint was scheduled to go to press. By that date, orders for some 600 copies had been received by the editorial department. As a safety factor, and in an attempt to anticipate late orders, this amount was increased by more than 60 per cent, and some 1,022 copies of the reprint were issued, after which the type was killed in accordance with established procedure.

In addition to the flood of orders that came in from members in the United States and Canada, orders were received from members in 18 foreign countries throughout the world. This widespread popular demand for reprints of the 13 special articles that appeared last year in ELECTRICAL ENGINEERING in itself constitutes a fitting testimonial of appreciation for the generous contributions of the several authors, and for the hard work underlying the project that was put in by Dean Robert E. Doherty of Yale University, during his term as chairman of A.I.E.E. committee on education (1932–33), and by those who assisted him in organizing and developing the project. Unfortunately, the reprint is out of stock, but the articles themselves are still available to those members who have kept their issues of ELECTRICAL ENGINEERING.

International Congress for Scientific Management. The International Congress for Scientific Management will be held in London, Eng., July 15–20, 1935. An attendance of about 2,000 is expected. There will be an official reception by the British government, and the Court of Common Council of the City of London will extend to delegates an invitation to an evening reception in the Guildhall. Several other official social functions are being organized.

A.S.T.M. to Meet in Detroit. The 38th annual meeting of the American Society for Testing Materials will be held in the Book-Cadillac Hotel, Detroit, Mich., June 24–28, 1935. An interesting technical program covering a large number of subjects has been arranged. Also, the society's third exhibit of testing apparatus will be open throughout the 5 days of the meeting. Exhibits of leading companies interested in testing apparatus and related equipment fields, and of several of the society's committees, will be presented.

Engineering Foundation

Notes on Activities Since January 1, 1935

Results of the election held by The Engineering Foundation at its annual meeting February 21, 1935, and a summary of the annual report of The Engineering Foundation for 1934, were presented in ELECTRICAL ENGINEERING for April 1935, pages 457–9. Supplementing this information, the following brief item on activities of Engineering Foundation since January 1, 1935, may be of interest. As pointed out in the previous issue, The Engineering Foundation is a department of United Engineering Trustees, Inc., joint agency of the 4 national societies representing the civil, mining and metallurgical, mechanical, and electrical engineers, and its present preferred activity is research.

On January 2, 1935, research on the plasticity of metal was begun under the leadership of Dr. A. Nadai, an international authority, in co-operation with the University of Pittsburgh and a number of industrial companies.

Through provision of a special contribution, a research associate engaged in barodynamic research was added on February 4 to Professor Bucky's staff at Columbia University. Appreciation of members of the mining profession in this work has been expressed. A clear picture of the action of mine roofs and of the proper placement of roof supports has been afforded by this work.

"Principles of Phase Diagrams," the fifth book in the series on alloys of iron, was issued in March 1935. It explains and illustrates the thermodynamic principles underlying the behavior of a system of metals or other substances under changing conditions of temperature, composition, and pressure. It is a tool book for metallurgists in industry and a textbook for colleges.

Progress has been made by a planning committee toward stating a co-ordinated, comprehensive project in welding research, arranging a conference of representatives of interested organizations and industries, and selecting men to be nominated for members of the proposed welding research committee. Members of the planning committee are: F. M. Farmer (A'02, M'12, F'13) *chairman*, chairman of the A.I.E.E. research committee; Dr. D. S. Jacobus (A'03) president, American Welding Society; and Prof. C. A. Adams (A'94, M'05, F'13) director, American Bureau of Welding.

Appointment of a welding research committee was authorized, if a plan for co-ordinated welding research and nominations for members be received from the A.I.E.E. and associated organizations. Other committee changes included the reappointment of the research procedure committee, D. Robert Yarnall, *chairman*, and the iron alloys committtee, George B. Waterhouse, *chairman*. A platform and program committee, Otis V. Hovey, *chairman*, was appointed. The education research committee, Harvey N. Davis, *chairman*, was discharged, with special appreciation for producing the booklet "Engineering: A Career—A Culture," and for other valuable services.

The annual report of The Engineering Foundation for 1934 (summarized in the April issue of ELECTRICAL ENGINEERING) was ordered printed.

American Engineering Council

The Federal Work-Relief Bill

American Engineering Council, as the agency of its sponsor societies and allied groups, is actively negotiating in Washington with regard to the engineers' part in the vast program of the $4,880,000,000 work-relief bill which gives to the president all of the money and most of the power he first asked.

The following excerpts from Council's recent news letter tell some of the story regarding this bill:

To engineers, this measure brings deep responsibilities, for without engineering technique, such a program could neither be planned nor executed. It brings complex problems of professional status and of adjustment to new lines of activity. But most of all, the program brings hope to thousands of engineers now losing their skill in idleness or in makeshift jobs.

The engineering nature of the program becomes evident from the type of projects earmarked in the bill. The $4,880,000,000 represents an appropriation of $4 billion plus the release of approximately $880 million from past appropriations. The latter sum is mainly for continuance of relief through June 30 and for repayment of P.W.A. funds temporarily used for relief while passage of the bill hung fire. Allocation of the $4 billion follows:

Highways; roads; grade crossings	$800 million
Rural rehabilitation and relief in stricken areas; water conservation; trans-mountain water diversion; irrigation; reclamation	500 million
Rural electrification	100 million
Housing	450 million
Assistance for educational, professional, and clerical persons	300 million
Civilian conservation corps	600 million
Loans and grants to states, municipalities, etc., not less than 25 per cent of each loan or grant for work	900 million
Sanitation; prevention of soil erosion; prevention of stream pollution; sea coast erosion; reforestation; flood control; rivers and harbors; miscellaneous	350 million
Total	$4,000 million

Not to exceed 20 per cent of the $4 billion

may be used to increase any one or more of the above items. This listing may be somewhat misleading in that it represents classes of work rather than functional divisions of the program. Any given item may be split between several operating agencies of the government.

Assistant Secretary Appointed by A.E.C.

L. V. Reese, who has been handling rural industrial communities in the rural rehabilitation program of the Federal Emergency Relief Administration resigned April 1, 1935 to become assistant secretary of the American Engineering Council in Washington, D. C. He has also served the F.E.R.A. as executive secretary of the District of Columbia Rehabilitation Corporation and as planning engineer for the Texas Relief Commission.

In his new position, Mr. Reese will assist the executive secretary, Frederick M. Feiker, in carrying out the enlarged program of the American Engineering Council voted at its recent annual meeting as a service agency for relating the organized engineering professions to national affairs in the public interest.

He will serve also as a liaison officer between the federal agencies and organized national, state, and local professional engineering societies, by which 222 localities are co-ordinated.

His assistance will be available both to government agencies and to the member

L. V. Reese

organizations of A.E.C., to make effective the engineers' contribution in planning and executing the $4,880,000,000 work-relief program, almost every phase of which is an engineering job.

Mr. Reese, who is 43, was educated in civil engineering at the University of Texas, and in mechanical, metallurgical, and industrial engineering at Columbia and New York Universities. His experience in engineering and executive capacities has been extensive. Prior to his service with federal agencies, he was engaged in the industrial, public utility, and construction fields. He was assistant to the president and manager of the research division of the American Laundry Machinery Company, vice president and general manager of the Erie City Iron Works and chief engineering executive of the American Metal Company and the United States Metals Refining Company. During the War, he was assistant supervising constructing quartermaster on cantonment work for the U.S. Army. For several years before the War, he managed his own engineering business, doing civil and industrial engineering and the construction of industrial plants, public buildings, and utilities. Along with his other experience, Mr. Reese has kept himself up to date on agricultural life through the side-line operation of farms and ranches.

Other Activities of A.E.C.

Other items taken from American Engineering Council's recent news letter reflecting activities of Council follow:

The new plan of organization for Council's regular and standing committees for 1935 has been completed. The report, which outlines the functions of each committee and lists the personnel, is available upon request. It is being mailed to member organizations and to committee members.

Council membership is gaining under the new plan of nominal dues for state and local societies, and several such societies have made definite application for membership within the last month.

The patent committee of A.E.C. has declared a general opposition to the Sirovich bill for regulation of patent pools and agreements.

Rural electrification plans were advanced by a delegation from the American Society of Agricultural Engineers, in Washington recently. The group headed by Dr. Glen W. McCuen, president of the A.S.A.E., called upon Doctor Tugwell and other prominent officials who will be influential in the rural work. They offered the services of A.S.A.E. to help the program in a constructive way.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or to reject them entirely.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Measurement of Quadrature Axis Synchronous Reactance

To the Editor:

The following simple test for experimentally determining the quadrature axis synchronous reactance of a salient pole synchronous machine may be of interest to your readers. It can be applied in cases where the well-known slip test cannot be performed satisfactorily—for example, in testing a synchronous machine which is not coupled to a prime mover by means of which the slip can be adjusted to a small value. In such cases, if it is attempted to perform the slip test by operating the synchronous machine as an induction motor, it will frequently be found that it is impossible to operate at a small slip without having the machine pull into synchronism and run as a reluctance motor.

Operate the machine at no load as a reluctance motor, the power supply being from a generator whose voltage can be varied and which is sufficiently large compared with the machine being tested so that the power source can be considered as an infinite bus. Gradually reduce the terminal voltage until the machine falls out of step, observing as carefully as possible the no-load power input and terminal voltage at which loss of synchronism occurs. From these readings, the quadrature axis synchronous reactance can be calculated as follows:

As is well known, the power input P to a salient pole synchronous motor of negligible resistance operating from an infinite bus can be expressed as

$$P = \frac{EV}{x_d} \sin \delta + \frac{V^2(x_d - x_q)}{2x_d x_q} \sin 2\delta \quad (1)$$

where

E = excitation voltage
V = terminal voltage
x_d = direct axis synchronous reactance
x_q = quadrature axis synchronous reactance
δ = load angle of the machine (angle between E and V)

If operated as a reluctance motor, $E = 0$, and hence

$$P = \frac{V^2(x_d - x_q)}{2x_d x_q} \sin 2\delta \quad (2)$$

If the machine is operated at no load and reduced voltage, P is practically equal to the friction and windage loss. As V is reduced, as in the test described above, δ will increase until pull-out as a reluctance motor occurs when

$$P = \frac{V^2(x_d - x_q)}{2x_d x_q} \quad (3)$$

The values of P and V at pull-out can be determined as in the above test. The direct axis synchronous reactance x_d can be determined by well-known methods. Hence x_q is the only unknown in equation 3. Therefore from equation 3

$$x_q = \frac{V^2 x_d}{V^2 + 2Px_d} \quad (4)$$

Pull-out will usually occur at a terminal voltage of approximately 0.25 per unit (25 per cent). Hence the magnetic circuit of the machine will not be saturated. The unsaturated value of x_d should be used in

equation 4 and the value of x_q obtained will be the unsaturated value.

If the resistance r of the machine is approximately taken into account, it can be shown that

$$x_q = \frac{V^2(x_d + 2r)}{V^2 + 2Px_d} \qquad (5)$$

There are several possible modifications of the above simple test. For example, from equation 2

$$x_q = \frac{V^2 x_d \sin 2\delta}{V^2 \sin 2\delta + 2Px_d} \qquad (6)$$

If resistance is approximately taken into account, it can be shown that

$$x_q = \frac{V^2(x_d \sin 2\delta + 2r)}{V^2 \sin 2\delta + 2Px_d} \qquad (7)$$

If a stroboscope or other means of measuring the load angle is available, any simultaneous readings of P, V, and δ taken with the machine operating as a reluctance motor can be substituted in equations 6 or 7 and the corresponding value of x_q obtained.

Very truly yours,

CHARLES KINGSLEY, JR. (A'30)
(Instructor, Mass. Institute of Technology, Cambridge)

The Engineer's Influence on Public Opinion

To the Editor:

Allow me to make somewhat of an answer to a question in B. D. Willis' "Letter to the Editor" on "New Use for Overproduced Products." (See ELECTRICAL ENGINEERING, January 1935, page 136.)

Referring to the symposium talks of Dr. Virgil Jordan and Col. W. T. Chevalier, (ELECTRICAL ENGINEERING, November 1934, pages 1546–51), and to the fact that the national administration has complained of criticism without accompanying helpful suggestions, Mr. Willis does then make several common-sense and constructive plans. He finally asked, "Why is it not practical to discover the full value of our surplus stocks and consume them?"

One reason "why not" can be handled rather summarily. Politics (the U. S. A. sort) could regard such a program with indifference only. Not only are the necessary steps dispassionate and impersonal; worse, they do not lend themselves to indiscriminate placement of faithful party workers.

Another reason, having a philosophical tinge, leads a bit farther afield. Mr. Willis' suggestions have no "success" appeal. They are not spectacular, but common-sense. Actually, they are scientific. And, the attitude of the layman toward science is one of "uncritical credulity," yielded only on account of the successes of science. "Owing to its success, the scientific method has obtained immense prestige in the eyes of the layman. In spite of its prestige, however, the scientific method still remains very unpopular. The patient accumulation of all relevant evidence, the cautious framing of hypotheses, and the careful verification of them are almost unknown in ordinary human pursuits—such as politics, for example. And any attempt to apply such methods is strongly resented."—from "Science and the Layman," by J. W. N. Sullivan, *Atlantic Monthly*, September 1934.

Please note: "owing to its success. . ." Colonel Chevalier also spoke of the prestige gathered by success—the success of the American system that got along fine for 150 years. But, having a scientific viewpoint, he had to give opportunism its deserts: "We have been able to make the old speculative thing work because every time we cleaned out one bunch of suckers there was a new place for them to go and dig up some more for the wise ones to take away from then on the next turn-over."

Thus it is we come a bit closer to fundamentals.

Everitt Dean Martin claims most people look on "liberty" as freedom to get rich. It was Henry Ward Beecher who urged people to get rich as a most worthy human endeavor. But it was a Roman emperor, we are told, who put it more succinctly: "*pecunia non olet.*"

What Colonel Chevalier dubs "the old speculative thing," is a vital component of the stimuli of public opinion. Human mental activity is largely wishful thinking, along the lines of personal vindication and aggrandisement. Its intellectual level is about that of the Alger books. Having had a frontier and prodigious reserves of natural resources, *ergo* and *of necessity*, it must yet be so. People, in the mass, seem unable to grasp the fact of there having to be more victims than racketeers, more betters than bookmakers, more lambs than either bulls or bears. They believe, implicitly, that "Every man a King" is perfectly possible.

Human nature, being what it is, has always believed, and still does, that "deals" are a more practical, a sounder, a more sensible basis of action than ideals. The leaders of the early United States—sometimes known as "the funding fathers"—subscribed pretty generally to this creed. The Credit Mobilier episodes of Grant's administration demonstrated it to be a lively principle 100 years later. The Teapot Dome activities of Harding's day showed it but waiting an opportunity to express itself again.

In brief, I have but tediously piled Ossa upon Pelion to indicate that public opinion and political expediency are instinctively against such common-sense proposals as are outlined by Mr. Willis.

Then, what to do? Some change must be accomplished in public opinion, if not in human nature. But how to accomplish it?

Manifestly, it will have to come through those the public accepts as mentors. On this principle, one suggestion I have seen is that newspapers, in reporting anti-social occurrences, refrain from adjectives and style that lend "glamour" to the events and participants. To do, rather, significant journalism, than to write sensational claptrap.

Another scheme is based on the motives which determine buying habits. Study has shown the character traits most useful in promoting large-scale purchasing are snobbishness, desires for adequacy, desires for vicarious romance, etc. Some overhauling to advertising methods would therefore seem helpful. Especially so, if the emphasis of appeal be shifted away from the more paltry emotions.

It can thus be deduced that engineers, in any scientific capacity, have no great opportunities here, no more than have medical men. Of the several professions, each acting in its professional capacity, clerics and legal persons would be of greatest aid. About all engineers can do is to convince themselves of the inapplicability of reason and scientific method to an emotional public sentiment. Then, *as ordinary citizens*, exert persuasion or pressure on those having influence to change their philosophy.

When, and if, the influential act on principle rather than in accord with policy toward constituents, congregations, clients—i. e., toward the "public" in any of its private and organizational manifestations—then, after a time, the methods of science may become applicable.

Very truly yours,

J. ANDREW DOUGLAS (A'18, M'29)
(Fairhope, Ala.)

Constant-Current A-C Transmission

To the Editor:

The presentation before the A.I.E.E. 1935 winter convention of the paper on "Constant Current D-C Transmission" by Willis Bedford and Elder (see ELECTRICAL ENGINEERING for Jan. 1935, pages 102–8) has introduced a most significant factor into the discussion of extra long distance transmission. It further has prompted the writer to here call the attention of the members of the Institute to the favorable possibilities of the use of constant alternating current in important transmission, a subject studied carefully by him some years ago.

This introduction of the constant current feature into the long distance d-c transmission system, adds a number of new and fundamental factors vitally affecting costs, efficiencies, and operability—sometimes favorably, sometimes not so favorably. The unique and to most engineers unfamiliar behavior of the current-potential conversion unit, in which equalized reactors and capacitors are similarly connected, so as to be in series in one circuit and in parallel in another, causes a profound modification of the natural performance of the system.

As appears in the paper, the characteristics of these conversion units depend upon the correspondence of the current in one circuit with the voltage in the other.

If equalized reactors and capacitors be connected in series across the primaries of the step up transformers of a typical existing 3-phase transmission system and the 3 constant-potential supply phases be applied between the mid points of these windings and the junction points between the reactors and the capacitors (see figure 1), a constant current will flow in the secondaries of the transformers and into the line. If similar and similarly connected reactors and capacitors be introduced in circuit with the secondary windings of the step down transformers, whose primaries are supplied with constant current, 3-phase constant-potentials will be produced between the mid points of the secondary windings and the junction points between the reactors and the capacitors, these being available for supplying the local

load. The connections, applicable to either end, are shown in the figure.

In this system, with the ideal circuit, free of all losses, the line *current* bears a definite ratio to the constant supply and delivery *potentials*, a ratio equal to the value of the equalized reactances or capacitances, and the *potentials* of the line bears the inverse ratio to the *currents* in the load and the generator, the current in the one circuit and the voltage in the other retaining a constant phase relation.

In such a system the generation of power is normal constant potential, the line transmission is constant current, and the delivery at the receiving end is normal constant-potential. In the ideal circuit no limitations to operation or load control are so introduced. The system as a whole, however, has certain striking inherent characteristics which may be briefly pointed out as follows:

1. In case of an overload on the receiving circuit an increase in potential in the line results, with the corresponding increase of line load transmitting capacity, this increase strengthening the tendency to hold synchronism. This behavior is in contrast to that of the constant potential line, in which an increase in load tends to drop the potential on the line and reduce its capacity and produce instability.

In favorable cases the adoption of this system will greatly increase the dependable capacity of existing lines. Provision must be made against too high a rise of line potential in the case of heavy overloads. There are several methods of accomplishing this result.

2. The lagging component of the load in the receiving circuit, as pointed out in the paper, becomes a leading component in the constant current line circuit giving more favorable line conditions. That is, the line instead of carrying a lagging current, has a leading current. The importance of this change from lagging to leading in its effect on the ability of the line to carry heavy loads is exceedingly important, as will be seen by comparing the line performance at 90 per cent or 95 per cent lagging load with that at 90 per cent or 95 per cent leading. The net result is a very great gain in the maximum stable load of a line. In this case the reactance of the line is operating to increase the line load capacity—and to this extent gives advantage over d-c transmission, in that the natural ohmic drop may thus be overcome in favorable designs.

On the other hand any variation of current strength along the line will tend to disturb the constancy of the potential at the receiving network, the line current being held automatically constant at the sending end. Some benefit may be secured in controlling the effect of such variation by synchronous condensers controlling the power factor at the receiving end and this may be made automatic. These matters become very complicated in considering the detail in any particular case. It should be noted that out-of-phase current components existing in the constant current line change sign in the constant potential generator circuit, but little importance attaches to this.

3. With the coustant line current set up, the maximum energy to be handled by high voltage circuit breakers, when due to trouble on the high voltage circuits, is greatly reduced, and lower cost, quicker acting units

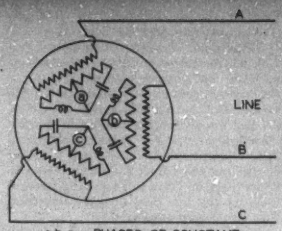


Fig. 1. Current-potential conversion unit

may be used. This is a matter of no small moment.

From another point of view it may be urged that no circuit breakers would be needed on the constant current circuit as such a current should not be interrupted. This is a matter to be considered in the light of circumstance existing in particular cases.

Further, the current interrupting duty on the lightning arresters is greatly reduced and either lower priced or more complete protection may be secured as a result. This feature may be compared to the ease of current interruption of ground faults in the constant current d-c line with the inverter operating in the reverse direction, as described in the paper.

Obviously a new system of relays is required.

4. The use of a constant line current means a constant line energy loss, equal to the full load loss, even at very light loads. While this may be unimportant for base load service, it would be prohibitive for emergency service. However, it is entirely possible to reduce this loss greatly in a polyphase transmission by using a lesser value of line current for the lighter loads, this calling for higher line potential for that condition. The change from one line current to the other may be made in a few minutes by making the change, leg by leg. The single line wire may be cut off at both ends—the phase transformers then de-energized and the low voltage taps changed and the load then resumed in that leg.

While the line resistance loss tends to remain constant as the load drops, the line voltage falls almost in the same proportion and the transformer core losses drop as well.

Since the maximum voltage exists only during a very small fraction of the year—when the maximum load occurs—it will be permissible to establish a materially higher value for the voltage than would be permissible in the normal constant potential system, no doubt at least 10 per cent higher. This means a valuable gain in capacity.

Many other important and interesting features might be considered, but space will not permit.

Any of the well known alternative forms of current-potential conversion units may be used in place of that shown here. In conclusion, it remains to emphasize the very great gain in capacity and stability offered by the constant current a-c transmission.

Very truly yours,

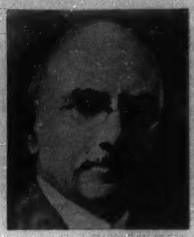
PERCY H. THOMAS (A'00, F'12)
(Federal Power Commission, Washington, D. C.)

Personal Items

ELIHU THOMSON (A'84, M'91, F'13, HM'28, past-president, and member for life) consulting engineer, General Electric Company, and director, Thomson Research Laboratory, Lynn, Mass., was awarded the medal of honor of the Verein Deutscher Ingenieure on the occasion of his eighty-second birthday in March 1935. The society which presents this outstanding award of the German engineering profession is the oldest and largest of engineering societies in the world, and the award has previously been conferred upon only 5 non-Germans, only one of whom, the late C. W. RICE (A'97, M'97, F'12) was an American. The citation read, "On Elihu Thomson, the great pioneer in the realm of engineering, the inventor and research scientist, the promoter of co-operation among engineers, there is conferred, on the anniversary of his eighty-second birthday, the V.D.I. medal of honor." Doctor Thomson was confined to his home by ill health, and the medal was accepted on his behalf by E. W. RICE, JR. (A'87, M'88, F'13, HM'33, past-president, and member for life). Many honors and awards for his achievements have previously been bestowed upon Doctor Thomson, who was one of the founders of the General Electric Company and holds more than 700 United States patents. He was a vice president of the Institute 1887–89, and president 1889–90, later serving as a member of the Edison medal committee, 1910–15, and as representative on the United States National Committee of the International Electrotechnical Commission, 1914–30.

D. C. JACKSON (A'87, M'90, F'12, past president and member for life) head of the department of electrical engineering, Massachusetts Institute of Technology, Cambridge, since 1907, will retire in June 1935. He was born at Kennett Square, Pa., and received the degree of civil engineer from Pennsylvania State College in 1885, subsequently taking 2 years of postgraduate study in electrical engineering at Cornell University. From then until 1889 he was vice president and engineer for the Western Engineering Company, Lincoln, Neb., engaged in the design and construction of electric light and power plants and distribution systems in that region. During 1889 and 1890 he was assistant chief engineer with the Sprague Electric Railway and

Motor Company, New York, N. Y., and the following year was chief engineer for the Edison General Electric Company, supervising in these positions the design and construction of many electric railway and power plants. The following year he formed a consulting engineering firm with W. B. Jackson (A'97, M'98, F'13, and Life Member) and also became professor of electrical



D. C. JACKSON

engineering at the University of Wisconsin. In 1907 he became professor and head of the department of electrical engineering at Massachusetts Institute of Technology. A partnership with E. L. Moreland (A'11, M'15, F'21) was formed in 1919, of which Professor Jackson was senior partner until 1930. The firm was particularly active in the field of railway electrification. Professor Jackson is at present Institute representative on the National Research Council and a member of the Institute's committees on standards, Institute policy, and legislation affecting the engineering profession, and has served on many others. He was a vice president of the Institute 1897–99 and president 1910–11. Among the honors which he has received is the Lamme medal of the Society for the Promotion of Engineering Education, of which he is a past-president. Professor Jackson is a member of a number of other technical societies in this and other countries, and is the inventor of a number of electrical devices as well as author of many papers and books on engineering subjects and engineering education.

E. L. Moreland (A'11, M'15, F'21) senior partner of the firm of Jackson and Moreland, consulting engineers, Boston, Mass., has been appointed head of the department of electrical engineering of Massachusetts Institute of Technology, Cambridge, to succeed D. C. Jackson (A'87, M'90, F'12, past-president, and member for life) who retires in June 1935. Mr. Moreland will also continue his affiliation with the engineering firm. He was born at Lexington, Va., and received the degree of bachelor of arts from The Johns Hopkins University in 1905. He then entered Massachusetts Institute of Technology, and graduated in 1908 with the degree of master of science. In this year he entered the employ of D. C. Jackson and W. B. Jackson (A'97, M'98, F'13, and Life Member), consulting engineers, as an assistant in their Boston office. In 1912 he was appointed manager of the office, and in 1916 became a partner. After overseas military service, Mr. Moreland formed the partnership with D. C. Jackson in 1919. The latter retired from the partnership in 1930. The firm has been engaged on many important engineering projects, including the electrification of the Great Northern Railway through the Cascades and the electrification of the Lackawanna Railroad. Many engineering studies for public utility companies have been made, including a study of electrical characteristics of transmission lines and generating stations for the Tennessee Valley Authority. Other projects on the development of power which have been studied have been in the petroleum industry and in connection with the proposed Passamaquoddy tidal power project in northern Maine. Mr. Moreland has been active in civic affairs and in the Technology Alumni Association, of which he becomes president this year, and now holds the rank of lieutenant colonel in the engineers, Officers Reserve Corps. In the Institute Mr. Moreland has presented several papers and has served on the electrical machinery and power generation committees, 1929–31; technical program committee, 1931–34; and Institute policy, 1933–34. He is now chairman of the standards committee, of which he has been a member since 1932, a member of the transportation

E. L. MORELAND

committee, of which he was chairman 1931–34, and Institute representative on the standards council of the American Standards Association. Among the organizations of which Mr. Moreland is a member are The American Society of Mechanical engineers, the American Society of Civil Engineers, the American Academy of Arts and Sciences, and the Boston Society of Civil Engineers.

J. J. Torok (A'27) former development engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has joined the research and development department of the Corning Glass Works, Corning, N. Y., where he will be concerned principally with insulators and allied products. Mr. Torok was born at Philadelphia, Pa., in 1903, and received the degrees of bachelor of science in mechanical engineering and electrical engineer from Pennsylvania State College in 1925 and 1928, respectively. In 1925 he entered the training course of the Westinghouse Electric and Manufacturing Company, and the following year was transferred to the high voltage laboratory in charge of impulse testing. In 1929 Mr. Torok developed a new type of lightning arrester now widely applied for transmission line protection. In 1933 he was transferred to the transformer engineering department in charge of special problems, and the next year he was transferred to the circuit breaker division in charge of lightning arrester development. Mr. Torok has written a score of articles and papers, some of which have been presented before the Institute.

J. T. Barron (A'07, M'20, F'27) who since 1926 has been general manager of the electric department of the Public Service Gas and Electric Company, Newark, N. J., has been named vice president in charge of electric operation. Mr. Barren graduated from the University of South Carolina in 1905, and after 2 years in the testing department of the General Electric Company at Schenectady, N. Y., entered the testing laboratory of the Public Service company at Newark. Shortly afterward he was assigned to the construction department, and in 1908 was made chief operator of substations and generating stations in the central division. In 1910 he became superintendent of this division, and in 1919 general superintendent of production, which title later was changed to general superintendent of generation. He was a member of the Institute's power stations (now power generation) committee 1919–24, and of the board of examiners 1929–30.

Marion Penn (M'21) who has been general superintendent of generation, Public Service Gas and Electric Company, Newark, N. J., has been appointed general manager. Mr. Penn is a graduate of Purdue University, class of 1911. He came to the Public Service Company from the General Electric Company at Schenectady, N. Y., in 1914, assuming the position of assistant division superintendent in the central division. During the war he was overseas, and shortly after his return became plant engineer at Newark in 1919. Following periods as chief engineer at various stations, Mr. Penn was promoted to general superintendent of generation in 1926. During the year 1927–28 he served as a member of the Institute's power generation committee.

C. S. McDowell (A'13, M'14, F'18, and past vice president) captain, U.S. Navy, and naval inspector of machinery, Camden, N. J., is now at the astrophysical observatory of California Institute of Technology, Pasadena, as supervising engineer for the construction of the 200 inch telescope there. Captain McDowell is a graduate of the U.S. Naval Academy, class of 1904, and has made various contributions to technical literature. He has been a member of the Institute's standards committee, the meetings and papers (now technical program) committee, the marine (now applications to marine work) committee, of which he served as chairman, and was a representative on

the U.S. National Committee of the International Electrotechnical Commission 1922–23. During 1920–21 he was a vice president of the Institute.

F. B. Jewett (A'03, M'10, F'12, and past-president) vice president of the American Telephone and Telegraph Company, and president of the Bell Telephone Laboratories, Inc., New York, N. Y., has accepted the position of national chairman of a campaign to raise a working capital fund of $161,000 for Engineering Index, Inc. The national committee, not as yet been completely enrolled, will endeavor to enlist the support of industry for the index and annotating service, discontinued a year ago as an activity of The American Society of Mechanical Engineers.

G. L. Knight (A'11, M'11, F'17) vice president, Brooklyn Edison Company, Inc., Brooklyn, N. Y., has been appointed chairman of the finance committee of United Engineering Trustees, Inc. Mr. Knight, who has served on a number of Institute committees and is now Institute representative of the board of United Engineering Trustees, Inc., was recently re-elected first vice president of United Engineering Trustees, Inc., as announced in Electrical Engineering for April 1935.

E. F. Smith (A'07, F'21) superintendent of substations, Commonwealth Edison Company, Chicago, Ill., retired in March 1935 after 41 years of service. He was a pioneer in operating procedure and safety practice in electrical substation work, with which he became identified early in his career when the substation system of distribution was adopted in Chicago. Mr. Smith served on many technical committees of the company and of the societies of which he is a member, and contributed a number of articles to the technical press.

H. R. Woodrow (A'12, F'23, and director) vice president in charge of electrical operations, Brooklyn Edison Company, Brooklyn, N. Y., has been appointed chairman of the real estate committee of United Engineering Trustees, Inc. Mr. Woodrow has served on a number of Institute committees, and is at present a member of the committees on publication, Edison medal, and economic status of the engineer, as well as Institute representative on the board of United Engineering Trustees, Inc.

H. P. Charlesworth (M'22, F'28, and junior past-president) assistant chief engineer, American Telephone and Telegraph Company, New York, N. Y., has been appointed a member of the Engineering Foundation committee on platform and general program. Mr. Charlesworth was re-elected recently as chairman of the board of Engineering Foundation as announced in Electrical Engineering for April 1935.

H. L. Hazen (A'26) assistant professor of electrical engineering, Massachusetts Institute of Technology, Cambridge, has been awarded the Levy gold medal of the Franklin Institute, which is given for outstanding technical papers appearing in the journal of the institute. The award was made to Professor Hazen "for 2 articles on the theory and design of servomechanisms, or devices for controlling the action of other machines."

Walter Breslauer (A'30) formerly public utility security analyst, Central Hanover Bank and Trust Company, New York, N. Y., is now an examiner for the Securities and Exchange Commission, Washington, D. C. Mr. Breslauer is a graduate of the University of Heidelberg and of the Technical College of Munich, and has contributed a number of articles on European utilities and electric transportation to publications.

A. G. Beljavsky (M'33) professor of electrical engineering at North-Caucas Institute of Energetics, Novocherkassk, U.S.S.R., recently was honored by his institution with a degree of doctor of technical sciences in recognition of his quarter century of faculty service and for his scientific and research work which has been principally in the field of a-c rectification.

J. W. Owens (A'10, M'20, F'27) former director, National Weld Testing Bureau, Pittsburgh, Pa., has accepted a position as director of welding with Fairbanks Morse and Company, Beloit, Wis. Mr. Owens was a member of the electric welding committee of the Institute 1927–31.

M. O. Evans (A'32) who was chief electrician and master mechanic with the Powhatan Mining Company, Powhatan Point, Ohio, has recently taken a position as electrical engineer with the Republic Steel Corporation, and is located at Uniontown, Pa.

V. R. Tate (A'28) formerly an electrical engineer in the patent department of the Minneapolis-Honeywell Regulator Company, Minneapolis, Minn., is now in charge of the patent department of Perfex Radiator Company and Perfex Controls Company, Milwaukee, Wis.

E. W. Grover (M'29) former assistant superintendent of substations, Commonwealth Edison Company, Chicago, Ill., has been appointed superintendent of substations to succeed E. F. Smith (A'07, F'21) who has retired.

R. U. Muffley (M'23) commercial manager, central district, Puget Sound Power and Light Company, Seattle, Wash., who recently became president of the Sales Managers Club in Seattle, has been elected to the board of trustees of the Seattle Chamber of Commerce.

W. J. Berry (A'31) former manager at Ashland, Kan., for the Western Telephone Corporation of Kansas has been transferred to Watonga, Okla., where he is manager of the Watonga, Canton, Seiling, Fay, and Greenfield exchanges of The Western Telephone Corporation of Oklahoma.

Edward Lipson (A'22) consulting and research engineer of Chelsea, Mass., is now research consultant for a laboratory maintained by a group of companies at Houston, Texas. Mr. Lipson has invented and patented various electrical, radio, and geophysical apparatus.

Samuel Ferguson (A'02) recently elected chairman of the board of directors of the Hartford Electric Light Company, Hartford, Conn., has been elected a member of the board of directors of the Arrow-Hart and Hegeman Electric Company.

H. J. Gille (A'01, M'13) manager, agricultural and industrial development, Puget Sound Light and Power Company, Seattle, Wash., was named president of the West Coast Mineral Association at its recent annual meeting in Seattle.

G. H. Gildersleeve (A'22) formerly district manager at the I-T-E Circuit Breaker Company at Cleveland, Ohio, is now connected with the Minneapolis-Honeywell Regulator Company with offices in New York, N. Y.

P. H. Trickey (A'30) who has been a design engineer with the Westinghouse Electric and Manufacturing Company, Springfield, Mass., is now a design engineer with the Diehl Manufacturing Company, Elizabethport, N. J.

C. H. Leatham (A'33) who has been sales research manager with the West Penn Power Company, Pittsburgh, Pa., is now with the Monongahela West Penn Public Service Company, Fairmount, W. Va.

O. L. Riggs (A'21, M'29) formerly assistant superintendent, has become superintendent of distribution in the electric department of the Lynn Gas and Electric Company, Lynn, Mass.

C. F. Osborn (A'24, M'31) formerly an electrical engineer with the Ralston Purina Company, St. Louis, Mo., is now with the Chandeysson Electric Company in St. Louis.

H. C. Fiske (A'24) former assistant chief engineer of the Jas. R. Kearney Corporation, St. Louis, Mo., is now with J. E. Sumpter Company, district consulting engineers, Minneapolis, Minn.

W. S. Barstow (A'94, M'99, F'12, and Life Member) retired, Barstow, Tyng and Company, Inc., New York, N. Y., was re-elected president of the Edison Pioneers at a recent meeting in New York.

F. L. Fuller (A'33) who has been an instructor at Stevens Institute of Technology, Hoboken, N. J., is now employed by the Western Electric Company at Kearny, N. J.

A. B. Newell (A'25) of Kirkwood, Mo., recently accepted a position as an assistant engineer with the Public Service Commission of Missouri, with headquarters at Jefferson City.

C. A. Mullen (A'20, M'20) superintendent of southern division, Jersey Central Power and Light Company, who was formerly at Asbury Park, N. J., is now at Morristown.

Stefaan Pirk (A'06) executive vice president, Syracuse Lighting Company, Inc., Syracuse, N. Y., has been elected a director of the Niagara Hudson Power Corporation.

William Kelly (F'25) president, Buffalo, Niagara, and Eastern Power Corporation, Buffalo, N. Y., has been elected a director of the Niagara Hudson Power Corporation.

Otto Snyder (M'25) president, New York Power and Light Corporation, Albany, N. Y., has been elected a director of the Niagara Hudson Power Corporation.

W. E. Stewart (A'32) formerly assistant engineer at Nebraska Wesleyan University, Lincoln, is now engineer at radio station WOI, Ames, Iowa.

A. W. Hawley (A'30) Winsted, Conn., is studying for the degree of electrical engineer at the Yale Graduate School, New Haven.

E. R. Riethmiller (A'29) former chief engineer, Cardon-Phonocraft Corporation, Jackson, Mich., has engaged in consulting engineering practice.

E. A. Skonberg (A'30) former sales manager, Electric Motor Repair Company, Springfield, Mass., is now with the Ekholm Corporation, engineers in Boston, Mass.

H. J. Smart (A'23) of Dalton, Mass., recently accepted a position in the engineering department of the Foxboro Company, Foxboro, Mass.

J. N. Helpbringer (F'26) electrical engineer, Ohio Electric Power Company, who was formerly at Sidney is now at Marion.

W. F. Turner (A'25) formerly division manager, Wisconsin Power and Light Company, Madison, is now resident engineer for the company at Fond du Lac.

F. S. Himebrook (A'32) is now an electrical engineer with the Master Electric Company, Dayton, Ohio.

R. E. Sinclair (A'31) Pacific Power and Light Company, has been transferred from Yakima, Wash., to Toppenish.

H. E. Mortimer (A'33) Gulf States Utilities Company, has been transferred from Beaumont, Texas, to Port Arthur.

E. R. Evans (A'20) Washington, D. C., has engaged in professional practice as a patent attorney and consulting engineer.

Obituary

Kenneth A. Reed (A'19) chief engineer, electrical division, Hartford Steam Boiler Inspection and Insurance Company, Hartford, Conn., died March 23, 1935. Mr. Reed was born at Gregory, Ark., January 30, 1883. Following graduation from the University of Arkansas with the degree of bachelor of electrical engineering in 1907 he entered the apprenticeship course of the Allis-Chalmers Manufacturing Company at Cincinnati, Ohio. The next year he was employed in the operating department of the Northwest Water and Light Company, Yakima, Wash., and in 1910 joined the Westinghouse Electric and Manufacturing Company in St. Louis, Mo., as an electrical engineer. He was engaged in construction work until 1917, when he became assistant district superintendent. In 1918 Mr. Reed accepted the position of maintenance engineer in the electrical operating division of the Interborough Rapid Transit Company, New York, N. Y., where he had charge of the maintenance of central stations and substations. Leaving this position in 1921 and joining the Hartford Insurance Company, Mr. Reed assisted in the creation of the then new insurance of electrical machinery. His principal responsibility was the organization of an inspection service for electrical machinery that would minimize preventable losses, and papers on the subject written by him have been published in technical journals. At the time of his death Mr. Reed was a member of the electrical machinery committee of the Institute, on which he had served since 1931, and for several years he was a member of the electrical apparatus committee of the National Electric Light Association (now Edison Electric Institute).

Rudolph Melville Hunter (A'86, M'87, and member for life) consulting engineer and expert in patent cases, Philadelphia, Pa., died March 19, 1935. He was born at New York, N. Y., June 20, 1856, and received a mechanical engineering degree from Polytechnic College in 1878. In 1881 he organized an electrical manufacturing company, and also engaged in practice as a consulting engineer and electrical expert in patent cases involving infringement. Mr. Hunter was a prolific inventor, and ranked high among the world's inventors as a holder of patents, licenses for more than 300 of his inventions having been granted to the General Electric Company and the Westinghouse Electric and Manufacturing Company. Among the achievements credited to him may be mentioned a plan placed before the British Parliament for an electric railway for the proposed tunnel between Dover and Calais, 1883; the development of a submarine vessel, 1879–81; electric transformer system inventions sold to the Westinghouse company, 1886; the design and building of the first moving-picture projector in the world, 1894; and the organization, in 1889, of the Electric Car Company of America, of which he was at one time president. He was retained by the General Electric Company as an engineer and patent counsel for 22 years, and for 17 years was an acoustics expert for the Victor Talking Machine Company.

Burch Foraker (A'07) chairman of the board of directors, Michigan Bell Telephone Company, Detroit, died March 29, 1935. He was born at Hillsboro, Ohio, February 17, 1872, and studied at Ohio Wesleyan University and at Cornell University, where he was a member of the class of 1895. During summer vacation in 1893 he obtained employment as an installer with the New York Telephone Company, New York, N. Y., and decided to continue with that work. He later entered the engineering department, and from 1907 to 1912 was plant superintendent in the Brooklyn and Long Island areas. Following this Mr. Foraker was general superintendent in charge of plant construction and maintenance in the Manhattan, Bronx, and Westchester divisions. In 1924 he was appointed a general manager of the company with headquarters at Albany, N. Y., and 2 years later he was elected president of the Michigan Bell Telephone Company, holding this office until October 1934, when he became chairman of the board of directors. Mr. Foraker was a member of the Telephone Pioneers of America, and served as that organization's national president in 1930.

Edgar Field Price (A'95 and member for life) vice president, Union Carbide and and Carbon Corporation, New York, N. Y., died April 15, 1935. He was born at Leaksville, N. C., in 1873. In 1891 he became connected with the Willson Aluminum Company, Spray, N. C., and it was here that the production of acetylene was noted when water contacted a charge withdrawn from an electric furnace after an attempt had been made to produce aluminum. When the Willson company retired from business Mr. Price joined the Westinghouse Electric and Manufacturing Company, and later he became connected with the Union Carbide Company, of which he rose to the presidency. In 1917, with the formation of the Union Carbide and Carbon Company, he became vice president, and was also an officer and director of some of the corporation's subsidiaries until his retirement in 1925. Mr. Price was decorated by the King of Norway in recognition of his interest in Norway's natural resources and the development of a water power system. He was a member of the Institute's electrochemistry and electrometallurgy committee 1914–16.

James Martin Kent (A'21, M'21) teacher and engineer, Kansas City School District, Manual Training High School, Kansas City, Mo., died March 24, 1935. Mr. Kent first joined the Institute in 1900. He was born at Kewanee, Ill., October 6, 1865, and graduated from the University of Illinois with the degree of bachelor of science

in mechanical engineering in 1885. After short periods of employment he went to Kansas City in 1886 as superintendent of the public lighting plant of Sperry Associate Electric Company, and later became chief engineer of a private power plant, the installation of which he designed and superintended. In 1897 he accepted a position as teacher of steam and electricity and as designer and operator of the power plant in the Manual Training High School. In addition to this work he carried on a small practice as a consulting electrical and mechanical engineer, and during the period 1912–17 was president of the Henrici, Kent and Lowry Engineering Company, during which time he was largely responsible for the design and installation superintendence of a number of municipal and private plants. Mr. Kent was also a member of The American Society of Mechanical Engineers, American Society of Heating and Ventilating Engineers, Institute of Radio Engineers, American Chemical Society, American Electrochemical Society, American Association for the Advancement of Science, American Forestry Association, Society for the Promotion of Engineering Education, National Society for the Promotion of Industrial Education, National Educational Society, and Missouri Society of Mathematics Teachers.

Charles George Adsit (A'05, M'09, F'13, and past vice president) president, Des Moines Railway Company, Des Moines, Iowa, died March 27, 1935. He was born at Ironton, Ohio, November 1, 1874, and studied at the University of Chicago. After short periods of employment with engineering firms he entered the testing department of the General Electric Company at Schenectady, N. Y., leaving in the next year to go to Breckenridge, Colo., taking charge of the construction of a hydroelectric plant there. During this period he was employed by several mining companies, going to Bisbee, Ariz., in 1906 for railway construction. In 1911 he was employed by the Georgia Railway and Power Company on its development at Tallulah Falls, and subsequently was concerned with other developments of this company and its successor, the Georgia Power Company. Mr. Adsit resigned as vice president and consulting engineer of the company to engage in consulting engineering in Atlanta, Ga., until he became president of the Des Moines Railway Company in 1930. He was a member of the Institute's finance committee, 1922–23, and of the power transmission and distribution committee 1925–26; representative on the American Engineering Council, 1923–26; and a vice president of the Institute 1921–23.

Wilfred Thomas Birdsall (A'23) consulting engineer and physicist, Montclair, N. J., died March 16, 1935. He was first elected an associate member of the Institute in 1913. Mr. Birdsall was born at Philadelphia, Pa., February 29, 1888. In 1908 he received the degree of bachelor of arts from Amherst College, and in 1910 the degree of bachelor of science in electrical engineering from the University of Pennsylvania. For a short time in 1910 he was employed by the Telluride Power Company, Grace, Idaho, and then entered the Westinghouse Lamp Company, Bloomfield, N. J., becoming engineer in charge of the mercury arc rectifier department in 1912. In 1915 he became engineer in charge of research work, and the following year joined C. E. Knoepple and Company, industrial engineers in New York, N. Y. After overseas service he was employed by the Columbia Graphophone Manufacturing Company, Bridgeport, Conn., becoming general superintendent of the record division in 1920. He engaged in private consulting practice in 1921, and since then perfected and sold a number of inventions, including a type of fixed radio detector.

Edgar Allen Cerf, Jr. (A'27, M'33) assistant engineer outside plant bureau, Brooklyn Edison Company, Brooklyn, N. Y., died April 9, 1935, at Welland, Ont., Can., as the result of an automobile accident. He was born at Atlanta, Ga., March 5, 1905, and received the degree of bachelor of science in electrical engineering from Georgia School of Technology in 1925. The following year he received the degree of master of science in electrical engineering from Yale University, and the degree of electrical engineer in 1931. Mr. Cerf was employed in the electrical construction bureau of the Brooklyn Edison Company in 1927, and had been in the outside plant bureau since 1928.

Ernest White (A'31) assistant commercial engineer, Associated Telephone Company, Ltd., Long Beach, Calif., died recently, according to word received at Institute headquarters. He was born at Huntingdonshire, England, January 12, 1901, and studied at the University of California, receiving the degree of bachelor of science in electrical engineering in 1923. Until 1926 he was employed by the Southern California Telephone Company, Los Angeles, leaving at that time for graduate work at the University of Southern California. For a year he taught in the high school at Banning, Calif., and in 1929 entered the employ of the Associated Telephone Company, where he was engaged in planning and economic studies.

Torsten F. son Holmgren (A'04) consulting electrical engineer, Stockholm, Sweden, died in May 1934, according to word just received at Institute headquarters. He was born at Upland, Sweden, August 1, 1874, and graduated from the technical university at Stockholm in 1904. During 1894–97 he was employed by Siemens and Halske, Berlin, Germany, and from then until 1899 by an electric light company in Sweden. In 1901 he started practice as a consulting electrical engineer in Stockholm, at which time he was chief electrical inspector of the Swedish board of fire underwriters.

Alonzo Brackett Bradley (A'02) factory manager, Fibre Conduit Company, Orangeburg, N. Y., died March 2, 1935. He was born at Avon, N. Y., January 21, 1880, and received the degree of electrical engineer from Columbia University in 1903. He had held his position with the Fibre Conduit Company since 1920, previous to which he had been in various engineering companies, including B. F. Wood Engineers, Inc., New York, and in private practice as a consulting engineer.

Membership

Recommended for Transfer

The board of examiners, at its meeting held April 24, 1935, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Cushing, Harvey M., chief engr., Buffalo Gen. Elec. Co., Buffalo, N. Y.
Gaylord, James M., chief E.E., Metropolitan Water District of Southern Calif., Los Angeles.

2 to Grade of Fellow

To Grade of Member

Albert, Arthur L., assoc. prof. of elec. engg., Oregon State College, Corvallis.
Balsbaugh, Jayson C., assist. prof., elec. engg. dept., Mass. Inst. of Tech., Cambridge.
Knipmeyer, Clarence C., head, elec. engg. dept., Rose Polytechnic Institute, Terre Haute, Ind.
Poole, Arthur B., E.E., The E. Ingraham Co., Bristol, Conn.
Smith, Don F., chief engr., Pacific Tel. and Tel. Co., Portland, Ore.
Van Ness, Bartow, Jr., E.E., Pa. Water and Pwr. Co., Baltimore, Md.
Whitehead, John H., lecturer in elec. engg., Constantine Technical College, Middlesbrough, Yorks, England.
Woodyatt, James B., president and gen. manager, Southern Canada Pwr. Co. Ltd., Montreal, Que.

8 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before May 31, 1935, or July 31, 1935, if the applicant resides outside of the United States or Canada.

Appleton, W. E., N. Y. & Queens Elec. Lt. & Pwr. Co., Flushing, N. Y.
Benoglou, G. D., 3951 Gouverneur Ave., Bronx, N. Y. C.
Blake, J. W., Fidelity & Casuality Co. of N. Y., Oklahoma City, Okla.
Brownlee, W. R., Tenn. Elec. Pr. Co., Chattanooga, Tenn.
Cain, D. C., Texas Elec. Serv. Co., Ft. Worth.
Castelin, L. P., N. Y. Pwr. & Lt. Corp., Albany.
Cooper, R. B., Oklahoma Gas & Elec. Co., Seminole.
D'Ippolito, M., P. O. Box 338, Dedham, Mass.
Downie, E. G., Gen. Elec. Co., Ft. Wayne, Ind.
Duehne, H. H. (Member), New York Central RR, New York City.
Ellmaker, H. C. (Member), Freeman Lang Studios, Los Angeles, Calif.
Emmerling, E. J., Union Gas & Elec. Co., Cincinnati, Ohio.
Fox, J. C. (Member), Virginian Ry., Narrows, Va.
Gakle, W. F., Kuhlman Elec. Co., Bay City, Mich.
Graham, W. F., Alabama Public Service Comm., Birmingham.
Hamilton, A. W., 3rd, Pa. RR., Washington, D. C.

Hastings, C. C., c/o R. E. Uptegraff Mfg. Co., Pittsburgh, Pa.
Hatz, E. W. (Member) Milwaukee Elec. Ry. & Lt. Co., Wis.
Hoadley, G. B., Mass. Inst. of Tech., Cambridge.
Honser, R. J., Morse Bluff, Neb.
Howell, A. H., Mich. Coll. of Mining & Tech., Houghton.
Hughes, P. H., N. J. Bell Telephone Co., Newark.
Kelley, F. B., Kansas City Pwr. & Lt. Co., Mo.
Koziol, R. J., 10 Brick Row, Southbridge, Mass.
Landis, G. G. (Member) Lincoln Elec. Co., Cleveland, Ohio.
Larson, N. G., Commonwealth Edison Co., Chicago, Ill.
Lemkin, H. J., F. A. D. Andres, Inc., Woodside, N. Y.
Lozano y Vez, J., Gen. Elec. S. A., Mexico City, Mex.
Magann, J. W. (Member) Okla. Gas & Elec. Co., Oklahoma City.
McMynn, J. D., Consolidated Mining & Smelting Co., Trail, B. C., Can.
Melton, R. L., Carborundum Co., Niagara Falls, N. Y.
Miller, J. R., Board of Purchase, N. Y. City.
Motherwill, L. J. N., Polymet of Canada Ltd., Hamilton, Ont., Can.
Novak, L. C., Gen. Elec. Co., Lynn, Mass.
Paige, E. R., Cornell Univ., Ithaca, N. Y.
Pound, J. C., U. S. Army Engineers, Portland, Ore.
Redrup, A. F. (Member) 223 S. Washington St., Van Wert, Ohio.
Ricciardi, D., 718 Fairmount Pl., New York, N. Y.
Savage, C. P., Jr., General Elec. Co., Lynn, Mass.
Schmidt, A. J., Gen. Elec. Co., Schnectady, N. Y.
Simpson, H. B., Standard Varnish Works, Elm Park, N. Y.
Smith, H. K. (Member) Westinghouse Elec. & Mfg. Co., Chicago, Ill.
Smith, W. O., Long Island Ltg. Co., Glenwood Landing, N. Y.
Stoller, F. E., Cleveland Elec. Illum. Co., Cleveland Heights, O.
Thompson, C. V., 3820 N. 15th St., Phila., Pa.
Tompkins, G. H. (Member) N. Y. Air Brake Co., Watertown, N. Y.
Walker, E. T., Jr., Underwriters' Lab., Boston, Mass.
Wayman, J. B., So. Calif. Edison Co., Ltd., Los Angeles, Calif.
Wens, R. C., Byllesby Engg. & Mngt. Corp., Chicago, Ill.

49 Domestic

Foreign

Alverson, G. D., U. S. Navy, Wallupe, T. H.
Chakravorty, S., Elec. Supply Co. Ltd., Gorakhpur, India.
Chopra, B. N., Renala Hydro Elec. Works, Punjab, India.
Dolan, H., (Member) English Elec. Co., Stafford, Eng.
El-Koshairy, M.A.B., City & Guilds Engg. Coll., London, S.W. 7, Eng.
Halton, G. H. (Member) Steatite & Porcelain Products Ltd., Stourport-on-Severn, Eng.
Ohri, S. R., Murree Elec. Supply Co., Ltd., Lahore, India.
Ranum, H., Cerro de Pasco Copper Corp., Oroya, Peru, S. A.
Sreenivasan, K. (Member) Indian Inst. of Science, Bangalore, India.
Tweedale, A. (Member) 7 Gordon Terrace Blackpool, Eng.

10 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the address as it now appears on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Dowty, Paul L., 1036 Sheridan Rd., Chicago, Ill.
Germenshausen, K. J., M.I.T. Dorm., Cambridge, Mass.
Golikoff, A., Main P. O. Gen. Del., Moscow, U. S. S. R.
Haddad, Raphael A., 500 Riverside Drive, N. Y. City.
Hansen, A. Fred, 2065½ W. 30th St., Los Angeles, Calif.
Hope, Harry M., Belvedere, Calif.
Houston, Chas. B., 400—10th Ave., S. E., Minneapolis, Minn.
Phillips, R. M., 20 Garth Rd., Scarsdale, N. Y.
Rasmussen, David, 439 Hickory St., Ridgway, Pa.
Shelley, William L., 203 Grease Ave., Brooklyn, N. Y.
Smedley, A. B., 82 Warner Ave., Hempstead, N. Y.
Verrier, E. J., Anglo Newfoundland Dev. Co., Grand Falls, Newfoundland.
Watson, J. Connell, 69 Cambridge Terrace, London, W. 2, Eng.

13 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

TORSIONAL VIBRATION. W. A. Tuplin. N. Y., John Wiley & Sons, 1934. 137 p., illus., 9x6 in., cloth, $5.50. This book aims to give the designer of machines in which torsional vibrations are important an understanding of the methods for calculating them. The fundamentals of vibration theory which are necessary for a complete understanding of practical problems are explained and the procedure in actual calculations is set forth in detail. No extensive mathematical equipment is required of the reader.

TAXATION des RADIOTÉLÉGRAMMES. By Olivier. Paris, Libraire de L'Enseignement Technique, 1934. 61 p., 10x7 in., paper, 12 frs. This is one of 3 volumes which form a course of instruction in the operation of radio services upon ships and aircraft, intended for those preparing for this work as operators. The laws governing these services, the rates in force, and the duties of the operator are covered.

Great Britain. Department of Scientific and Industrial Research, REPORT of the RADIO RESEARCH BOARD for the period 1st January 1932 to 30th September 1933. London, His Majesty's Stationery Office, 1934. 137 p., illus., 10x6 in., paper, $.80 (British Library of Information, N. Y.). Among the topics discussed in this report are: the propagation of waves; directional wireless; atmospherics; electron oscillations giving rise to centimeter waves; radio-frequency standards; electrical measurements at radio frequencies; interference and receiver selectivity, the new transmitting installation at the National Physical Laboratory; time bases for use with the cathode-ray oscillograph.

ELECTROLYTES. By H. Falkenhagen, translated by R.P. Bell. Oxford (Eng.), Clarendon Press; N. Y., Oxford University Press, 1934. 346 p., illus., 10x7 in., cloth, $9.50. A systematic, comprehensive presentation of the modern theory of electrolytes, as developed by Milner and Debye and their co-workers. The book is a translation of the German original, which appeared in 1932, with revisions to include work done since that date.

EDISON, His Life, His Work, His Genius. By W. A. Simonds. Indianapolis and N. Y., Bobbs-Merrill Co., 1934. 364 p., illus., 9x6 in., cloth, $3.50. The author has carefully studied the collection of Edisonia at the Edison Institute, visited the scenes of Edison's life and consulted his associates widely. The result is an interesting book which corrects a number of current errors and legends and supplies a picture of the man and his work.

ELEKTRISCHE GASENTLADUNGEN, Ihre Physik und Technik. Bd. 2. Entladungseigenschaften technische Anwendungen. By A. v. Engel and M. Steenbeck. Berlin, J. Springer, 1934. 352 p., illus., 9x6 in., cloth, 33.50 rm. This is the second and final volume of a comprehensive review of the subject, the first volume of which appeared in 1932. The present instalment discusses the properties of the various forms of discharges that actually occur, together with their practical uses.

HANDBOOK of CHEMISTRY and PHYSICS, 19th ed. Rd. by C. D. Hodgman. Cleveland, Ohio, Chemical Rubber Pub. Co., 1934. 1933 p., tables, 7x5 in., lea., $6.00. A collection of tables, formulas, and other data frequently needed by chemists, physicists, and engineers. Fifteen important tables have been revised and 18 new ones added, among them one giving X-ray crystallographic data for about 1,500 elements and compounds.

HYDRAULICS. By E. W. Schoder and F. M. Dawson, 2 ed. N. Y. and Lond., McGraw-Hill Book Co., 1934. 429 p., illus., 9x6 in., cloth, $3.50. This is intended as a basic course in the hydraulics of engineering which will serve both as an introduction to specialized studies and a text and reference book. The physical phenomena of hydraulics are described, fundamentals are developed into useful formulas, and numerous examples of the analysis and solution of typical practical problems are given.

INTRODUCTION to MECHANICS and HEAT. By N. H. Frank. N. Y. and London, McGraw-Hill Book Co., 1934. 339 p., diagrs, 9x6 in., cloth $3.00. This text represents the basic elementary course required at M.I.T. The course is intended to lay a thorough quantitative foundation, by a logical unified treatment of mechanics, acoustics, and heat, which will teach the student to appreciate and utilize fundamental and general methods of attack on problems in all branches of physics.

DIESEL ENGINEERING HANDBOOK (formerly the Diesel Power Plant Handbook). 7 ed. edited by L. H. Morrison and T. A. Burdick. N. Y., Business Journals, Inc., 1934. 320 p., illus., 12x9 in., lea., $5.00. A compendium of miscellaneous information upon the diesel engine and its uses. The basic principles are discussed, data are given on production and economics and modern designs are described. A chapter is devoted to super charging and scavenging, and another to lubricants and fuels. Oil purification is discussed. Other chapters consider plant planning, water cooling systems, diesel-electric stations, operation, maintenance, uses in transportation, etc. A catalog section closes the volume.

INTRODUCTION TO QUANTUM THEORY. By G. Temple. N. Y., D. Van Nostrand, 1934. 196 p., diagrs., 9x6 in., cloth, $3.75. Being intended as an introduction, the present book is more concerned with the historical and philosophical matrix of the theory than with the theory itself. It includes an account of the principle of duality and its implications in electromagnetic theory, the field theory of matter, quantum algebra, matrix mechanics, the relativistic wave equation, and the spinning electron.

PRACTICE of ABSORPTION SPECTROPHOTOMETRY with HILGER INSTRUMENTS. By F. Twyman and C. B. Allsopp. 2 ed. Lond., Adam Hilger, 1934. 140 p., illus., 10x6 in., cloth, 12s 6d. A guide for those commencing spectrophotometric work of extending it into unfamiliar fields. It introduces the theory of absorption spectra and describes various typical applications of absorption spectrophotometry, and discusses technique, including an account of the instruments developed by the publishers.

RIVETING and ARC WELDING in SHIP CONSTRUCTION, by H. E. Rossell. N. Y., Chicago, and San Francisco, Simmons-Boardman Pub. Co., 1934. 210 p., illus., 8x5 in., cloth, $2.25. The author discusses riveted and arc-welded joints from both the practical and theoretical points of view, with special reference to ship design and construction.

Engineering Societies Library

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MAINTAINED as a public reference library of engineering and the allied sciences, this library is a cooperative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

Industrial Notes

General Electric Sales Rise.—Sales billed by the General Electric Company for the first quarter of 1935 amounted to $40,393,-538, compared with $34,935,551 for the same quarter a year ago, an increase of 16%. President Gerard Swope announced to stockholders of the company at their annual meeting on April 16. Orders received during the first three months this year totaled $49,379,932, compared with $38,-148,654 for the same period of 1934, an increase of 29%.

Large U.S. Navy Order to Westinghouse.—According to a recent announcement, the Westinghouse Electric & Mfg. Co. has received a contract from the United States Navy Department amounting to approximately $1,750,000 for electrical equipment for eighteen 1500-ton destroyers. This apparatus consists of turbo-generator sets, regulators and switchboards which are to be installed in these new vessels now under construction. The equipment will be manufactured at Westinghouse plants in East Pittsburgh, South Philadelphia and Newark, N. J.

Heaviest Single-Car Shipment.—What is believed to be the heaviest single-car shipment ever made left the Schenectady Works of the General Electric Co. recently for its destination at the Potomac Electric Light & Power Co., at Bennings, D. C. The load consisted of a generator shaft, rotor and poles for a 25,000-kw frequency converter set, with a total weight of 367,000 pounds. The converter will be used to deliver 25-cycle single-phase power to the Pennsylvania Railroad. The freight car employed has a carrying capacity of 200 tons and alone weighs over 52 tons.

A New Electrical Equipment Sales Agency.—Announcement has been made of the formation of a new company, the Harris-Green Co., with headquarters in the Farmers Bank Building, Pittsburgh, for the sale of motors, control apparatus, transformers, line material, power factor corrective devices and similar materials used by public utilities, industrial and commercial establishments. The new firm is composed of G. N. Harris, with the Pittsburgh sales office of Westinghouse since 1929; J. G. Green, who was manager of the Westinghouse general industrial and resale sections at Pittsburgh; and Henry Harris, who organized and managed the United Electric Light Co., at Wilmerding, Pa., up to the time of its purchase by the Duquesne Light Co., in 1927, at which time he retired from active business.

Large Steel Mill Order to General Electric.—Included in an order amounting to more than $1,250,000 for new electric equipment to be furnished and completely installed by the General Electric Company at the Lackawanna plant of the Bethlehem Steel Company, are 7 d-c motors totaling 22,500 horsepower for driving the finishing end of Bethlehem's new continuous hot strip mill—one of the world's largest. This finishing end drive will consist of two 4500-hp and three 3500-hp motors, and one each of 2500-hp and 500-hp ratings. In addition, the order includes two 3-unit, 6000-kw motor-generator sets to supply power for the above motors; one 3-unit, 6000-kw motor-generator set to supply power to the drives of two tandem cold strip mills; the most modern ventilating system yet used in a steel mill motor room; and complete switchgear and control equipment for the preceding apparatus, including 19 metal-clad oil circuit breakers each with an interrupting capacity of one-half million kilovolt-amperes.

A New, Light Utility Truck.—The Four Wheel Drive Auto Company, of Clintonville, Wis., has introduced its new model HS into the line construction and utility field. This is of $1^1/_2$-ton capacity with the usual traction of four driving wheels. There are 46 lockers in the body to provide handy storage for all necessary tools and equipment. All compartments are covered by heavy doors and are weatherproof. The HS is powered with an 84-hp engine, and has four speeds forward and one reverse.

Trade Literature

Disconnecting Switches.—Bulletin 44. Describes outdoor, hook-operated disconnecting switches in ratings from 7500 to 69,000 volts. Pacific Electric Mfg. Corp., 5815 Third St., San Francisco, Calif.

Lightning Arresters.—Bulletin, 16 pp. Describes L-M valve-type, lightning arresters, types A, B, C, for the protection of distribution transformers, up to 15,000 volts. Line Material Co., South Milwaukee, Wis.

Metallic Zinc Powder. Bulletin, 16 pp. Describes the advantages of zinc dust paint as a primer and finishing coat for iron, steel and galvanized surfaces. Industrial applications, including several on electrical equipment, are illustrated. The New Jersey Zinc Co., 160 Front St., New York.

Armature Winding Machine.—Bulletin 201. Describes type 20 automotive generator armature winding machines. This equipment is largely automatic and is devised for large production numbers. The operator's skill is said to be a negligible factor in the operation of these machines. P. E. Chapman Electrical Works, 1820 Chouteau Ave., St. Louis, Mo.

Oil Aging Test Apparatus.—Bulletin, 4 pp. Describes the "Oxydator," an apparatus for determining the oxidability of lubricating and transformer oils, insulating compounds and varnishes, paints, etc., and indicating accurately their resistance to aging, to deterioration and life expectancy. Herman A. Holz, 167 East 33rd St., New York.

Wires & Cables. Bulletin LS-1, 4 pp., on the Vacuum Process Lead Sheath; Bulletin UC-1, 12 pp., on Non-Metallic and Metallic Armored Cables for direct earth installation, covering four general types—Trenchlay (non-metallic armored); Steel Taped Parkway (metallic armored); Lead Sheathed, with an outer covering of jute or saturated duck tape; Series Street Lighting ("Thiokol" sheathed). Bulletin WP-1, 4 pp., on Peerless Weatherproof Wires and Cables. Photographs illustrate specimens of this type of wire after 13 to 24 years of service. General Cable Corp., 420 Lexington Ave., New York.

Oil Fuse Cutouts.—Bulletin FC. Describes type "FC" subway oil fuse cutouts, available in two sizes for 2500 volts, 100 amperes, and 5000 volts, 200 amperes. A closed expansion chamber is used so that the cutouts are suitable for all subway installations and for locations exposed to corrosive fumes, explosive gases, salt air and inflammable dust. The larger size cutout clears 25,000 kva in $^1/_2$ cycle using modern accepted principles of arc quenching. Unit detachable sealed type potheads provide complete protection to the cable ends. The potheads are located on the bottom of the tank. This feature eliminates sharp bends of cable within the tank thus avoiding trouble due to surges. A comparatively narrow width of tank also results in less wall space being required. G &W Electric Specialty Co., 7780 Dante Ave., Chicago, Ill.

New General Radio Catalog.—"H," 188 pp. A comprehensive presentation of a wide line, including resistors, condensers, inductors, frequency and time-measuring devices, oscillators, amplifiers, bridges and accessories, standard-signal generators, oscillographs, cameras and analyzers, meters, power supplies, etc. A section on industrial devices appears in the catalog for the first time. Recognizing the fact that the application of electronic apparatus and technique, once confined to the communications industry, has rapidly invaded other fields, the company has extended its development program somewhat beyond the limits of the communication phase to include more general applications of electrical measurements. The instruments described in this section are the first result of this program. General Radio Co., Cambridge, Mass.

Voltage Regulation.—The Eight-Point Plan for Profitable Voltage Regulation. Consists of 9 bulletins and represents a comprehensive outline of voltage regulation for every vital point on a power system, from generator to consumer which, though long desired, was not previously economically justified. The devices described in this plan will provide efficient regulation at low first cost. The bulletins are numbered and titled as follows: GEA-2029- Generator-voltage Regulators; GEA-2054- Station-type Induction Voltage Regulators; GEA-2018A-Branch-feeder Induction Voltage Regulators; GEA - 2038A - Branch - feeder Step Voltage Regulators; GEA-2036A-Branch-feeder Step Voltage Boosters; GEA-1577B- Step Voltage Regulators for Higher-voltage Circuits; GEA-2055- Series Capacitors for Reducing Lamp Flicker; GEA-1971A- Autotransformers for Reducing Lamp Flicker. General Electric Co., Schenectady, N. Y.

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H. H. Henline, National Secretary

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Front Cover

The famous 200 inch astronomical mirror cast at the Corning Glass Works, last December, and now cooling. Production equipment for this mirror may be inspected during the Institute's forthcoming summer convention.

Photo by Ayres A. Stevens

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Employment Notes . . (See Advertising Section)
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In This Issue—

PRINCIPAL engineering features of 3 large modern electric power generating stations are discussed in 3 papers appearing in this issue. In the first, the Boulder Dam hydroelectric plant now being constructed by the federal government on the Colorado River is described. This plant, half of which is in Arizona and half in Nevada, will have an ultimate capacity of 1,317,500 kva (*pages 583–94*). The second paper describes the Huntley station No. 2, largest 60-cycle steam-electric generating station of the Niagara-Hudson system and a thoroughly modern plant (*pages 632–45*). In the third paper, the rehabilitation program for the Connors Creek plant in Detroit, Mich., is outlined. This paper should be of particular interest to engineers of power companies still operating obsolete or obsolescent equipment (*pages 610–17*).

MANY processes in modern steel mills depend upon drive characteristics that can be obtained only with electric motor. The special requirements of the steel mill, however, demand specially designed equipment for these electric drives; some of this equipment is described in 2 papers in this issue. One paper describes circuit breakers for use in d-c steel mill circuits in which currents are extremely high and have a high rate of rise (*pages 594–8*); the other describes automatic and semiautomatic screw-down equipment for 3-high roughing mills (*pages 651–5*).

READING lists for junior engineers have been appearing month by month in ELECTRICAL ENGINEERING since December 1934. The concluding section of this list, prepared by the committee on professional training of the Engineers' Council for Professional Development, appears in the present issue (*page 681*). This reading list, together with a method of self-appraisal and critical analysis to assist the junior engineer in improving himself, have been combined in a pamphlet made available by the E.C.P.D. (*pages 676–7*).

KNOWLEDGE of the purposes, accomplishments, and future plans of the 4 national engineering societies known as the "founder societies," and of their several jointly sponsored functional organizations, was made available at a meeting held recently in the Engineers' Club, New York City. That members may be informed of these activities, detailed reports of the information presented at the meeting are being published in this and future issues (*page 677*).

NATIONAL Institute prizes have been announced for all classes of papers presented during 1934, and district prizes have been announced by 3 of the Institute's districts. The high caliber of papers submitted made selection difficult in several cases. Authors presenting papers before the Institute during 1935 should bear in mind that to be considered for prizes, the papers must be submitted specifically for that purpose, to the proper committee (*page 677*).

AUTOMATIC resistance-type metal heaters for heating metal bars, rods, rivets, and similar parts to a heat treating or forging temperature by passing electric current through them, have been made practical by the development of photoelectric temperature control. Increased production and better temperature regulation than can be obtained with manually controlled heaters are 2 of the principal advantages of the automatic control (*pages 645–50*).

HAZARDS resulting from the complexity of modern living and the ingenious audacity of the modern crook contribute greatly to the interest and possibilities in the field of protective signaling as well as to the difficulty of providing adequate protection. Modern electrical signaling systems for protecting property and life against fire, burglary, robbery, and related risks, are described in this issue (*pages 617–23*).

BREAKDOWN strength and dielectric loss of mica tape insulation have been improved materially by the development of an improved bonding compound, by exercising more effective control over the quality of component materials, and by improved methods of manufacture and application. Present mica tape insulation is said to be adequate for stator windings of 33,000 volt generators (*pages 624–31*).

CORNELL University, Ithaca, N. Y., will be the scene of the Institute's 51st annual summer convention, June 24–28, 1935. The technical program, discussion conferences, inspection trips, and entertainment features were outlined in the May issue of ELECTRICAL ENGINEERING (*pages 560–4*). The final announcement, together with the subjects of additional conferences, are given in the present issue (*pages 668–9*).

FULL-VOLTAGE starting of a-c motors causes high transient voltages across some of the turns of the machine windings. Capacitors connected between each phase of the winding and ground near the machine terminals have been found to provide effective protection against these transients (*pages 599–603*).

SPARKLESS sphere gap method of measuring very high voltages, in which the spheres are held at a distance greater than the spark-over distance and the voltage is determined from the mechanical force between the spheres, has several advantages over the conventional spark-over method (*pages 655–60*).

INSTITUTE Section and Branch activities for the year 1934–35 have been summarized in the annual report. Data on the number of meetings held and the attendance for each Section and each Branch, together with data on Student conferences and conventions, and joint Section and Branch meetings are included (*pages 674–5*).

OKLAHOMA City was host to the Institute's South West District at the meeting held there April 24–26, 1935. Records were set in attendance and in the interest of those attending. A symposium on engineering education and the Student sessions played a prominent part in the meeting (*pages 670–2*).

A STUDENT conference of all the Institute's branches in the Southern District (number 4) was held at Virginia Polytechnic Institute, Blacksburg, April 11–13, 1935. One hundred and sixty-two were registered at this interesting meeting, at which several outstanding student papers were presented (*page 676*).

RESEARCH on insulating liquids shows that the conductivity-time relations, the reduction of conductivity and dielectric loss by the continuous application of continuous potential, and the occurence of space charges at the electrodes are intimately related phenomena (*pages 603–9*).

PROGRESS of the Federal work-relief bill, the survey of the engineering profession being made by the U.S. Bureau of Labor Statistics, and other items of interest to engineers are contained in the current news letter of American Engineering Council (*pages 682–3*).

IMPROVEMENTS in electronic tubes have provided the basis for development of many controlling and regulating devices; one such device for automatically regulating the voltage of an alternator is described in this issue (*pages 663–7*.)

DISCUSSIONS of A.I.E.E. papers have been omitted from this issue in order that more space might be devoted to the publication of summer convention papers.

Engineering Features of Boulder Dam and Power Plant

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The combination flood control, water conservation, and power development now being constructed on the Colorado River by the federal government represents one of the outstanding engineering achievements of recent years. The dam, which is 726 feet high and 1,180 feet long at the crest, and which contains 3,250,000 cubic yards of concrete, will create a reservoir having a capacity of 30,500,000 acre-feet, a length of 115 miles, and a maximum width of about 8 miles. The power plant is designed for an ultimate installation of 15 82,500 kva units and 2 40,000 kva units, making a total ultimate capacity of 1,317,500 kva; 4,330,000,000 kilowatt-hours of firm energy and an average of 1,500,000,000 kilowatt-hours of secondary energy per year will be made available. The principal engineering features of the dam and power plant and appurtenant structures and equipment are described in this paper.

THE Boulder Canyon Project which now is being constructed by the federal government under the provisions of the Boulder Canyon Project Act is located on the Colorado River where it forms the boundary between the states of Arizona and Nevada, about 25 miles southeast of Las Vegas, Nev. The project is a combination flood control, water conservation, and hydroelectric power development. The need for flood control is very urgent as the danger of loss of life and property from floods in the lower valleys is increasing constantly as the bed of the river is built up by the deposition of silt in the delta region. There is also a very definite need for conservation of the waters of the Colorado River for both irrigation and domestic purposes. The cities of southern California now are looking to the Colorado River for their future water supply, and the natural flow of the river is inadequate for present irrigation requirements.

Electric power that will be made available by Boulder dam will be used for commercial and industrial purposes in southern California, Arizona, and Nevada, and for pumping water through the aqueduct of the Metropolitan Water District of Southern California. Contracts have been entered into with the Metropolitan Water district of Southern California, the cities of Los Angeles, Burbank, Glendale, and Pasadena, The Southern California Edison Company, Ltd., The Southern Sierras Power Company, and The Los Angeles Gas and Electric Corporation. These contracts provide for the disposition of all electric energy that will be available and insure sufficient revenue to repay the entire cost of the project, including interest charges at the rate of 4 per cent per annum, within 50 years; in addition they provide for annual payments to each of the states of Arizona and Nevada of approximately $625,000 in lieu of taxes.

Dam and Reservoir

The dam is a concrete structure of the arch-gravity type, 726 feet high from lowest point of foundation to roadway, 1,180 feet long at the crest, 660 feet thick at the base, and 45 feet thick at the top. The dam will raise the water surface 584 feet above normal low water in the river and will contain 3,250,000 cubic yards of concrete.

The reservoir created by the dam will have an area of 227 square miles, a capacity of 30,500,000 acre-feet, a length of 115 miles, and a width at the widest point of 8 miles. The lake thus created will be the largest artificial lake in the world. The top 9,500,000 acre-feet of storage capacity is allocated to flood control; the bottom 5,000,000 acre-feet is reserved for storage of silt which will accumulate in the reservoir at the rate of 137,000 acre-feet per year; and the middle 16,000,000 acre-feet will be active storage to regulate the stream to suit the needs of irrigation and power.

Power Output and Plant

The annual runoff of the Colorado River at Boulder dam varies from a minimum of 4,300,000 acre-feet to a maximum of about 25,200,000 acre-feet with an average of 15,000,000 acre-feet. The Boulder dam will make available a firm continuous

A paper recommended for publication by the A.I.E.E. committee on power generation, and scheduled for discussion at the A.I.E.E. summer convention, Ithaca, N. Y., Jun. 24–28, 1935. Manuscript submitted Mar. 15, 1935; released for publication April 1, 1935.

The author acknowledges the co-operation in working out plans for the power plant of the following: E. F. Scattergood, Bureau of Power and Light of the City of Los Angeles, and staff; F. E. Weymouth, and J. M. Gaylor, Metropolitan Water District of Southern California; H. A. Barre (deceased) and N. B. Hinson, Southern Calif. Edison Co., and staff; R. H. Halpenny, Southern Sierras Power Co. The author also acknowledges the assistance of engineers of the General Electric Company and Westinghouse Electric and Manufacturing Company in preparing designs and specifications for the electrical equipment installed in the plant. The design of the Boulder power plant was prepared under the direction of the author. All designs prepared by the Bureau of Reclamation are under the general direction of J. L. Savage, chief designing engineer; all engineering and construction work is under the direction of R. F. Walter, chief engineer with headquarters at Denver, Colo.; and all activities of the bureau are under the general charge of Dr. Elwood Mead, commissioner of reclamation, with headquarters at Washington, D. C.

output of 663,000 horsepower or 4,330,000,000 kilowatt-hours of firm energy per year. The amount of firm energy will be reduced gradually by future upstream developments, and it is estimated that the reduction in firm energy from this cause will be at the rate of 876,000 kilowatt-hours per annum. In addition to the firm energy, large amounts of secondary energy will be available during periods when the runoff of the river is above average. It is estimated that an average of 1,500,000,000 kilowatt-hours of secondary energy will be available per year.

The Boulder power plant is designed for an ultimate installation of 15 main generating units of 82,500 kva capacity each and 2 main generating units of 40,000 kva capacity each, making a total generating capacity of 1,317,500 kva. The initial power installation comprises 4 82,500 kva units and one 40,000 kva unit. The initial installation will be ready for operation about March 1, 1936. Two additional 82,500 kva units will be ready for operation about January 1, 1938, and subsequent units will be added as needed.

Figure 2 shows the general plan of the dam, power plant, and related features and figure 3 is a typical cross section through a main generating unit.

Spillways

Two spillways are provided, one on each side of the river. Each spillway consists of a concrete lined open channel about 650 feet long, 150 feet wide, and 120 feet deep with the side next to the river formed into an ogee-shaped crest. On top of the crest are mounted 4 steel drum gates, each 100 feet long and 16 feet high, which may be controlled either automatically or manually. Each spillway has a maximum discharge capacity of 200,000 cubic feet per second. The flow over each spillway when discharging full capacity would be about the same as the flow over Niagara Falls, and the total drop would be more than 3 times as great. The spillways discharge through inclined shafts 50 feet in diameter and 600 feet long into the outer 50 foot diversion tunnels which return the water to the river below the dam.

Fig. 1. A model of Boulder dam and power plant showing general arrangement of structures

Intake Towers

Four intake towers, 2 on each side of the river a short distance upstream from the dam, control the upper ends of the 4 30 foot outlet pipes through which water is conducted to the turbines in the power plant and to the discharge valves. The intake towers are reinforced concrete structures 403 feet high from base to top of dome. Each tower consists of an inner cylinder with an inside diameter of 29 feet 8 inches and with 12 radial buttresses which support the trash racks and emergency bulkhead gates. The towers are 82 feet in diameter at the base and 64 feet at the top.

Each intake tower is provided with 2 steel cylinder gates, one at the base of the tower at elevation 895 feet and the other about half way up the tower at elevation 1,045 feet. These gates have an outside diameter of 32 feet and a vertical travel of 9 feet. In normal operation both upper and lower gates will be fully open. When the water is to be shut off from any one of the outlet pipes the lower gate will be closed first under balanced pressure, and then the upper gate will be closed. Under this procedure the cylinder gates never will have to be operated under an unbalanced head greater than 170 feet. Normally these gates will be opened and closed with the pressures on the inside and outside of the gates equalized.

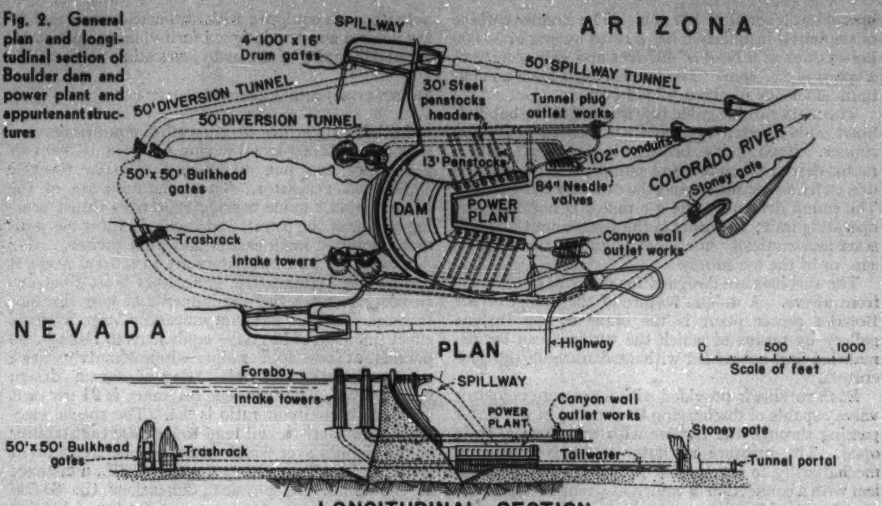
In order to make it possible to inspect and repair the cylinder gates provision is made for placing cast steel bulkhead gates over the 12 entrances to each cylinder gate. Grooves in the radial buttresses are provided for lowering the bulkhead gates into position, and each intake tower is provided with a special revolving electric crane for raising and lowering these gates.

Spaces between the radial buttresses of the intake towers from elevation 894 feet to elevation 1,200 feet are provided with steel trash racks to prevent trash from entering the towers.

Outlet Pipes and Penstocks

There are 4 independent penstocks each consisting of a main penstock 30 feet in diameter with 4 branch penstocks each 13 feet in diameter leading to the turbines and a pipe 25 feet in diameter extending from the main penstock to a group of 6 needle valves on the downstream end. The penstocks are made of plate steel varying in thickness from $2^3/_4$ inches to $^5/_8$ inch. All shop joints are electrically welded and stress-relieved, and each weld is inspected by means

Fig. 2. General plan and longitudinal section of Boulder dam and power plant and appurtenant structures



of X ray photographs. Erection joints between sections of pipe consist of a special type of welded and riveted girth joint. The girth joint consists of a butt strap of the same thickness as the pipe shell electrically welded to one end of each section of pipe in the shop. This butt strap has a shrink fit over the end of the adjoining pipe section; after being shrunk on, it is attached to the adjoining pipe section by means of a double row of steel pins pressed into place and locked by trepanning the plate around the pin and then peening the plate under the head of the pin. The pins vary in diameter from $1^1/_2$ to $3^1/_{16}$ inches. The penstocks comprise 4,700 feet of 30 foot main headers, 1,900 feet of 25 foot pipes, 5,800 feet of 13 foot penstocks leading to the turbines in the power plant, and 2,000 feet of $8^1/_2$ foot pipes leading to the needle valves. A total of 44,000 tons of steel plate is required for the fabrication of the steel outlet pipes and penstocks.

Butterfly Valves

Each main turbine has a butterfly-type hydraulic-rotor-operated shutoff valve at the inlet to the turbine casing. Valves for the 115,000 horsepower turbines are 14 feet in diameter and those for the 55,000 horsepower turbines are 10 feet in diameter. The valves are designed for closure under a pressure of 300 pounds per square inch and with a flow of 8,000 cubic feet per second through the larger valves and a corresponding flow through the smaller valves. Each 14 foot valve has 2 by-passes each 12 inches in diameter, and each 10 foot valve has 2 by-passes each 8 inches in diameter. Each by-pass is provided with one motor-operated needle-type service valve and one hand-operated gate valve for emergency closure.

The hydraulic rotor is enclosed in a fixed vertical cylinder and is connected directly to the upper end of the stem of the butterfly valve. Oil under pressure may be applied to either side of the 2 vanes of the rotor causing the valve either to open or to close. A brake or locking device is incorporated in the rotor for automatically locking the valve in any position; this brake is released automatically by oil pressure when the valve is being operated. Each butterfly valve has an individual motor-operated high-pressure oil pump which supplies oil under a maximum pressure of 1,800 pounds per square inch for operating the hydraulic rotor.

Normally, the butterfly valves will be operated under balanced pressure. They will not be closed until after the turbine wicket gates are closed; and they will not be opened until after the by-passes have been opened, the turbine casing filled, and the pressure therein is equal to the pressure in the penstock. The butterfly valves are arranged for remote control from the switchboard and the operation is entirely automatic.

Turbines

Turbines are of the vertical-shaft single-runner Francis type with cast steel spiral casings and single-piece cast-steel runners. They are designed to operate under a net effective head varying from a minimum of 360 feet to a maximum of 590 feet. These extreme head conditions will prevail only at infrequent intervals of short duration. For 90 per cent of the time the net effective head will be between 450 and 560 feet and the average net effective head will be 530 feet. The 4 large turbines of the initial installation have a rated output of 115,000 horsepower each at a head of 492.5 feet and will

operate at a speed of 180 rpm. The smaller turbine of the initial installation has a rated output of 55,000 horsepower at a head of 467 feet and will operate at a speed of 257 rpm. The turbines will have a maximum efficiency of about 92 per cent.

The main turbine guide bearings are of the babbitt-lined oil-lubricated type and are located above the runner. Each guide bearing is provided with 2 motor-driven oil-circulating pumps, one of which is driven by an a-c motor and the other by a d-c motor. The pump driven by the a-c motor is normally the operating unit; the other is the reserve unit and will start automatically in case of failure of the oil pressure or of the a-c supply.

The turbines are designed for removal of all parts from above. A unique feature of the design of the Boulder power plant is the crane in the turbine gallery by means of which the turbines can be dismantled and assembled without disturbing the generators.

Each turbine is provided with a pressure regulator valve capable of discharging 80 per cent of the water passing through the turbine with wicket gates wide open. The pressure regulator valve is connected mechanically to the turbine gate operating mechanism with a connection of sufficient strength to prevent movement of the servomotor pistons if the pressure regulator valve sticks or fails to open. Each pressure regulator valve discharges into a cast steel energy absorber where the energy of the jet will be dissipated largely as heat.

Governors

Governors are of the oil-pressure relay-valve actuator type with speed responsive element, driven by an a-c motor which receives its power supply from a small permanent magnet type a-c generator direct connected to the shaft of the main generating unit. The speed responsive elements are sensitive to speed changes of 1/100 of one per cent. The governor equipment is designed for an oil pressure of 300 pounds per square inch, although it is probable that somewhat lower pressure actually will be used.

Governor oil systems are arranged so that the servomotors of 2 turbines and 2 actuators are served by one twin pumping unit consisting of 2 motor-driven gear-type oil pumps. The oil piping between pumps, pressure tanks, actuators, servomotors and sump tanks is arranged so that any part of the oil system can be taken out of service for maintenance or repairs without interfering with the operation of the main generating units. The oil pumps are controlled automatically, and either pumping unit may be used for normal operation with the other serving as a reserve. The second pumping unit is arranged to start automatically if either the oil pressure or oil level in the pressure tanks falls below a predetermined amount.

The actuators, oil pumping units, pressure tanks, and sump tanks are located in the governor gallery where the operation of all hydraulic equipment is centralized at the same elevation as the main turbine floor, which results in the minimum amount of oil piping between the actuators and servomotors. The actuators are equipped with automatic speed matching devices and are designed for full automatic starting and stopping of the main generating units.

Generators and Exciters

Initial installation of generating equipment consists of 4 82,500-kva 180-rpm 60-cycle 16,500-volt generators and one 40,000-kva 257-rpm 60-cycle 13,800-volt generator. The generators are of the conventional 2-guide-bearing type with thrust bearing on top of the frame, and each generator has a direct connected main exciter and pilot exciter.

The 82,500 kva generators are in several respects the largest hydroelectric generators built thus far. In order to meet the requirements of long distance transmission they have an unusually large flywheel effect (moment of inertia)—equivalent to 110,000,000 pounds at one foot radius—approximately twice what a generator of this rating of normal design would have. The transient reactance is 21 per cent and the short-circuit ratio is 2.4. The special electrical characteristics all tend to increase the stability of the circuits over which power will be transmitted from Boulder Dam to Los Angeles, Calif., a distance of 266 miles. In physical dimensions the 82,500 kva generators are as large as a generator of 125,000 kva capacity of normal design. They are 40 feet in diameter and 32 feet high above the base, and each generator weighs approximately 2,000,000 pounds. The rotor weighs approximately 1,100,000 pounds.

The 40,000 kva generator has a flywheel effect of 10,000,000 pounds at one foot radius, a transient reactance of 26 per cent, and a short circuit ratio of 1.6. This machine is 32 feet in diameter and 19 feet high above the base, and weighs 720,000 pounds. The rotating parts weigh 340,000 pounds.

Generator shafts are made of forged heat-treated carbon steel with coupling flanges forged integrally with the shaft. Shafts of the 82,500 kva generators are 38 inches in diameter and weigh approximately 100,000 pounds. The shaft of the 40,000 kva generator is 25 inches in diameter and weighs about 35,000 pounds. Each shaft has an inspection hole approximately 6 inches in diameter bored axially throughout its length for inspecting the metal in the interior.

The generators are provided with air operated brakes having sufficient capacity to bring the rotating parts to a stop from half speed within $7^1/_2$ minutes. The brakes are designed to be used as hydraulic jacks for raising the rotating parts off the thrust bearing, and a portable motor operated high pressure oil pumping unit is provided for operating the jacks.

Each generator is provided with a thrust bearing located on top of the machine and supported by the upper bearing bracket which carries the weight of the rotating parts of the generator and turbine. The Allis-Chalmers and Westinghouse generators have Kingsbury type thrust bearings, and the General Electric generators have spring type thrust bearings.

Each generator has an enclosed ventilating system with surface coolers through which cold water is circulated for removing the heat from the circulating

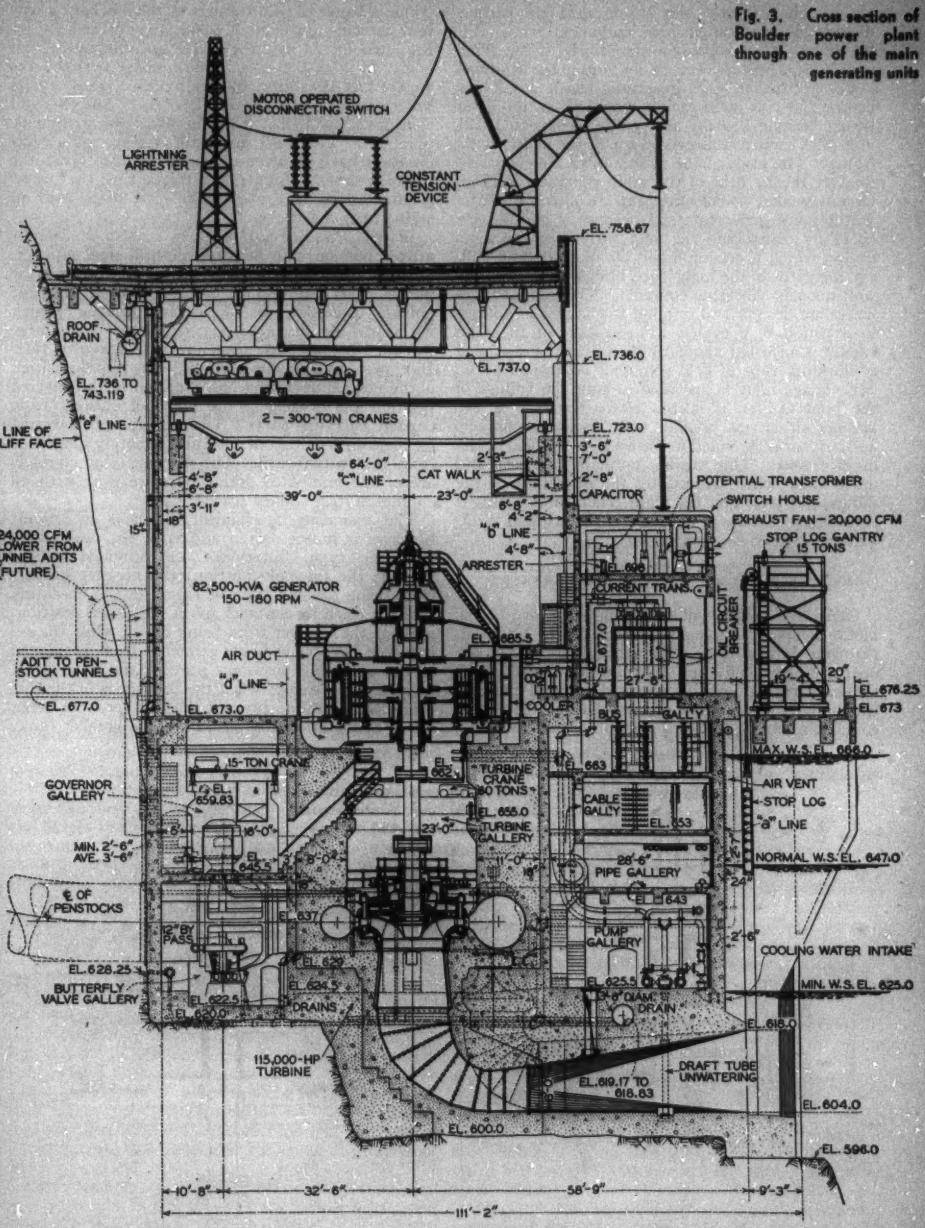


Fig. 3. Cross section of Boulder power plant through one of the main generating units

air. Each generator also is equipped with carbon-dioxide-gas fire-extinguishing equipment arranged to fill the generator housing automatically if the differential relays operate because of a fault in the windings.

For excitation, each generator has a direct-connected 250-volt main exciter mounted on top of the thrust bearing housing and a direct-connected 250-volt pilot exciter mounted on top of the main exciter frame. The leads of the main exciter are connected directly to the field of the main generator without circuit breaker or field rheostat. Control of exciter voltage and generator field current is effected entirely by controlling the field current of the main exciter which is accomplished by an automatic voltage regulator of the high-speed bridge type with non-continuously vibrating contacts. The voltage regulators are designed to respond to changes in voltage in a period of 3 cycles. The voltage of the pilot exciter is adjusted manually by a field rheostat, and a vibrating type of field contactor controlled by an overvoltage relay is provided to limit the voltage of the pilot exciter at speeds above normal. A 200 ampere air circuit breaker with discharge contacts and resistor is provided in the leads to the field of the main exciter. This breaker normally is closed and opens only when tripped by the operation of the differential relays on the main generator. Figure 4 shows cross sections of the General Electric and Westinghouse 82,500 kva generators.

Generator Voltage Oil Circuit Breakers

Generator voltage oil circuit breakers are of the metal-enclosed triple-pole single-throw non-oil-throwing indoor type with vertical lift; they are operated electrically and are fully automatic. All current carrying parts are enclosed in metal housings which provide complete phase isolation. Breakers connecting the 82,500 kva generators and the 165,000 kva banks of transformers to the bus have a current carrying capacity of 4,000 amperes and are insulated for 23 kv; they have an interrupting capacity of 2,500,000 kva. The breaker between the 40,000 kva generator and its bank of transformers has a current carrying capacity of 2,000 amperes and is insulated for 15 kv; it has an interrupting capacity of 500,000 kva. All generator voltage oil circuit breakers have an over-all operating time, from the time the trip coil is energized to the time the circuit is interrupted, of 8 cycles (60 cycle basis) and an arcing time of 2 cycles.

Briefly, these circuit breakers consist of 2 parts: a fixed portion with heavy structural steel supporting structure, fixed disconnecting contacts, and the raising and lowering mechanism; and a movable portion consisting of the circuit breaker proper with movable disconnecting contacts. Four large threaded screws with traveling nuts serve to raise and lower the movable portion. The raised position is the normal operating position, and in the lowered position the breaker is disconnected entirely from current carrying parts. The raising and lowering mechanism is motor operated and remotely controlled from the switchboard. The disconnecting contacts are of the laminated spring pressure type with all contact surfaces silver plated.

The operating mechanism of these oil circuit breakers is motor driven and is of the mechanical trip free type. Interlocks are provided which: prevent the movable portion (the breaker proper) from being lowered from or raised to the operating position when its contacts are in the closed position; prevent the breaker from being closed while the removable portion is being removed from or placed in the operating position; prevent the removal of breaker tanks except when the breaker is in the disconnected position; prevent the breaker from being raised to the operating position if the breaker tanks

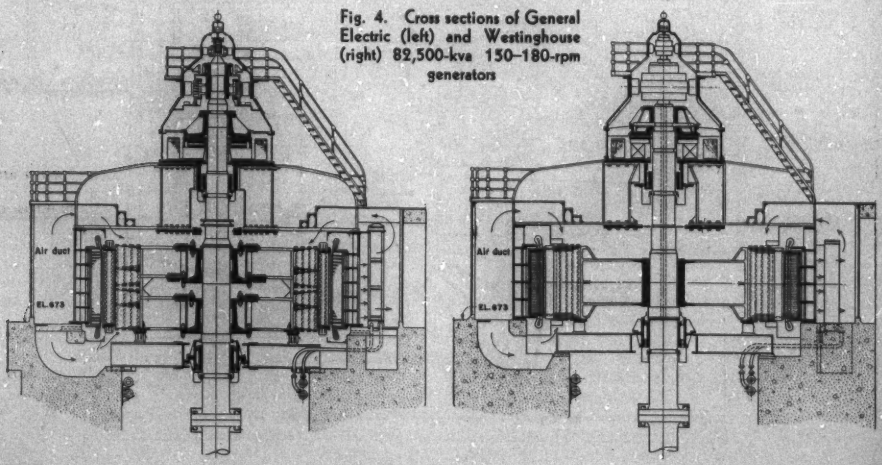


Fig. 4. Cross sections of General Electric (left) and Westinghouse (right) 82,500-kva 150–180-rpm generators

are not in place; prevent the doors affording access to the interior of the housing from being opened if the breaker is in the closed position; and prevent the breaker from being closed, except in the test position, if the doors to the housing are open. Figure 5 is a one line diagram of the principal electrical equipment showing the high and low voltage switching scheme.

23-Kv Connections and Bus Structure

Connections between generators and transformers and the generator transfer bus are all of the air-insulated metal-enclosed type. The conductors consist of 2 6 inch copper channels, with the flanges toward each other forming a hollow square section with a small ventilating space between the edges of the flanges. Each channel has a cross-sectional area of 2.92 square inches. The channels are clamped rigidly at 18 inch intervals by specially designed spacer clamps. Expansion joints consisting of several thin copper sheets are provided at frequent intervals to allow for expansion of the bus sections. Contact surfaces of all splices, expansion joints, and connections are silver plated in order to reduce contact resistance and minimize local heating.

Bus bars are supported on single piece porcelain insulators with nonferrous caps and pins. Bus supports are spaced 6 feet apart, and they have a strength in cantilever of 60,000 inch-pounds, a rated dry flashover voltage of 85 kv, a rated wet flashover voltage of 40 kv, and a leakage distance of 13.5 inches. The bus housing and the barriers between phases are made of hard rolled copper $^1/_8$ inch thick. Copper was selected for the bus enclosure after tests showed the desirability of a low resistance material in order to reduce the eddy current losses. Removable panels are provided in the housing at each bus support to facilitate inspection and cleaning of the insulators. The bus structure provides complete phase isolation.

The 23 kv bus structure is located in a gallery along the river side of each wing of the power plant and across the central section immediately below the transformer deck. Artificial cooling is provided for the bus gallery to remove the heat produced by the electrical losses in the bus and housing.

Power Transformers

The initial installation of power transformers consists of: 7 single-phase oil-insulated water-cooled units each rated 55,000 kva, 16,320 volts delta to 287,500 volts wye, 60 cycles; and 4 single-phase oil-insulated forced-oil-cooled units each rated 13,333 kva, 13,600–16,320 volts delta to 138,000 volts wye, 60 cycles. The transformers are of the inert gas filled outdoor type with shielded windings. The high voltage bushings are of the oil filled type and are provided with capacitance taps and accessories for supplying 115 volts for voltage indication and relay operation.

The transformers are placed on a platform along the river side of the wings of the power plant and over the draft tubes of the turbines. Fire walls separate the transformers, and fire protection is provided by means of a water curtain over the top and front of each transformer bay.

The 55,000 kva transformers will be shipped from the factory with core and coils completely assembled in a special tank car. The transformer cases will be shipped in 2 sections which will be welded together electrically at destination.

High Voltage Switching Equipment

High voltage switching stations are located on the Nevada side of the river a short distance back from the canyon rim. The initial installation of high voltage switching equipment comprises 4 287.5 kv oil circuit breakers on the 2 transmission circuits that the Bureau of Power and Light of the City of Los Angeles is building from Boulder Dam to Los Angeles. These oil circuit breakers are of the dead-tank high-speed type designed to operate in less than 3 cycles (60 cycle basis). They have an interrupting capacity of 2,500,000 kva and have 6 breaks per pole, each break being equipped with a deionizing grid arc extinguishing device.

Each oil circuit breaker is provided with motor-operated vertical-break disconnecting switches on each side. The disconnecting switches have 3 pillar type insulator supports per pole, one of which rotates to operate the blade and the other 2 fixed. The 2 disconnecting switches for one oil circuit breaker are arranged to operate from a single control, and interlocks are provided to prevent the disconnecting switches from being opened or closed except when the oil circuit breaker is open. Oil circuit breakers, disconnecting switches, and grounding switches are operated by remote control from the main switchboard in the control room of the power plant, and they may be operated also from local push button control stations at the switching station.

The high voltage switching station is provided with oil storage, handling, and treating facilities for treating the oil in the circuit breakers. Four oil storage tanks of 7,500 gallons each are installed in the basement of the control house. Two of these tanks will be kept full of clean oil; the others will be kept empty, ready to receive dirty oil from the circuit breakers. A portable oil purifying outfit consisting of a centrifuge and filter press capable of treating 1,200 gallons per hour is provided at the switching station. This outfit may be used to treat oil as it passes from the dirty to the clean oil tanks or it may be used to treat the oil in the circuit breaker tanks while the breakers are in service.

The switching station control building contains the relay equipment, storage batteries and charging equipment for operating the oil circuit breakers, store room, wash and locker room, and office.

Control cables between the switching station and the power plant are installed in a control tunnel. These cables are laid in trays supported by structural steel brackets along the sides of the tunnel. The trays are built of asbestos lumber reinforced with steel angles.

The high voltage circuits connecting the transformers at the power plant with the switching sta-

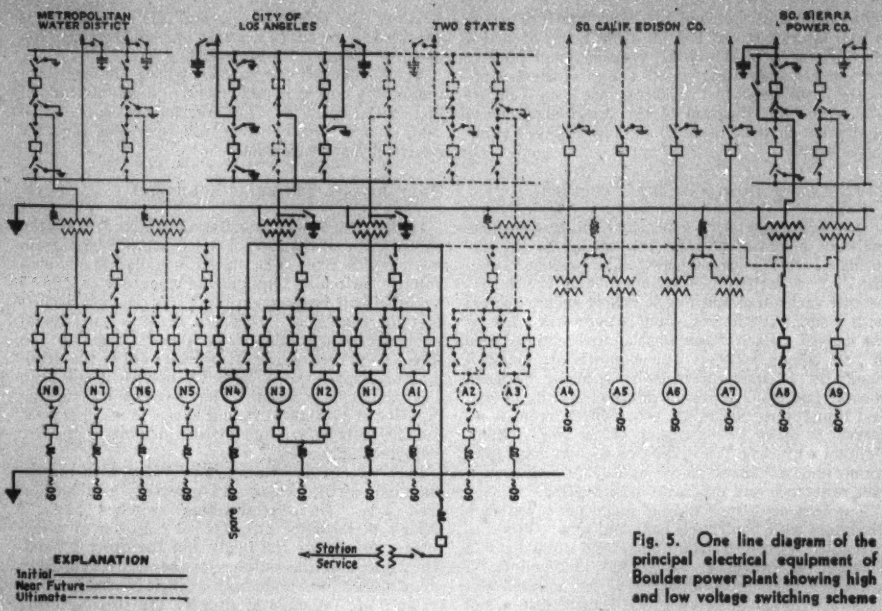


Fig. 5. One line diagram of the principal electrical equipment of Boulder power plant showing high and low voltage switching scheme

tion are supported on special steel towers. In order to keep the proper tension in the almost vertical spans from the power plant to the rim of the canyon the insulators at the lower ends of these spans are attached to cables which pass over sheaves and are attached to weights (see figure 3).

The towers at the rim of the canyon are inclined at an angle of 30 degrees from the vertical in order to afford sufficient clearance between the conductors and the cliff. The circuits between the power plant and the switching station are provided with overhead diverter wires supported on separate towers to shield the circuits from lightning.

Conductor spacing on the 287.5 kv circuits is 32 feet 6 inches, and the normal clearance to structures is 11 feet with a minimum of 8 feet. All spans have double strings of strain insulators at each end consisting of 22 units each with 6 inch spacing between units. Jumper loops are supported by suspension insulator strings with 24 units per string and 5 inch spacing between units. An automatic oscillograph is provided at the switching station for recording line and bus faults. Each outgoing transmission line is provided with a station type lightning arrester, and each circuit between the power plant and the switching station also is provided with a similar lightning arrester mounted on the power house roof to protect the main transformers. Each phase of each incoming transmission line has a coupling capacitor connected between conductor and ground for relaying and carrier current purposes.

Space available in the canyon between the dam and the 150 ton permanent cableway near the downstream end of the power plant is very limited for the high voltage circuits between the transformers and the switching station. This space limitation was one of the principle reasons for using a single bank of transformers for 2 main generators. Consideration was given to having a bank of transformers for each generator and eliminating all low voltage switching equipment and transfer bus; this arrangement, however, would have necessitated twice as many high voltage circuits between the transformers and the switching station as required by the adopted arrangement, and the space available was inadequate for the additional circuits.

Station Service Equipment

Two station service generating units, one in the upstream end of each wing of the power plant, provide power for all station auxiliaries. In addition, a bank of transformers is provided by means of which power for station auxiliaries may be obtained from the main generating units.

Each station service generating unit consists of a 3-phase horizontal a-c generator rated at 3,000 kva, 2,400 volts, 60 cycles, 300 rpm, with direct connected main exciter and pilot exciter, direct connected to a double overhung Pelton water wheel. Each Pelton wheel has a governor of the oil-pressure-relay valve type with individual motor driven oil pump and

pressure tank. Like the governors for the main units, the speed responsive elements of the station service governors are driven by electric motors receiving their power supply from small permanent magnet a-c generators direct connected to the main shafts of the station service generating units. The station service turbines receive water from a penstock which by means of valves may be connected to any one of the 4 main 30 foot penstocks. The station service penstock may be used to fill the main penstocks after they have been drained for inspection or maintenance purposes.

Station service generators as well as the bank of auxiliary power transformers are connected through oil circuit breakers to a 2,300 volt double bus from which all station auxiliaries, station lighting, and miscellaneous power loads are served. The 2,300 volt switching equipment is of the metal-clad vertical-lift draw-out type.

Station service load is divided into 2 groups. The first group comprises all equipment the operation of which is essential for the generation of power by the main units and includes the governor oil pumps, butterfly valve operating motors, and lubricating oil circulating pumps for the turbine and generator guide bearings. These essential auxiliaries are supplied with 440 volt power from 4 600 kva banks of transformers in the central section of the building. One bank of transformers supplies the essential auxiliaries for the even numbered generating units and a second bank the odd numbered units in the Nevada wing of the power plant; the other 2 banks are arranged in the same manner in the Arizona wing. Cross connections between the 2 440 volt busses permit all essential auxiliaries in each wing to be served from either bank of transformers so that each group of essential auxiliaries is provided with 2 independent sources of power.

The second group of station service auxiliaries comprises the less essential equipment the operation of which may be interrupted without interfering with the operation of the main generating units. This group includes the cranes, battery charging equipment, machine shop equipment, elevators, compressors, and other miscellaneous equipment. These nonessential auxiliaries are arranged in 2 groups each supplied with 440 volt power by a 600 kva bank of transformers in the central portion of the building. Cross connections permit all nonessential auxiliaries to be supplied from either bank of transformers. The general scheme for supplying power to the station auxiliaries is indicated by the single line wiring diagram shown in figure 6.

The 2,300 volt switching equipment is controlled and operated from a miniature control board in the main control room. The 440 volt control boards for the essential auxiliaries are located in the governor gallery adjacent to the turbines. This arrangement centralizes the control and operation of the butterfly valve, actuator, governor oil pumps, lubricating oil pumps, cooling water, and all other apparatus involved in the operation of a main generating unit at one point, except the electrical control of the generator which is handled by the switchboard operator in the control room.

Control Equipment

The Boulder power plant is divided into 2 distinct operating groups: One group consists of units *N*1 to *N*8 and *A*1 to *A*3 and the station service generating units, and will be operated by the Los Angeles Bureau of Power and Light; the other group consists of units *A*4 to *A*9, which will be operated by the Southern California Edison Company, Ltd. Control of the generating units, including the station service units and the switching equipment, is centralized in 2 control rooms on the top floor of the central section of the plant. Terminal boards are located on a floor below and directly beneath the control boards they serve, and the floor below the terminal boards serves as a distributing space for the control cables.

Main control boards are of the miniature type and provide for remote control of all main generating units and associated transformer banks, switching equipment, and outgoing transmission lines. Indicating instruments of the miniature type with 3 inch scales mounted on the vertical panels of the control board afford the operator all information needed for operating purposes. These indicating instruments include an ammeter, voltmeter, speed indicator, megavarmeter (mega-reactive-volt-ampere meter), and megawattmeter on each generator; 3 line ammeters, one for each phase; voltmeter and frequency meter for each line; megavarmeter, megawattmeter, and voltmeter for each bank of transformers; and gate limit stop and gate position indicator for each turbine. A group of annunciator drops for each unit is provided to indicate and call the operator's attention to any abnormal operating conditions.

The drops in the annunciator groups include the following:

Main generators	Main transformer banks
1. Low governor oil pressure	1. Excessive temperature
2. Hot main guide bearings	2. Cooling water failure
3. Cooler failure	3. Oil circulating pump failure
4. Excessive temperature	4. Excessive temperature in bus gallery or switch house
5. Differential relay operation	5. Transformer fire alarm
6. Overspeed	6. Differential relay operation
7. Excessive exciter voltage	7. Outgoing line relay operation
8. Overcurrent	8. Relief valve operation
9. High water in turbine pit	9. Gas pressure alarm
10. Ground on bus	10. 3 extra drops
11. 6 extra drops	

Should any abnormal operating condition be called to the switchboard operator's attention by the annunciator system, he can take the necessary steps to remove the cause by adjusting the controls, or he can call the matter to the attention of the generator or turbine floor man and instruct him as to proper procedure to correct the trouble.

Switches for controlling the operation of the various oil circuit breakers and disconnecting switches, with indicating lights to show the position of each breaker and disconnecting switch and a mimic bus showing the connections between the various electrical units, are mounted on the upper half of the in-

clined section of the control board. On the lower half of this section of the board are mounted the regulating controls which include control switch for generator regulator voltage adjusting rheostat, voltage control transfer switch, manual voltage control switch, butterfly valve operating control switch, governor speed adjusting control device, turbine wicket gate limit control switch, and governor speed droop control device.

The station service control board is also of the miniature type, similar to the main control board; it is located in the main control room of the Los Angeles Bureau of Power and Light. If necessary or desirable for any reason the main generating units as well as the station service units may be operated from local control stations adjacent to each unit and entirely independent of the main control board. Each generator has a control cubicle equipped with all necessary switches and instruments for starting, stopping, and controlling the operation of the unit, including control of the butterfly valve, actuator and generator oil circuit breakers. A key operated transfer switch serves to transfer the control of the generating unit from the main control board to the generator cubicle, or from the generator cubicle to the main control board. Transfer of control to one point renders control at the other point inoperable.

In addition to providing an emergency operating station for the generating units, the generator cubicles contain all relays, watt-hour meters, graphic meters, voltage regulator, and other equipment not required in the main control room. Each generator cubicle is equipped with a high-speed motor-operated rheostatic type of automatic voltage regulator which is provided with reactive compensator to equalize the wattless kilovolt-amperes between generators. Each transformer bank has a recording ammeter to record the current in the neutral. This instrument has 2 chart speeds, a slow speed for normal operation and a high speed which automatically comes into action when line-to-ground faults occur on the transmission lines.

Each main generator is provided with balanced differential relay protection. These relays have a characteristic with a 5 per cent slope, and they are interconnected with 3,000 to 5 ampere current transformers in the main generator leads balanced with 1,500 to 5 ampere current transformers in the neutral end of one half of each phase of the stator winding. This arrangement affords protection against faults to ground, faults between phases, and faults between turns. Operation of the differential relays opens the generator oil circuit breakers to isolate the generator from other sources of power, closes the turbine wicket gates, applies the generator air brakes, removes field excitation, opens the generator neutral oil circuit breaker, and admits carbon dioxide gas to the generator housing.

The main transformer banks are provided with differential relay protection similar to the generator differential relays except that the characteristic of the transformer relays has a 25 per cent slope. The 16.5 kv bus also is provided with high speed differential relay protection. Resistance temperature detectors are used to record the temperatures of bearings and generator stator windings, and to operate alarms and annunciator drops if the temperatures should exceed predetermined amounts. Thermometers with contacts are arranged to cause automatic shutdown of the unit if the temperature of the bearings becomes excessive.

A cable gallery running the full length of each wing of the power plant and across the central section immediately below the bus gallery provides space for the control cables between generating units and control room. The control cables are supported by asbestos-cement lumber trays arranged one above the other and supported by structural steel columns and brackets.

Auxiliary control boards in the main control rooms have recording instruments mounted on the front facing the operator's desks, and the automatic load and frequency control equipment is mounted on the rear. Multipoint recorders keep a record of the temperatures of bearings and transformers. The temperatures of the rotors of the main generators are recorded by single point Kelvin bridge type instruments which function by means of slip ring voltage and the voltage drop across a shunt in the rotor leads. Totalizing instruments record and totalize the outputs of the main generators by means of electrothermic load converters which deliver direct current output proportional to the kilowatts of generator output. These totalizing instruments are calibrated to record primary a-c output.

The automatic load and frequency control equipment is arranged so that any generator may be placed on frequency, base load, or proportionate load control. The frequency is corrected automatically whenever the deviation amounts to 0.01 cycle or more. Accumulated time errors are corrected automatically. Each auxiliary control board has an automatic synchronizer of the thermionic type for controlling the speed matching and synchronizing of the main and station service generators.

Clocks in the power plant, as well as all graphic charts, are operated by synchronous motors which receive their power supply from a special circuit, the frequency of which is controlled accurately by means of a special tuning fork and amplifier system operated from a storage battery. The tuning fork controls the frequency of 2 7.5-kva single-phase a-c generators driven by d-c motors. The speed of these inverted motor generator sets is controlled accurately by means of electron tubes which control the field excitation of the motors.

An automatic telephone switchboard in a telephone room in the central section of the power plant provides communication facilities throughout the plant and at various points on the dam and related structures. It has trunk connections with an automatic switchboard at Boulder City. There is also a cordless type manually operated telephone switchboard in each control room by means of which the operators can communicate with operating stations in the power plant. These cordless switchboards also will connect with trunk lines to Los Angeles, with the carrier current channels to the switching stations on the transmission lines, and with the terminal substations at Los Angeles. A code call

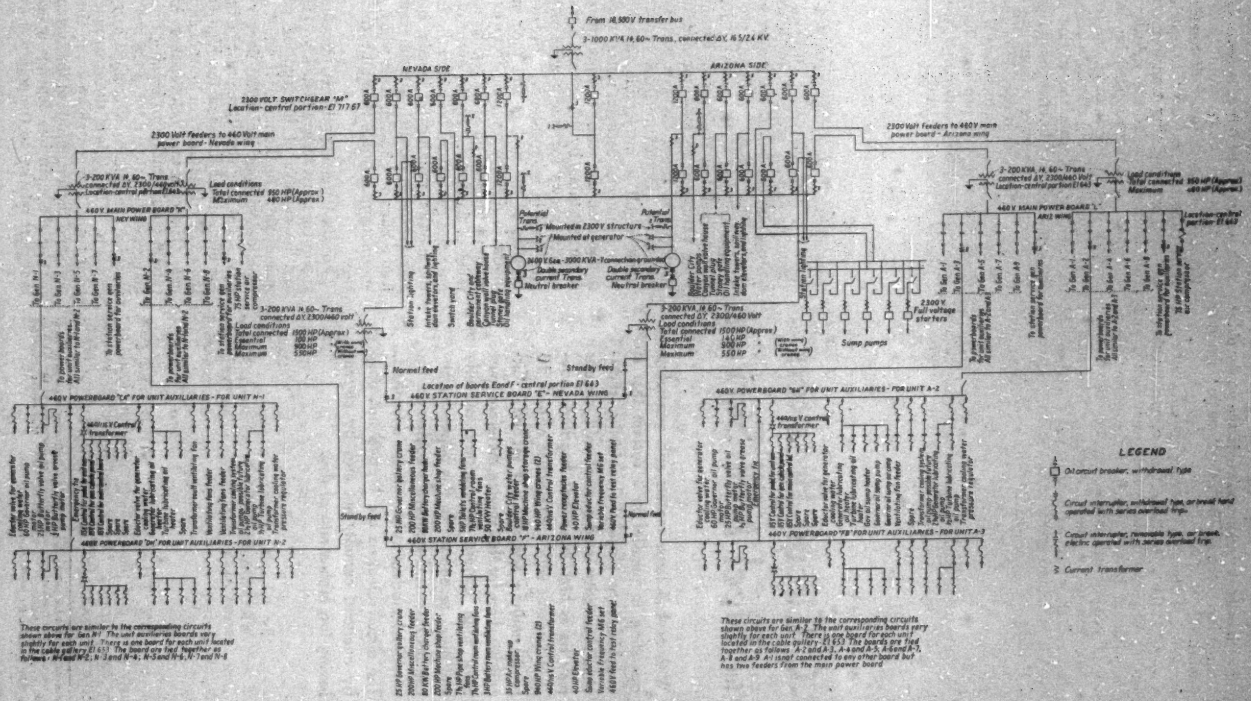


Fig. 6. Single line diagram of 2,300 and 460 volt station service and auxiliary feeders

system with bells at various points in the power plant and dam is incorporated in the automatic telephone equipment.

Two 120 cell storage batteries provide 250 volt d-c power for the operation of oil circuit breakers, lubricating oil pump motors, emergency lights, and other equipment in the wings of the power plant, and one 60 cell storage battery supplies 125 volt d-c power for the main control rooms. The storage batteries and their control boards and charging sets are located in a battery room in the central section of the building.

Lighting

Two 2,300 volt feeders from the 2,300 volt station service power busses supply the lighting circuits in both wings of the power house. At 4 points in each wing taps are taken from these lighting feeders through enclosed fused disconnecting switches of high rupturing capacity to single phase 2,300 to 230/115 volt lighting transformers. Each lighting transformer supplies the lighting for 2 bays, and alternate bays are supplied by different 2,300 volt feeders so that a failure of one feeder would affect only the lighting in alternate bays. A d-c lighting circuit supplied from the station storage battery is arranged to provide emergency lighting at essential points in the event of a complete failure of the a-c supply. The central portion of the building is supplied with lighting by means of 2 independent banks of transformers with provision for supplying the entire central portion from either bank in the event of a failure of the other bank.

D-C Circuit Breakers for Steel Mill Service

With several large motors and generators operating in parallel in a system that is coupled very closely electrically, short-circuit currents in d-c steel mill circuits may be as high as several hundred thousand amperes with a rate of rise of from 10 to 20 million amperes per second. Circuit breakers for this service therefore must have high current interrupting capacity and quick response. In this paper the circuit breakers and associated equipment for a typical modern strip mill are described. The circuit breakers are tripped not only by overload current, but also by current having too high a rate of rise.

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IN THE STEEL MILL, and particularly sheet and plate rolling mills, the loads are highly concentrated. In normal operation several large d-c motors are fed from generators operating in parallel in a system that is coupled very closely electrically. The generators, usually driven by synchronous motors, are built for inherently close voltage regulation, and this together with the effect of quick acting voltage regulators produces a very stiff system voltage. The motors driving the rolls are built to maintain their speeds within close limits over wide variations in load, for maintenance of proper relativity of speed between successive rolls is most necessary. Departure from proper relative speeds would result in intolerable stretching or accumulation of material between rolls. Changes in load on a motor then are reflected immediately in magnitude of current taken by the motor; a graph of motor load current shows extremely wide swings in intervals measured in microseconds. Because of the characteristics of the motors and their supply circuits, a motor in distress resulting from excessive load will attempt to carry on at its regular speed, even to the point of flashover. In the event of a flashover, not only the generators feed into the fault, but also all the motors, running by inertia, become generators and operate in parallel with the regular generators to feed a current into the fault which tends toward an enormous magnitude with an extremely high rate of rise.

For the foregoing reasons, therefore, the protective apparatus must respond quickly to critical conditions and be capable of interrupting currents of great magnitude; furthermore it must be arranged to function without incidental danger to life or property. The bus structure must be built to withstand the mechanical forces of the high currents, likewise the connections between motors and generators and bus. Indeed it may be even more important to give careful consideration to bracing the leads to motors and generators than most of the bus for the leads of a machine that flashes over must carry the total fault current. The leads of the other machines carry only their respective contributions to the total fault current, and the magnitude of the current in a particular part of the main bus depends upon the location of that part relative to the points of connection of the

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Fig. 1. Fully enclosed truck type circuit breaker equipment and associated enclosed bus structure for a typical modern strip mill

several machines and the point where the fault exists. Of course, should the motor connected to the end of the bus flash over, the bus to the motor leads, being in effect part of the leads, carries the same current as the leads and must be braced equally well.

A typical strip or plate mill involves 600-volt d-c motors of from 2,500 to 5,000 horsepower each and generators of 2,000 to 4,000 kw each. One such mill uses 5 or 6 such large motors for the main rolls, and 4 or 6 such generators; in addition, there are 1 or 2 smaller motors of about 500 horsepower each for the edgers. There is, therefore, generator capacity of the order of 16,000 kw, to which is connected a motor load of about the same magnitude. Consequently, there is somewhat more than 30,000 kw. of d-c rotating machinery operating at 600 volts, all closely coupled electrically on a bus having a total length of less than 100 feet. When a flashover occurs, a fault current magnitude of 5 or 6 hundred thousand amperes is quite within the realm of possibility as an ultimate value. Toward this value, the current tends at a very high rate of rise, governed largely by the combined inductances of the armatures. It is difficult to quote specific values for the rate of rise of current, but it is safe to say that the rise is at least of the order of 10 to 20 million amperes per second. Should the current actually reach these values, the mechanical forces on the busses and leads would be expressed in tons per foot of length.

Circuit Breakers for a Typical Strip Mill

In one of the most recent installations of strip mills, the protective circuit breakers for the motors and generators all are of the fully enclosed truck type, and the bus is built into, and thus is an integral part of, the complete assembly. Figure 1 is a view of the structure taken during factory assembly. The circuit breaker and bus assembly will be located in a gallery beneath the motor and generator room. The leads from the machines pass down through the floor of the motor room and into the respective circuit breaker cells of the structure. Those parts of the leads between the ceiling of the gallery and the tops of the circuit breaker cells will be suitably enclosed by rectangular sheet steel "pant-leg" arrangements. Each circuit breaker is located in the gallery as nearly as possible directly below its machine, motor or generator, and the main bus is carried horizontally between and through the groups of circuit breakers so located.

Referring to figure 1, at the far end is an assembly of 3 circuit breakers, one for the 500 horsepower edger motor, the middle one for a 3,000 horsepower motor, and the next for a 3,300 kw generator (consisting of 2 1,650-kw 300-volt units operating in series). A bus run connects this group with the next circuit breaker which is for a 3,000 horsepower motor alone. Next is a group of 2 circuit breakers, one for a 3,000 horsepower motor, the other for a generator similar to that just referred to. Next there is a single circuit breaker for one 3,000 horsepower motor. At the near end is a group of 2 circuit breakers, one for a 2,500 horsepower motor, the other for the third generator, which is similar to the other 2. The groups of circuit breaker cells and each of the bus runs between them are fabricated in the factory and are each shipped assembled complete in themselves; the installation thus consists only of erection of the several factory-assembled elements.

Figure 2 is a view of one of the cells with the side removed to show the manner of connection between the stationary male contacts in the cell and the bus above. The under side of the bus run enclosure was removed to show the bus as it runs between circuit breaker groups and through the cells. The leads to the machine from the circuit breaker are not shown in the figure, but the insulators that will support them and the terminals to which they will connect appear in the rear of the cell. In each cell provision is made for mounting a shunt for metering on that machine.

The circuit breakers, themselves, are all of the 2-pole air type, with 6,000 ampere rating for the motors and 8,000 ampere rating for the generators. Each is solenoid operated, with provision for hand operation from the outside of the truck. Each breaker also is equipped with special features, such as magnetic blowouts and rate-of-current-rise trip, in addition to instantaneous overcurrent trip and mechanism arranged for quick opening, which together particularly fit them for the service.

Figure 3 is a close-up of one pole of a breaker from which the arc chute was removed so as to show parts that otherwise would be hidden. The iron and the pole pieces of the blowout coil are shown mounted on the upper stationary terminal. The movable contact structure consists of a group of silver-faced laminated copper bridges as the main current carry-

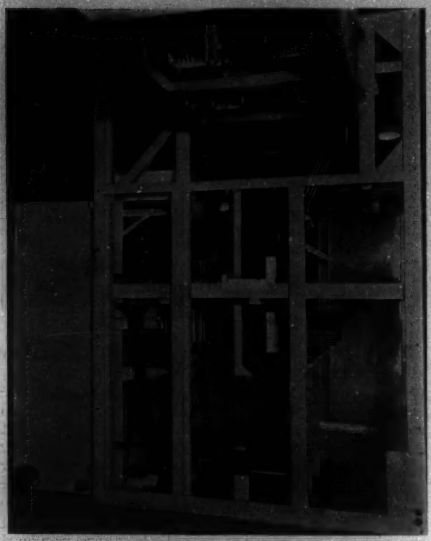


Fig. 2. One of the circuit breaker cells with side panel removed and truck partially withdrawn

ing member, a secondary contact, and an arcing contact. The secondary and the arcing contacts are carried by a stiff member, rigidly attached to the moving arm of the circuit breaker, so that in effect the mechanical forces incidental to operation of the breaker under high currents must serve only to accelerate the moving parts toward the fully open position. Deformation of the arm of the breaker is prevented effectively by the rigidity of construction of the member that carries the secondary and arcing contacts. These contacts are so pivoted and the current is led to them in such manner that the contact pressure between stationary and movable members of both secondary and arcing contacts is increased by the mechanical forces resulting from the magnetic action of the current. The great contact pressure thus developed accomplishes 2 purposes: The resistances of the paths through the secondary contact and through the arcing contact are reduced greatly so that the current is transferred more easily from the main current carrying member; and because both the auxiliary contacts are pivoted in a rigid extension of the main bridge arm, these same forces serve to accelerate the opening of the breaker. Thus the mechanical forces created by the current are used (1) to insure correct sequential operation of main, secondary, and arcing contacts, and (2) to cause faster opening action at high currents. The arcing contacts are of nonwelding alloy and open in the field of the iron blowout magnet, which is excited by a coil of copper worked into the stationary contact.

Response of a circuit breaker to an initiating condition is in 3 stages, which are, in reverse order; the time of arcing after the breaker contacts have opened effectively, the time taken by the breaker mechanism to open its contacts effectively after being unlatched, and the time to unlatch the breaker mechanism after conditions for opening the circuit are fulfilled. It has just been explained that the magnetic blowout reduces the time of arcing and that the breaker mechanism, already inherently fast, is speeded up further by the reactions of the mechanical forces created by the magnetic effect of the current; it remains to indicate how the interval to unlatch the breaker is reduced.

All breakers are tripped directly by a magnet acted upon by the main current. In order that there may be minimum hysteresis on rapidly changing current, both the tripping magnet and the armature are laminated; and to maintain at a minimum the mass to be accelerated, the armature is spring loaded and the air gap small—of the order of $^1/_4$ inch. When, therefore, conditions under which the breaker should unlatch are attained, a low-inertia moving member is caused to move through a short distance, to accomplish the result.

Fig. 3. Closeup of one pole of a 600-volt d-c breaker with arc chute removed

Rate-of-Current-Rise Tripping Feature

The tripping feature of the breaker responds not only to direct load current but also to the rate of rise of that current. When serious trouble occurs, the current rises very rapidly; and if the tripping depended upon magnitude of current only, the current might grow to dangerous proportions while the circuit is in process of being opened.

Figure 4 illustrates the manner in which rate of rise of current is combined with overcurrent as the criterion for tripping. The lower lead of each pole of the circuit breaker is divided into 2 parallel paths, one of which links with, and thus is the exciting means for, the tripping magnet. This is a path of higher resistance than the other. The other path is made of high inductance by the presence of closely stacked iron laminations. For a steady, unchanging current in the circuit, the total current will divide in

this lead according to the conductances of the 2 parallel paths. For a slowly rising current, substantially the same conditions obtain; thus if the slow growth continues, the circuit breaker will trip at a critical value of total current, according to the calibration. If, however, the current tends to rise with great rapidity, the inductance of the path that does not excite the tripping magnet becomes effective and a greater proportion of the total current is forced through the other (the trip-magnet-exciting) path. Thus the actual value of the total current may be less than the value at which the breaker is set to trip by calibration at steady currents, and the opening of the circuit breaker commences much earlier than if it were necessary to wait for the current to reach the steady-current-calibrated value.

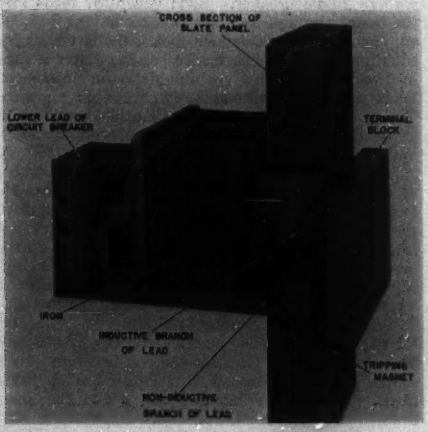
Force acting on the tripping armature is great and continuous, in fact increases steadily, because of the growth of current and also because of the reduction of air gap; it does not depend upon an impulse, so the tripping is insured, and positive. The efficacy of the magnetic loading of the inductive member of the parallel arrangement depends, of course, upon the change of magnetic flux surrounding that member, not upon its absolute value. The continuous flow of current naturally tends to magnetize the choke iron; hence to avoid loss of sensitiveness resulting from saturation, air gaps are provided at top and bottom in the stack of choke iron. The amount of iron provided is adjusted to distinguish between allowable rates of rise of current such as occur in starting or in working changes in load and higher rates which indicate the existence of a fault. This relative action is adjusted by the length of the air gaps between the halves of the stack.

Thus, the breaker not only is tripped when the current increases to a particular value, but also by being sensitive to the rate of rise of current, and because the rate of rise is high in case of fault, the opening of the circuit is instituted at the beginning of trouble instead of waiting until it reaches a certain magnitude.

Main Bus

The main bus deserves a few words. Figure 5 is a view taken with the camera set upon the top of one of the circuit breaker cells and with the tops of the bus run enclosures removed. The cell in the center of the picture is the one shown in figure 2. The leads to the motor will pass upward through the opening in the rear of the top. Several different designs were considered for the main bus. Aluminum finally was chosen as the material, and a combination of one channel and several flat bars as the form. This form seemed to meet best the requirements of leads to the circuit breakers and to the machines. For other reasons the leads were of flat bar form, and the combination of flat bars and channel in the main bus afforded a most satisfactory manner of clamping; the channel gave necessary rigidity to the bus. The flat bars of the leads were clamped between the flat bars of the bus and between the near flat and the back of the channel.

Each bus is supported in special clamps carried by heavy porcelain insulators mounted horizontally, so that the insulators are subjected to compression by the mechanical forces on the busses caused by the current. Bus runs between groups of circuit breaker



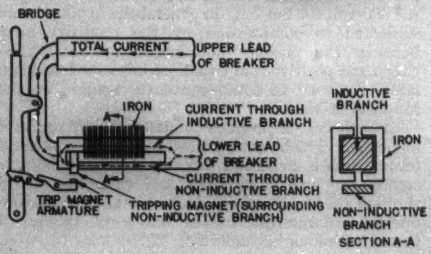


Fig. 4 (left). Details of lower lead of circuit breaker and diagram showing how rate-of-rise feature is incorporated in the breakers

Fig. 5 (right). Top of bus structure with top of enclosure removed

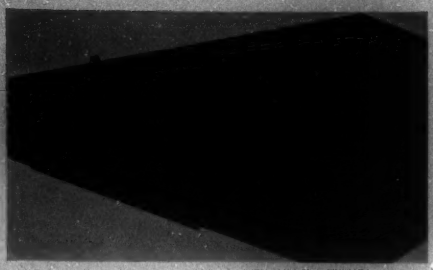


Fig. 6. Steel enclosed circuit breaker board for controlling and distributing 440-volt a-c power in the mill

cells are supported by a deep steel channel on each side. These serve as sides of the enclosure and as supports. At frequent intervals along each bus run there is a ring welded of structural steel in turn welded to the side channels. These rings support the bus supporting insulators, and hence also take the repulsive forces between busses. The supporting insulators and the rings are spaced closely enough along the length of the bus run so that for heavy short-circuit currents the stresses in the busses are held safely below the elastic limit. At each group of circuit breaker cells, one end of the bus run to the next group is held rigidly to avoid lateral forces on circuit breaker and machine leads, and at the opposite end of each bus run an expansion joint is provided. The top and bottom of the bus runs are covered with sheet steel in which are protected openings for ventilation. The enclosed bus has a nominal rating of 10,000 amperes. Short sections of the bus were mounted in each circuit breaker group making it possible to assemble all such groups and all bus runs in the factory. Each was shipped without disassembly, completely fabricated in itself and ready for installation in the field.

The whole assembly is about 91 feet long, consisting of 5 groups of circuit breakers and the 4 interconnecting bus runs. It is planned that at some later date a unit will be added to the group of 3 circuit breakers shown at the far end in figure 1, and the bus and the structure itself are arranged for making this change conveniently.

440-Volt A-C System

For controlling and distributing the 440-volt a-c power in the mill, a steel enclosed circuit breaker board illustrated in figure 6 was furnished. Each of 2 3,000-kva 13,800 460-volt 3-phase transformers feeds through aluminum channels arranged in pairs to a 4,000-ampere 3-pole circuit breaker in the board. From each of these circuit breakers aluminum channel busses extend toward respective ends of the board, and at each end individual circuits are taken care of by 1,250-ampere 3-pole breakers. In the center a 3,000-ampere 3-pole bus-tie breaker is provided, and on one side, in addition to the smaller breakers, a 2,000 ampere feeder breaker is built into the board. In the corresponding space on the other side a fully equipped cell is built in so that in the future, a 2,000 ampere feeder breaker may be added to the equipment.

All circuit breakers of 2,000 ampere and higher capacity are of the truck type and are of a design similar in general to those described for the 600 volt d-c assembly, except, of course, that they do not have the rate-of-current-rise feature. The 1,250 ampere breakers each are mounted in separate compartments and are carried on a pantograph structure. Thus they have many of the features of the truck type breakers, such as convenience of removal, provision for test position, separable contacts, etc. All circuit breakers are solenoid operated, and except for the bus tie breaker they are equipped so that they will reclose automatically 3 times upon being tripped on overload and then lock open.

250-Volt D-C System

The board for the 250-volt d-c system is similar in general design to that for the 440-volt a-c system in that it is a compact arrangement of circuit breakers protecting incoming and outgoing circuits. A breaker for each generator and for each feeder is provided, and all are completely bussed together in the structure. Each feeder is protected by a 3,000-ampere 2-pole breaker. Each generator feeds into the board through a circuit breaker having 2 8,000 ampere and 1 4,000 ampere poles, the latter for the equalizer circuit. The feeder breakers have a dual overload trip, which gives time delay on small overloads and instantaneous action on high currents. The generator breakers have instantaneous overload trips with rate-of-current-rise feature on all poles, including that for the equalizer.

All breakers are of the truck type similar to those used for the 600-volt d-c system. The cells are assembled into one unit and a bus runs the length of the board. In this case, space was of importance rather than weight, and copper was chosen as the material for the bus. In form each bus consists of a copper channel in combination with flat copper bars, forming a bus similar to that described for the 600-volt d-c board. The same form of bus was used also for the equalizer. The positive and negative busses are rated at 15,000 amperes and consist of an 8-inch copper channel combined with copper bars $^3/_8$ inch thick. The equalizer bus was built of a 4 inch copper channel combined with flat bars. Each bus is supported by heavy insulators similar to those used for the 600-volt d-c bus, and in general the insulators are subjected to compression by the repulsive force between the positive and negative busses. Between the positive and equalizer busses strain insulators are used to avoid cantilever loading on the supports of either.

In each cell, a shunt is mounted, to be used for metering. The board is 73 feet long and includes 18 feeder and 5 generator breakers. The generator connections are flat copper and enter the board through the top from the floor above. Feeder conductors are multiple cables and leave the board through the floor in conduits.

Transient Voltages in Rotating Machines

The unequal distribution of voltage in rotating machine multiturn coils caused by switching transients, and means for alleviating the stresses occasioned by these transients, are discussed in this paper. A brief description also is given of field measurements of switching transients and of tests to determine the effectiveness of capacitors as a protection against switching transients. It is shown that capacitors connected between each phase and ground near the machine terminals gives effective protection.

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THE present trend in the application of a-c motors is to eliminate all reduced voltage starting equipment by using motors that are suitable for full voltage starting, because the amount of equipment necessary for a given installation is reduced. Also, some water wheel generators, especially those in automatic and semi-automatic stations, are arranged to be started by being brought up to nearly synchronous speed, and then, without excitation, switched onto a line bus; this method of starting permits the generator to be placed in service quickly without the formality of synchronizing. Obviously, with either of these 2 methods of starting, the electrical stresses in a machine subjected to full voltage during the starting period are higher than those in machines started at reduced voltage or synchronized, because of the higher applied voltage.

The data described in this paper show that full voltage switching or the sudden application of line voltage to a machine winding produces a transient voltage across the first line terminal coil that is frequently of the order of 70 per cent of the crest of the line-to-neutral voltage. This results in high transient voltages across some of the turns of the winding. Insulation failures may occur unless the machines are either insulated for or protected from these transient voltages. Protection may be secured by connecting capacitors of the order of 0.1 microfarad or more between each phase and ground on the machine side of the circuit breaker which connects the machine to the line. These capacitors slope the wave front of the transient to a value which is safe for the turn insulation.

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General Considerations

The sudden application of rated voltage to an unexcited machine, such as takes place on all machines subjected to full voltage starting, produces a switching transient which causes an initial unequal voltage distribution throughout the winding. Most of the voltage is concentrated across the line terminal coils. Consequently, the transient voltage appearing across the first turn in a line terminal coil is much higher than the normal turn voltage. Since the turn stresses in machines started at full voltage are higher than in machines started at reduced voltage, it is clear that if equal performance and reliability are to be realized, either more turn insulation is required or protective equipment must be used to reduce the switching transients to safe values.

Cathode ray oscillograph measurements, to be described later, show that the magnitude of the switching transients which occur during the starting period is of the order of the crest of the normal frequency line-to-neutral voltage and so they should have little deleterious effect on the insulation between the conductors and ground. These measurements indicate also that the transients have very steep wave fronts.

Now it is a fundamental fact that all machine windings have inherent capacity both between turns and from the turns to the sides of the slot. This capacity is small and can be neglected at normal frequencies but must be considered at the higher frequencies. The impact of a steep front switching transient against a machine winding, with a crest equal to the crest of the normal line-to-neutral voltage, causes charging current to flow in these capacities. This charging current produces relatively high turn voltages especially in the line terminal coils. The voltage distribution between the turns in the terminal coils is not uniform, the highest voltage occurring across the first turn. The turn voltages become progressively smaller away from the line terminals because of the rapid attentuation and reduction of front of the switching transient as it travels into the machine winding.

Tests to determine the adequacy of turn insulation of a machine winding have never been the subject of national standardization such as has been true of the major insulation by standardizing groups like the A.I.E.E. and National Electric Manufacturers Association. The turn insulation must have considerable strength for mechanical reasons and, as the normal volts per turn are usually low, it can withstand the normal voltage easily. However, when it is considered that a switching transient may produce a potential difference between turns from 10 to 100 times the normal turn voltage, it is appreciated that special consideration must be given to the turn insulation in machines subjected to full voltage during the starting period.

Methods of Protecting Against Transients

The maximum line-to-ground transient voltage recorded in the tests to be described was approximately equal to the crest of the applied 60 cycle line-to-neutral voltage. The maximum transient voltage across the first line terminal coil was a little less than the measured transient line-to-ground voltage and, therefore, the electrical requirements for the turn insulation should logically be based upon the normal line-to-neutral voltage rather than the normal turn voltage. However, the space available for insulation in a machine is usually limited. It is the common practice today to supply the same grade of insulation throughout a winding. Since the transient high turn voltages are all located in the line terminal coils, it may prove to be more economical to insulate for these transient voltages in the line terminal coils only, the additional space for this insulation being obtained by having one less turn in these coils. This suggested procedure has one disadvantage in that coils with different numbers of turns are used in the machine, so that care must be taken in assembling the winding or in making coil replacements to assure that the correct coils are used; otherwise there will be high circulating currents.

For those cases where it is uneconomical to insulate for the maximum turn voltages which may be encountered in service, it is fitting to examine what devices are available for protecting a machine from switching transients.

Any discussion of protection against the effects of transient voltages immediately suggests lightning arresters. A lightning arrester is effective in reducing the magnitude of transient voltages but it has little or no effect on the wave-front. Also, an arrester cannot even reduce the magnitude of the voltage, unless the voltage exceeds the normal system voltage by some margin, because the arrester must be set to operate above normal voltage; otherwise it will function continuously and be destroyed. Since the switching transients do not exceed the crest of the normal line-to-neutral voltages, the arrester is not applicable.

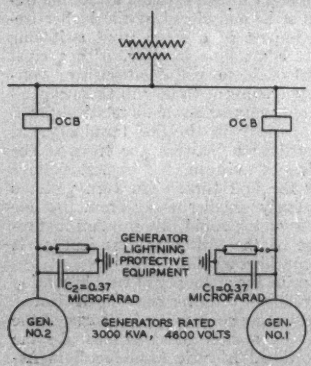


Fig. 1. One line diagram of station in which switching transients were measured

The capacitor, on the other hand, is an absorbing device for transient voltages and because of this property, it can alter the front of the switching transient. Because it is the high turn voltages resulting from steep wave fronts which may damage the turn insulation, the capacitor appears to be a suitable device for protecting a machine winding against switching transients. An arrester is needed with the capacitor only when there is a possibility of resonant voltages.

Fig. 2. Cathode ray oscillogram of terminal line-to-ground voltage at the instant of switching the unexcited generator onto the bus

There is still much to learn regarding these transient voltages and their effect on the insulation commonly used between turns in machine windings. A machine apparently does not fail the first time it is subjected to one of these transient voltages. Both voltage and time are necessary to cause an insulation breakdown, since energy is required. Should the turn insulation in a machine become punctured, it is probable that on account of the very short duration of these transients and the low normal turn voltages, the gap in the insulation would not remain ionized for a sufficient time to permit the establishment of short-circuit current, with the result that the insulation could be punctured many times before the damage resulted in a short circuit. Also, the number of times a machine winding is subjected to these transient voltages depends directly upon how often the machine is started. Thus, it is possible that a machine with insufficient turn insulation for full voltage starting duty may operate for a long period, possibly several years, before a total breakdown of the insulation occurs.

Field Tests of Voltage Transients

A one line diagram of the station in which the switching transients were measured, showing the arrangement of the machines and oil circuit breakers, is given in figure 1. The machine under test was a water wheel generator rated 3,000 kva, 4,600 volts, 60 cycles. There were approximately 35 feet of single conductor cable between the machine and the 4,600 volt bus with the oil circuit breaker located adjacent to the bus. The "self-synchronizing" method of starting was used to connect this generator to the system, i. e., the generator was brought up to 96 per

cent of normal speed by the water wheel under governor control and at this speed the generator was connected to the line unexcited. Excitation was applied to the field of the generator a few cycles after the oil circuit breaker was closed. This was the normal method of starting.

Fig. 3. Cathode ray oscillogram of the terminal coil transient voltage at the instant of switching the unexcited generator onto the bus

Crest of transient equals 2,600 volts

Cathode ray oscillograms were obtained of the magnitude of the transient voltages occurring from one machine terminal to ground and across the first line terminal coil. The oscillograph was timed to trip so that the record included the instant the oil circuit breaker first made contact during the starting period. No change was made in the normal starting sequence except that the arcing contact on the oil circuit breaker pole on the phase to which the oscillograph was connected was adjusted to insure that this phase would be energized first.

The wave shape of the transient coil voltages was not taken because its importance was not considered sufficient to warrant the extra complications to the testing equipment necessary to co-ordinate the closing of the oil circuit breaker and the tripping of the cathode ray oscillograph to obtain a record of the transient coil voltage, which lasted probably not over 10 microseconds.

The oil circuit breaker was not adjusted to close at any particular point on the 60 cycle voltage wave and as might be expected on these tests, it was just a matter of chance as to where contact would first be made. The tests indicated that 1 out of 6 oil circuit breaker closings would result in contact near the peak of the wave on any one phase.

In general, the tests were conducted so as to obtain as true a record as possible of the transient voltages as they occur during normal system operation.

The terminal line-to-ground voltage at the instant the oil circuit breaker made contact near the peak of the 60 cycle voltage wave is shown by the cathode ray oscillogram of figure 2. The wave appears not unlike a 60 cycle cosine wave with a superimposed damped sine wave oscillation on its crest. The 2 discontinuities on this curve were caused by the closing of the oil circuit breaker contacts on the other 2 phases. The frequency of the oscillation correlates with the natural frequency of certain of the known system constants. The sweep of the oscillograph for this test was approximately 7,000 microseconds. With this timing, the front of the wave appears to rise vertically.

The maximum transient voltage measured across the first line terminal coil is shown by the cathode ray oscillogram of figure 3. This transient voltage has a crest of 2,600 volts and a duration which is estimated to be less than 10 microseconds. It was caused by the rapid rise of the applied voltage and is not to be confused as being associated with the superimposed damped sine wave oscillation on the crest of the wave shown on figure 2. This superimposed oscillation has a frequency of about 7,000 cycles per second and hence for all practical purposes, the first terminal coil transient was over before this oscillation got under way.

Since the generator under test had 42 armature coils per phase per circuit, the first terminal coil is only 2.4 per cent of the winding. The crest of the rated line-to-neutral voltage of the generator was $4{,}600 \times \sqrt{2}/\sqrt{3} = 3{,}760$ volts, and each coil with a uniform distribution of voltage throughout the machine winding would have 90 volts crest across it. The measured transient voltage across this coil was 2,600 volts crest. Thus, 70 per cent of the line to neutral voltage appeared across 2.4 per cent of the winding.

Each armature coil had 4 turns and the normal voltage per turn was 22.5 volts crest. Since it was not feasible to measure the turn voltages, they could only be estimated. A uniform transient voltage distribution across the turns of the terminal coil would result in 650 volts per turn. Actually, it is known from laboratory tests on other machines that this voltage distribution is not uniform and that a larger proportion of the total transient coil voltage appears across the first turn. It is estimated that approximately 1,300 volts actually appeared across the first turn. This is 58 times the normal volts per turn.

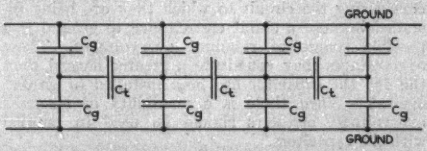


Fig. 4. Equivalent condenser network for a 4 turn coil in a rotating machine

The turn insulation on this generator had a strength which, based upon previous tests of insulation, was estimated to be above the crest of the line-to-neutral voltage and consequently was sufficient for these switching transients.

Effectiveness of Capacitors for Reducing Switching Transients

As the stresses in the line terminal turn insulation were caused by the steep front switching transients, tests were made with capacitors connected from line

to ground and located between the generator and the oil circuit breaker to obtain a measure of the ability of a capacitor to slope off the front of the transients. Part of the lightning protective equipment on this generator consisted of single phase capacitors having 0.37 microfarad per phase. With these capacitors in the circuit, the first terminal coil transient was reduced from 2,600 volts to 675 volts. This capacitor sloped off the front of the switching transient and produced a more nearly uniform initial voltage

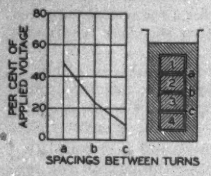


Fig. 5. Initial transient voltage distribution between turns of a 4 turn coil

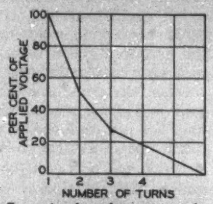


Fig. 6. Initial transient voltage distribution through a 4 turn coil

distribution throughout the generator winding, which resulted in less voltage across the line terminal coils.

The effectiveness of the capacitor in reducing steep wave fronts depends upon its size (microfarads) and also upon the surge impedance through which the transient must pass. For most applications, the capacitors probably need not exceed 0.1 microfarads, although the larger the capacitor is, the lower the line terminal turn voltages are likely to be. However, capacitors should not be used without first considering the circuit to which they are being installed because a shunt capacitance to ground is a possible source of resonant overvoltages. These overvoltages may constitute a greater hazard than the one the capacitor has been installed to protect against. When there is a possibility of resonant overvoltage, arresters should be used in parallel with the capacitors.

The location of the capacitors in the circuit is also important. To be effective, the capacitors must be installed on the machine side of the switch.

Appendix I—Maximum Initial Voltage Distribution Across Turns in First Line Terminal Coil

An approximation of the initial distribution of voltage resulting from the impact of a steep wave front transient on a rotating machine may be obtained from the capacitance network of the slot portion of a line terminal coil. This network consists of series capacitance between the turns and shunt capacitance from the turns to the sides of the slot.

The cross section of a 4 turn coil side in a slot, showing the arrangement of the turns and the turn and coil insulation is given in figure 5. It is to be noted that the insulation between the turns and that between each turn and the sides of the slot comprise the dielectrics for condensers whose plates are made up from the surfaces of the turns adjacent to each other and the sides of the slot. The capacitances of these condensers may be obtained from the formula for a parallel plate condenser. The equivalent condenser network for a rotating machine winding consisting of a 4 turn coil is shown in figure 4. Two methods for reducing this capacitance network so that the distribution of voltage may be obtained are available:

1. By determining the current in the different branches of the network, either from a longhand or a d-c calculating table study, and estimating the voltage distribution from these currents.
2. By determining the equivalent capacity of the network $C_0 = \sqrt{2C_0C_1}\tanh n\sqrt{\frac{2C_0}{C_1}}$ (where n = number of turns) and the voltage across a turn as the ratio $\frac{C_0}{C_1 + C_0}$ of the applied voltage.

Curves have been prepared to show the initial voltage distribution through a 4 turn coil and also between turns, for a coil in which the thickness of the coil insulation is 8 times the thickness of the turn insulation. These curves are shown in figures 5 and 6, and indicate that a nonuniform distribution of voltage initially exists across the coil, with the highest turn voltages occurring between the first and second turns.

Appendix II—The Effects of Capacitors Connected to the Bus

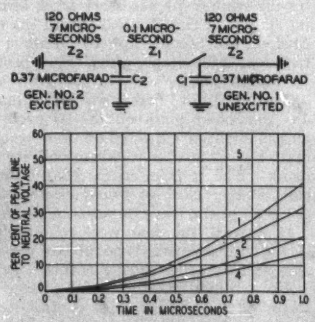
Capacitors which are used for lightning protection purposes are connected from line to ground and are often located on the system rather than the machine side of the oil circuit breaker. With the capacitors in this location they may be charged to full system voltage and they will discharge into the unexcited machine when the switch is closed. As this may occur on some one phase of the winding, each time the switch is closed, it is conceivable that it might be a greater hazard than the lightning transient against which the capacitors are intended to protect. Some data were obtained on this subject during the test previously described.

Referring to figure 1, both number 1 and number 2 machines have 0.37 microfarad capacitors on their terminals. Transient voltages across the first turn of number 1 machine unprotected by capacitors were measured with the cathode ray oscillograph with and without the number 2 capacitor and generator in service. No increase in the terminal coil transient voltage was found with the number 2 capacitor and generator in service. This was due to the fact that the surge impedance of the cable between the capacitors was sufficient to limit the rise of the voltage on number 1 generator.

A theoretical study of this rate of voltage rise, with capacitors on both machines, for the first microsecond after the switch was closed

Fig. 7. Voltage rise on unexcited number 1 generator when switched onto the bus

1. Z_1 = 60 ohms surge impedance
2. Z_1 = 45 ohms surge impedance
3. Z_1 = 30 ohms surge impedance
4. Z_1 = 0.0172 millihenrys inductance
5. Z_1 = 0.0074 ohms resistance



is shown on figure 7. The distance between the capacitors has been taken as 0.1 microsecond, and the voltage rise for several values of surge impedance of the cable have been worked out. Curves are also given as a matter of interest for the voltage rise by assuming the tie between the capacitors to consist of resistance of 0.0074 ohms and also of inductance of 0.0172 millihenrys, which were the resistance and reactance values of the cable.

These curves show that the rate of voltage rise is a function of the surge impedance and the length of the cable between the 2 capaci-

tors and that the build-up of voltage does not progress very far in one microsecond even for a cable with a length of 0.1 microsecond. These theoretical and test studies did not indicate anything from which it might be concluded that the capacitors increased the switching hazard, but on the contrary, the tests showed that the capacitors reduced the switching transients to safe values.

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D-C Cleanup in Insulating Oils

Three unusual types of behavior of insulating oils have been subjected to a series of experiments which indicate that all 3 are closely related. These types of behavior are the reduction of conductivity and a-c dielectric loss following a sustained application of continuous potential (called "d-c cleanup"), the current-time relation under continuous potential, and the unequal potential distribution under continuous stress due to the accumulation of space charges toward the electrodes. Theories regarding a common cause of these different types of behavior are drawn from the experiments.

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ALL highly insulating or dielectric liquids show some residual conduction and dielectric loss. After careful purification by successive redistillation and other methods, a very low figure of conductivity may be reached (10^{-18} mhos per cubic centimeter) and, in its volt-ampere characteristic, the liquid shows a definite saturation region followed by an up-turn at higher values of voltage gradient. This has suggested a behavior similar to that of gases, and a corresponding theory of ionic conduction corresponding to that for gases has been proposed and is sustained with substantial evidence.[1] However, even in these cases under alternating stress the dielectric loss is not accounted for by the final steady state conductivity and the complete explanation of this loss is not to be found in the simple theory mentioned.

The very pure liquids referred to in the foregoing paragraph are not available for insulating purposes by reason of the costly and elaborate processes necessary for purification and the impossibility of maintaining such purification. On the other hand, the insulating oils of practice, derived largely from the petroleum crudes, do attain in the process of refinement a very advanced state of purification and have a very high level of insulating characteristics. Final conductivities of the order of 10^{-10} to 10^{-16} mhos per cubic centimeter may be well maintained if the oil is protected from oxidation and other contamination. However, the electrical behavior of these oils is even more highly anomalous and the problem of theoretical explanation is correspondingly complex. This is largely due to the variety of phenomena exhibited and the plurality of suggestions in explanation. Among such explanations are electrolytic conduction due to dissociated impurities, inherent dissociation of the liquid molecule itself, dissociated organic acids due to oxidation, polar properties of molecules or molecular aggregates, and the like. Each of these phenomena is suggested by the behavior in particular cases or conditions but the picture often changes as the whole range of anomalous behavior is explored.

The purpose of this paper is to report a series of experiments which show that 3 types of anomalous behavior of insulating oils are closely related to each other and to throw some light on the nature of their ultimate common cause. The first of these is the so-called "d-c cleanup" of an insulating liquid, which is the progressive decrease in dielectric loss under alternating stress following a sustained application of continuous potential difference. This phenomenon has long been known. It was noted by Jaffé[2] in 1909, who attributed it to the gradual removal of electrolytic ions, and has recently been studied by Jackson[3] as related to the losses at high frequencies. The second phenomenon is the current-time relation

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1. For all numbered references see list at end of paper.

under continuous potential. The steady decay of current with time in an insulating liquid has also long been known, but the phenomenon seems to be governed by no definite law. In particular, one of the authors[4] has shown that the current-time curve, if observed sufficiently close to the instant of application of continuous potential, may have 3 regions of different types, suggesting a corresponding number of different phenomena. The third type of behavior here studied is that of the unequal potential distribution[5] under continuous stress due, as shown also by one of the authors and his co-workers,[6] to the accumulation of space charges toward the electrodes.

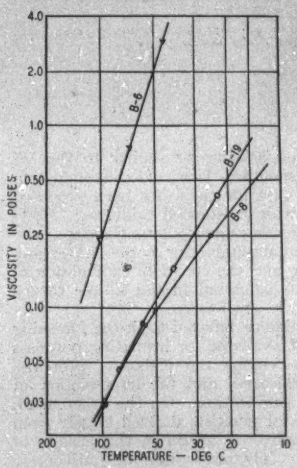

Fig. 1. Viscosity-temperature characteristics of 3 different oils

Oils B-6, B-8, and B-19

Table I—Physical Properties of Oil Samples

Oil No.	Base	Spec. Gravity 45 deg C	Flash Point deg C	Pour Point deg C	Surface Tension 45 deg C	Viscosity —Poises 45 deg C	Break down-Voltage Kv
B-6	Undewaxed paraffin	0.879	274	− 2	48	2.95	27.9
B-8	Refined water-white oil	0.824	139	0	32	0.112	31.1
B-19	Refined thin oil	0.877	149	−29	27	0.133	28.6

The Oils

Three different oils have been studied, of characteristics as shown in table I and figure 1. Two of these oils, *B*-6 and *B*-19, are commercial cable impregnants, the former for the so-called "solid," and the latter for the "oil filled" type of cable. The third oil, *B*-8, is of the same general type as that of *B*-19, except as regards the pour point temperature. Both these oils are thin highly refined liquids; the samples had suffered a slight deterioration during their storage life. Other properties of these oils have been reported elsewhere.[7]

The Measurements

Continuous records of both charge and discharge currents beginning 0.001 second after the application of voltage, were made with the amplifier oscillograph.[8] Beyond the range of the film of the oscillograph the record was picked up with a high sensitivity d'Arsonval galvanometer. The maximum sensitivity of the oscillograph was 1.7×10^{-8}, while that of the galvanometer was 3×10^{-12} amperes per millimeter.

Power factor or phase difference under alternating stress (60 cycles) was measured with a shielded Schering bridge capable of reading power factor to 0.000005. The test cell is a circular plate guard ring condenser. The measuring electrode is 52.7 centimeters in diameter. Provision is made for varying the distance of plate separation within the range of 4 to 10 millimeters. The whole cell is enclosed for thermal insulation and is provided with electric heat control and temperature measurement. The condenser is that used by Whitehead and Marvin,[6] modified, however, by enclosure of the cell in a gas-tight box which was kept filled with nitrogen before and after the oil was introduced so as to protect the latter from oxidation during the experiments.

The d-c cleanup was studied by applying constant values of continuous voltage within the range 500 to 1,500 volts and over the temperature range of 30 degrees to 80 degrees centigrade. At intervals of time the continuous stress was interrupted sufficiently long to measure the phase difference and loss. After approximately steady state was reached, the continuous potential was removed and the subsequent changes in phase difference were studied under both open-circuit and short-circuit conditions.

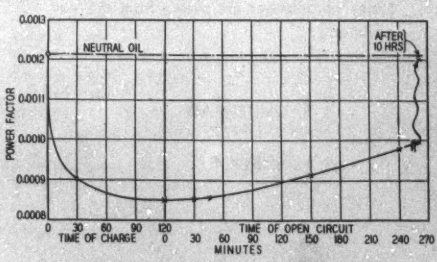

Fig. 2. Cleanup and recovery on open circuit

Oil B-6. at 500 volts direct current, and 45 degrees centigrade

The d-c current-time curves were taken for the corresponding ranges of potential gradient and temperature.

The space charge behavior was studied principally through observations on the current-time curve attendant upon reversal of continuous voltage following the long-time application of the opposite value

of voltage. As shown by Whitehead and Marvin[6] this phenomenon is related to the unequal potential distribution associated with space charge accumulation.

Results—
D-C Cleanup

Typical examples from a large number of observations on d-c cleanup and subsequent recovery are shown in figures 2, 3, 4, and 5. Figure 2 indicates a decrease of about 30 per cent in the value of phase difference in the steady state reached after 2 hours at 500 volts. Thereafter, with the condenser on open circuit, a slow recovery takes place, the original value of power factor being reached again after about 10 hours. Figure 3 gives a more comprehensive picture on the same oil at a higher temperature and higher voltage. Under the increased stress and diminished viscosity, the cleanup process is initially more rapid and the over-all improvement very much greater. The lowest value of phase difference reached in the 2 cases is, however, about the same. This figure also shows the difference in behavior in the recovery period as between open and short-circuit conditions. Recovery under short circuit is roughly twice as fast as under open circuit. Two curves for oil *B*-8 are shown in figures 4 and 5. These figures show the higher rate at which cleanup takes place under the higher stress but show apparently a lower over-all cleanup at the higher than at the lower voltage.

Exact duplications of d-c cleanup curves are difficult to obtain. The whole process seems to be very sensitive to the foregoing history of the specimen as

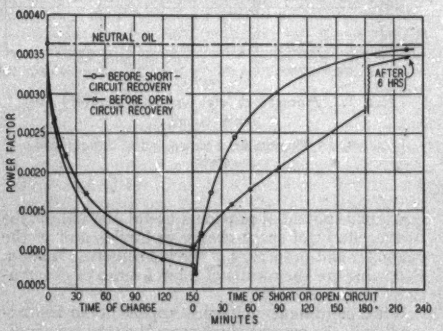

Fig. 3. Cleanup and recovery on open circuit and on short circuit

Oil B-6, at 1,500 volts direct current, and 60 degrees centigrade

regards value of stress, temperature, or other changes bearing on the diffusion or movement of the liquid between the condenser surfaces. It is believed that the unexplained behavior as between figures 4 and 5 may be due to this cause. Other examples are shown in figure 6, in which on recovery oil *B*-19 attains a phase difference value 9 per cent higher than that preceding the cleanup process, and in figure 7 in which oil *B*-8 suffered an increase of phase difference during the cleanup and a decrease during the recovery period. These variations from the more normal type of behavior apparently are due to

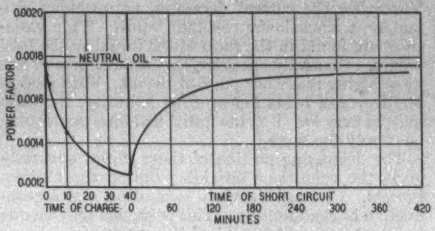

Fig. 4. Cleanup and recovery on short circuit

Oil B-8, at 500 volts direct current, and 45 degrees centigrade

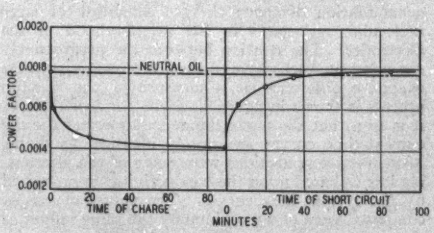

Fig. 5. Cleanup and recovery on short circuit

Oil B-8, at 1,500 volts direct current, and 45 degrees centigrade

clouds of space charge remaining from preceding tests and which, owing to the low mobilities of the ions involved, have remained intact during intermediate periods and so make their appearance only under the sustained voltage of subsequent tests. Several cases of this type were noted, but in each of them a variation in the normal cleanup period was followed by the opposite variation in the recovery period as indicated in figure 7.

In general the cleanup experiments are consistent with the view that the cleanup process is due either to the complete withdrawal of ions from the liquid, or, in order to account for the process of recovery, to the accumulation of ions as space charges near or at the surface of the electrodes, or perhaps to both. The experiments support this view principally in the influence shown of variations of temperature and electric stress. Increase of temperature lowers the viscosity and increases ionic mobility; higher stress obviously increases ionic velocities; both effects thus accelerate the cleanup process.

Conductivity Time

Figure 8 shows the time-current relations under continuous potential for oil *B*-8, the record beginning

a few milliseconds after the application of potential. These curves are typical for oils of these types. The initial horizontal portion represents a value of conductivity which accounts completely for the loss under alternating stress over a wide range of values.[4] It will be noted that this initial constant value is limited to a time interval of less than one second. Thereafter the current decreases, approaching ultimately a much lower constant value. Wide variations are found in the ratio of the initial to the final values. Generally speaking this ratio is greater the more highly refined or purified the oil. With moderate degree of oxidation or other impurity, the ratio may be very low, i. e., the initial and final values may be closely the same.[7]

The decreasing portion of these curves obviously gives the conditions obtaining during the cleanup process. Cleanup therefore is in effect a steady reduction of conductivity. This reduction may be due to the steady withdrawal of the excess of ions over their normal rate of production in accordance with gas theory, or as seems more important here, to the accumulation of space charges consisting of large molecular aggregates in the neighborhood of the electrodes. The relation between the progressively changing conductivity and the corresponding change of phase difference as a measure of the cleanup process is shown in figure 9. Here, for 2 of the oils, it is seen that the phase difference-time and the d-c current-time curves are closely identical in shape. Moreover, computations were made of the alternating loss as based upon the conductivities represented by the current-time curves. The values of loss so computed were of approximately the same values as the measured losses. The computed losses were, however, always somewhat lower than the measured values. This is attributed to the fact that these oils all show an ascending phase difference-voltage curve,

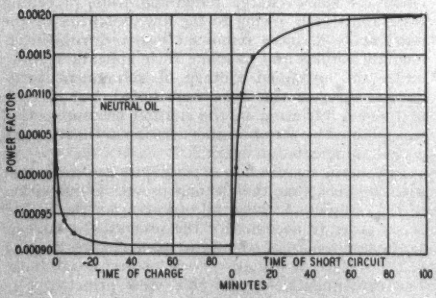

Fig. 6. Cleanup and recovery on short circuit

Oil B-19, at 1,500 volts direct current, and 45 degrees centigrade

indicating that under alternating stress new ions are created, probably by the process of secondary ionization. In such a case, the excess of measured over computed losses, referred to in connection with figure 9, would be explained. These results clearly indicate that d-c conductivity is the origin of the a-c losses (in the low frequency range), or in other words, that the cleanup process as measured by phase difference is due to a reduction of conductivity, and that the alternating loss is due to the motion of the same ions which are involved in d-c conduction.

Space Charge

It has been shown by Mie[8] and others that on application of continuous potential difference to insulating liquids, the potential gradient is not uniform but is steeper near the electrodes than at the center. The time rate of accumulation of these nonuniform gradients was studied by Whitehead and Marvin[6] who showed that it was generally contemporaneous with the slow decay of charging current and that the phenomenon was accompanied by a volumetric accumulation of space charges near the electrodes. These space charges obviously account for the higher potential gradients near the electrodes, and through their counter electromotive force of polarization for the slow decay of current under continuous potential, as shown in figures 8 and 9. The same authors also showed that current-time curves taken with the oscillograph for very short time intervals following a reversal of the applied

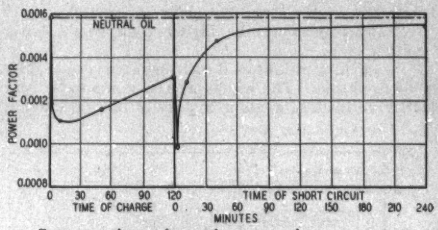

Fig. 7. Anomalous cleanup and recovery on short circuit

Oil B-8, at 1,000 volts direct current, and 45 degrees centigrade

continuous potential provide a useful method for the further study of space charge in liquids and of the character and properties of the ions involved therein. Following are the results of a brief series of observations of this character.

When continuous voltage is applied to an insulating liquid, the current-time curve is of the type indicated in figure 9 (the initial stages are of the type shown in figure 8). At the end of a sufficiently long time, in the above cases 40 or 50 minutes, the current reaches a constant value fixed by the relation between the applied potential difference, the counter electromotive force of polarization due to space charges, and the rate at which new ions are formed in the liquid. Now, if following a brief instant of short circuit for the passage of the geometric charge, the applied potential be reversed, the reverse current begins at a relatively low value, from 1 to 2 times the

value of the preceding steady current under opposite polarity, and thereafter rises sharply to a maximum from which the descent of current value may be more or less rapid according to the potential difference, but which ultimately reaches the same final constant value representative of the preceding long-time state under opposite polarity. An example of such a curve is shown in figure 10 taken on oil *B*-19. The initial steady low value may last for a second or more.

This type of behavior is readily accounted for by the effect of the reversal of polarity on the accumulated space charges. On reversal of polarity there is a much higher internal potential gradient, since the polarizing potential difference due to the space charges and that of the applied potential are now in the same direction. Consequently, the space charges

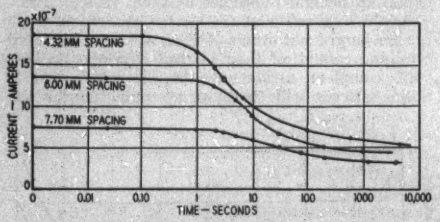

Fig. 8. Initial current-time relations on charge

Oil B-8, at 1,500 volts direct current, 60 degrees centigrade, and at millimeter spacings shown

begin to move, and with increasing velocity and increasing numbers in motion they unite to form the maximum as shown. As they pass to the opposite electrodes, a new accumulation of space charge takes place with counter potential difference due to polarization and the consequent slow approach to the steady state as in the preceding case of opposite polarity. In this picture, however, explanation of the initial constant value of current is not immediately obvious. Apparently it must be assumed that the ions constituting the space charge are large, heavy, and either that their mobilities are so low that they contribute little to the initial current, or that there is a time lag in reaching final velocities. The initial current on reversal therefore would be due as indicated by its initial value to the same ions constituting the final current at opposite polarity. This question is discussed in some detail below.

Figure 11 shows the general type of variation of the value of the current at the maximum with temperature. For 3 values of potential gradient it is seen that the maximum of current increases rapidly with temperature but considerably less rapidly with stress. Both types of behavior are readily accounted for by the increased ionic velocities due to reduced viscosity and higher potential gradient, respectively. The quantitative relationships indicated for the variation with potential gradient should be considered with some reserve as the variation in gradient was obtained by varying the distance between electrodes. This introduces the factor of the volumetric distribution of space charge as related to distance between plates, which has been found in other observations to have an important influence on both value and time variation of the current.

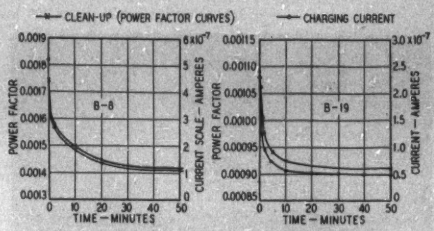

Fig. 9. Correlation of power factor-time and continuous current-time characteristics

Oils B-8 and B-19, at 1,500 volts direct current, and 45 degrees centigrade

The variation of the elapsed time from the application of reversed potential to the occurrence of the reversed current maximum, with applied stress and constant electrode separation, is shown for 3 temperatures in figure 12. Here, again, the normal influence of increasing stress and decreasing viscosity on the ionic velocities is evident. Toward lower stresses both the elapsed time to the maximum of current and the value of the maximum increase rapidly. This is evident in many oscillographic records. In some of these in the lower range of stress, it is difficult to detect the maximum. Under these circumstances it appears that the conditions obtaining on short circuit without reversing potential are approached. On short circuit, it is rarely possible to detect any reversed current. The space charges under their mutual attraction slowly diffuse toward each other and recombine. This behavior alone would constitute a reversed current. Such current, however, is neutralized by equal and opposite current in the external circuit caused by the liberation of the stored or bound charge on the condenser plates due to the space charge. In considering these observations on short-circuit conditions, it is to be remembered that the geometric charge corresponding to the capacitance of the condenser has been dissipated during the first instant of short circuit, its effect on the measuring equipment being eliminated by corresponding short circuit of the latter.

The relation of space charge movement to the initial period of the current-time curve is also indicated in figure 8, in which this curve is shown for 3 different values of potential gradient. It will be noted that there is an increase in the duration of the initial constant value of current as the potential gradient is decreased. If it is assumed that this initial constant value is in large measure due to the motion of accumulated ions in the body of the liquid in the original neutral condition, it is to be supposed that these would move to the electrodes more

rapidly at higher values of potential gradient and so establish the counter potential difference of polarization at an earlier instant than that corresponding to lower values of gradient. Other studies have been made, and are continuing, of the relations of the time intervals and values found in these reversed curves

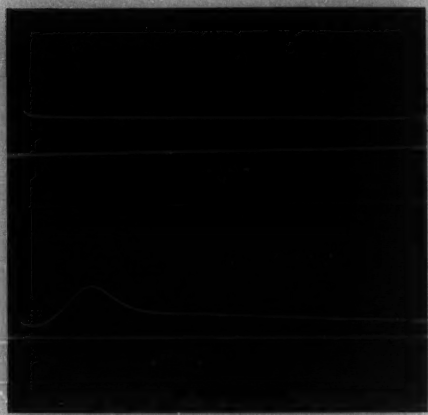

Fig. 10. Oscillograms of current-time relation for charge and subsequent voltage reversal

Oscillogram 1—Oil B-19, at 1,500 volts charge voltage, 60 degrees centigrade, 4.32 millimeter spacing

Oscillogram 2—Oil B-19, at 750 volts charge voltage, 750 volts reversal voltage, 72.5 degrees centigrade, 4.32 millimeter spacing

to the total value of space charge, to variations in potential gradient, and other aspects all in their bearing on the probable character, sizes, and mobilities of the ions involved.

Discussion

The phenomena underlying the electrical behavior of insulating liquids may therefore be pictured somewhat as follows:

In the neutral state even when highly purified, such liquids always show some electrical conductivity, albeit of exceedingly low values. This conductivity is due to ions arising either in traces of impurities, inherent dissociation, radioactive influence, or cosmic rays. Obviously, all these causes may be involved. The rates of recombination and diffusion of the ions so formed will at first be slower than that of their generation and the total number present will rise to an equilibrium condition where the number of recombinations is equal to the number of new ions formed per second. Some of the free ions so present attract to themselves clouds of neutral molecules thus constituting large and sluggish ions. Under normal electric gradients, an ion may carry with it as it moves a part of this surrounding cloud. As the gradient increases, however, it may be expected finally to shed the cloud completely. Further, at low gradients, positive and negative ions may be drawn together, but still remain separated owing to the intervening cloud, thus forming large polarized aggregates.[10]

When a potential difference is applied, if not too high, there will be motion of both the old heavy ions and the newly generated free ions toward the 2 electrodes. The heavy ions will move much more slowly, and if they are sufficient in number, a practically steady initial value of current may result as shown in figure 8. The tendency to a decrease in current due to the arrival of some of the ions at the electrode would be off-set by an increase in the mobility of the heavy ions due to the shedding of the clouds of neutral molecules as their velocity rises.

As the ions arrive at the electrodes some of them are discharged but others of them are not discharged retaining enough of their neutral envelopes to prevent complete arrival at the electrode surface. Space charges will therefore accumulate near the

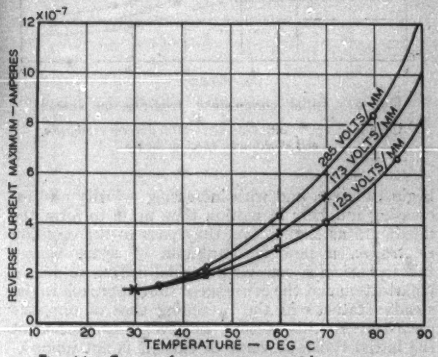

Fig. 11. Curves of reverse current at the maximum, versus temperature

Oil B-19

electrodes due partly to the steady withdrawal of freshly formed ions from the central regions, and their greater density near the electrodes (following a similar behavior in gases) and also due to the accumulated and stationary heavy ions with their surrounding clouds of neutral molecules. Both of these elements of the space charge are necessary for a complete explanation of the phenomena as observed. With the progressive accumulation of the space charges so formed, the potential gradient increases near the electrodes but falls off in the central region with resulting decrease of current so that the final steady current, if the gradient is sufficiently high to reach the saturation region, is due only to the number of free ions formed per second.

The long-time charging current is due principally to the steady supply of newly formed and more

mobile ions. The space charges reduce the internal potential gradient below that due to the applied field. On reversal of the applied field, therefore, the counter space charge potential gradient is now added to that of the applied field. As a consequence, the initial reverse current should be greater than the preceding final current of opposite direction. As stated above, this initial reverse current is invariably greater than the preceding final current, usually twice as great or somewhat less than twice as great. Moreover, the initial reverse current is of constant value over an appreciable interval, say up to one second. These facts strongly indicate that the initial reverse current is also due only to the newly generated mobile ions, the conductivity for this brief period being the same as the final conductivity of the preceding opposite period.

The reverse current maximum is due apparently to the space charge stored up in the large sluggish ions, for no such maximum is to be expected from the new more mobile ions. The initial reverse current represents the maximum current due to these latter. Consequently, the pronounced maxima of from 2 or more times the value of the initial charging current of the neutral liquid must be due to the additional supply of heavy ions stored in the space charge. Additional support of this view is found in the relation between the numerical values of the initial reverse current (A), the maximum reverse current (B), and the initial charging current of the neutral liquids (C). In surprising degree throughout many observations, the relation $B - A = C$ was found. Inasmuch as both A and C are attributable only to the newly formed mobile ions, it is clearly suggested

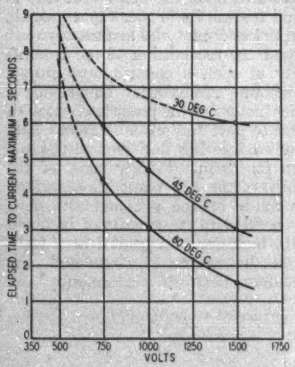

Fig. 12. Variation with voltage of elapsed time to maximum of the reverse current

Oil B-19, at 750 volts direct current, and at 6 millimeters spacing

that the excess of current over the initial reverse current must be due to an additional supply of ions, i. e., to the sluggish ions with their crowds of neutral molecules.

In the cleanup process, there is the accumulation of space charge due to both types of ion and the decrease of conductivity as described. During recovery on open circuit the space charges are more or less bound in position by the stored charges on the condenser plates. Diffusion and recombination are therefore retarded and recovery of initial conductivity is slow. On short circuit the geometric charges of the condenser combine through the external circuit, and the forces of diffusion and recombination have free play resulting in a much greater rate of recovery of initial conductivity.

Dielectric loss is due to the freshly formed more mobile ions. The central ions of the heavy aggregates are restricted in motion by their envelopes of neutral molecules and as a consequence, contribute little to the loss. Dielectric loss (at low frequencies) is therefore at all times related to the measured value of conductivity, as for example, in the initial value of the charging current of the neutral oil, and in the successively diminishing values of charging current during the cleanup process. During the recovery period the increase in loss is due to the increase in the number of new mobile ions.

Summary

In insulating liquids the conductivity-time relations, the reduction of conductivity and dielectric loss by the continuous application of continuous potential, and the occurrence of space charges at the electrodes are intimately related phenomena. In the purer liquids, the conductivity decreases with time after a brief initial period in which the conductivity is approximately constant. The decrease in conductivity is due to the accumulation of space charges at the electrodes, made up in part of freshly formed mobile ions and in part of heavy molecular aggregates with ions at their centers. The high maxima of current observed on reversal of the applied potential are due to the space charge in the heavy sluggish ions. These heavy ions thus have an important influence on the final measured value of conductivity under continuous potential, but contribute little if any to the dielectric loss under low frequency alternating potential. Dielectric loss is in most cases a pure conduction phenomenon as determined by the brief initial constant value of conductivity.

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Rehabilitation of the Connors Creek Plant

A decision as to when and how an electric power plant should be rehabilitated is largely a matter of judgment. In deciding to begin rehabilitation of the Connors Creek plant in 1933, the engineers of the Detroit Edison Company gave careful consideration to many factors including obsolescence of equipment, expected load growth, and general economic conditions. In deciding to rehabilitate the plant by replacing the boilers and generating units, they studied carefully such factors as the better heat rate obtainable with new equipment, the possibility of salvaging parts of the old plant, operating and maintenance costs, and reliability. This rehabilitation program is scheduled to be carried out in 4 major steps, the first of which will be completed during 1935. The process of reasoning followed in the development of this program and the principal results obtained and anticipated are outlined in this paper.

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ALTHOUGH a power company usually is thought to have a monopoly in the sale of electricity in its territory, its product is in constant competition with other forms of power and small plants available to its customers. It follows then that the operating company must furnish energy at the lowest possible cost consistent with satisfactory service, and to this end old plant and equipment should be replaced with modern and more efficient units when economically sound to do so.

The determination of when to rehabilitate a power plant presents a very complex problem the solution of which cannot be obtained by formulas. In the first place equipment does not become obsolete in any given span of time; instead, obsolescence is determined by improvements in the art in a given period. Again depreciation is a matter of quality of material and labor of which there is a considerable range. Factors such as the financial condition of a company, general economic conditions, and expected growth of load will have a very important bearing on when such projects should be started. Consideration of these factors makes it quite evident that no general statement can be made of the age at which a plant should be rehabilitated. Instead each project presents a separate and distinct problem having its own particular solution.

There is a lack of certainty in results of most rehabilitation projects even though there is a full knowledge of physical conditions and operating characteristics of old apparatus and of new equipment available. Usually the work can be done in several different ways, each of which may show some advantage depending upon the conditions assumed. As studies must be based upon predicted costs of fuel, labor, and materials, and upon an assumed growth of load, results obtained cannot be foreseen exactly. This is compensated in part by the fact that such programs usually proceed in steps which can be adjusted with changes in conditions.

Summed up, when and how to rehabilitate a power plant is largely a matter of judgment. The decision will be influenced to a great degree by past experience and belief in future trends, and in addition by engineering facts and conditions existing.

This paper describes the rebuilding program for the Connors Creek power plant of The Detroit Edison Company. Some phases of this project were immediately necessary to provide satisfactory operating conditions, while others were dependent upon load growth. The decision to proceed with the entire project was based upon the belief that load in Detroit soon would resume its former rapid growth, upon the fact that prices of material and money were favorable, and upon the recognition of the benefits to the community of such a construction project under existing economic conditions. To provide a background, a brief history of the plant is given with particular reference to past and probable future load conditions. Basic engineering decisions are stated and reasons given for them. Finally some of the outstanding features of the new plant are described and comparisons made of the old and the new. Descriptions are confined to statements of fact and opinion without the inclusion of a great deal of technical data. When the project is completed, the plant will be modern both in performance and appearance.

History

Construction on the original Connors Creek plant was started in 1914. When completed it housed 3 20,000 kw, 1 30,000 kw, and 2 45,000 kw generating units. These machines and the ties to the rest of the system permitted a load of 150,000 kw in the Connors Creek area.

Steam was used at a pressure of 220 pounds per square inch and a temperature of 600 degrees Fahrenheit. In its early days the plant heat rate was 21,000 Btu per kilowatt-hour and by 1929 this rate on the

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completed station had been reduced to 19,000 Btu per kilowatt-hour. Although Connors Creek was better than its contemporaries, with time it had fallen behind the company's more modern plants where the heat rate is approximately 14,100 Btu per kilowatt-hour.

The electrical system of The Detroit Edison Company is divided into load areas interconnected by ties for mutual help in emergencies. Connors Creek plant serves a load area consisting of the east side of Detroit in which is concentrated a great deal of the city's automobile industry. It is history that load increases at a greater rate in this area than in the others and that after a depression the "comeback" is most rapid. All information indicates that future load growth in the area will follow past trends. In 1929 the area load nearly equaled the firm rating of facilities available to serve it.

The original switching station in the generating plant building had become inadequate, as a result of system growth. Interrupting capacities of circuit breakers were less than the possible short circuits, proper segregation of equipment consistent with changed conditions was not provided, and the cable vault was crowded. In general, the standards of this important supply station were considerably below those of the more modern ones of the company. Because of these facts, studies were begun in 1928 on programs that would provide adequate switching facilities, additional capacity, and the rehabilitation of the comparatively old and inefficient equipment.

Basic Engineering Decisions

In the beginning, studies of the switching problem were pressed, as it was necessary to provide improved switching facilities regardless of what was done to the generating plant. Furthermore, it was desirable to get this work out of the way of the then future generating project.

Switching Station. As reported and discussed in detail in a previous A.I.E.E. paper[1] investigations soon indicated that it was not feasible to "revamp" the then existing switching equipment housed in a bay of the power house building, and that the proper procedure was to build a new detached switch house, with a bus and equipment arrangement that would be flexible enough to accommodate any probable future generating plant development. The station operates at 24 kv, supplying the cable system of that voltage. Generators are connected to the busses through autotransformers, each generator and its autotransformer operating as a unit.

The scheme of connections chosen was that of the single-bus single-breaker equalizer or synchronizing bus type, a choice consistent with The Detroit Edison Company's fundamental plan for system development which permits indefinite growth without making existing switching equipment inadequate. This plan provides that the transformers of the substations in a load area be fed radially from the supply station, that the feeds for a particular substation be distributed among the bus sections of the supply station, and that the tie lines to adjacent load areas be brought to the equalizer bus of the supply station. Thus, by changing the reactance of the equalizer reactors, generator sizes can be changed without changing the switching equipment. This co-ordination of system and switching station design makes the use of single busses and switches entirely logical.

Work on the switching station was begun in 1930, and it was put in service in 1932.

Generating Plant. In conducting the generating plant studies, the principle was laid down that simplicity and reliability were to be emphasized and that no attempt for an efficiency record was to be made at the expense of these factors. Also, experience gained in other plants of the company was to be utilized and practices there developed were to be followed, if they stood up under close scrutiny. At the start it was recognized that certain predilections existed in the minds of the operating staff, and it was agreed that these should be tested and followed out only when found to be sound.

It was decided that for either a new or a rehabilitated plant, the steam pressure would be 600 pounds per square inch and the temperature 850 degrees Fahrenheit, and that a simple regenerative cycle would be used. Although these steam conditions are higher than those in the company's other plants, they were not adopted without some previous experience. Since 1931 an experimental 10,000 kw machine using steam at 365 pounds and 1,000 degrees has been in operation at Delray station, and experience gained from this machine influenced to a great degree the selection of steam conditions for Connors Creek. Reheat cycles were studied but were ruled out because of the belief that the gain they provided did not warrant the added complexities, and because the company did not have a background of operating experience with them.

Although pulverized fuel is used successfully at the company's Trenton Channel plant it was decided to continue the use of stokers at Connors Creek. This decision was based primarily upon the ability to reuse the bunkers and coal handling facilities of the old plant and upon the difficulty in disposing of the ash of pulverized fuel. At Trenton Channel the ash has been used as fill in the large area around the plant, but in the future its disposal will become a problem. At Connors Creek it would have to be hauled away at the expense of the company, whereas cinders can be disposed of at no cost. Also, it was believed that the characteristic stack discharge from the stoker plant would be more satisfactory to the public as it had become used to this from the old plant.

Methods Considered

The desired results could be obtained by one of 2 general methods. By the first, the old plant would be retained as long as possible and added capacity installed in a completely new plant on the site as needed. Ultimately, the old plant would be replaced. The second general method was to rehabilitate the old plant, at the same time providing

1. For all numbered references see list at end of paper.

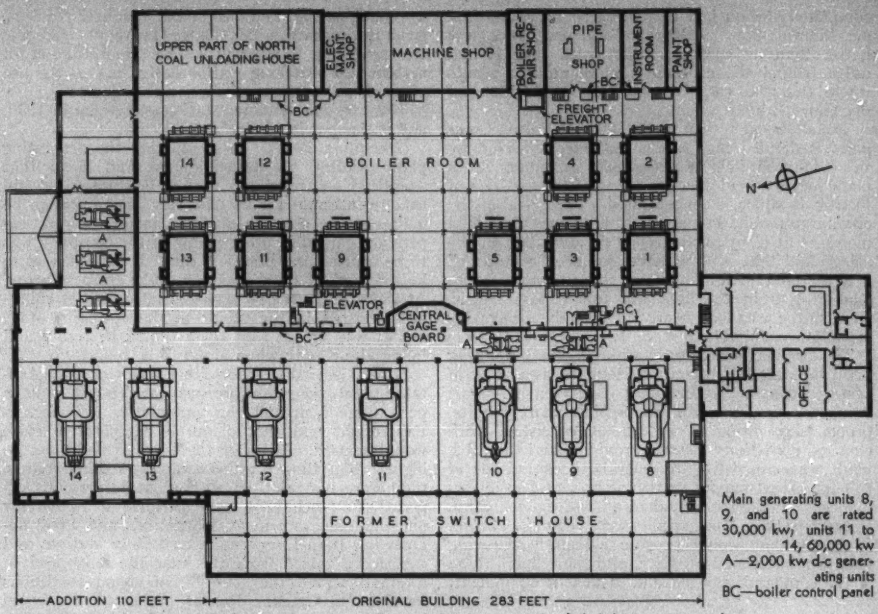

Fig. 1. Operating floor plan of Connors Creek station after rehabilitation is complete

for increased capacity. This could be accomplished by replacing the old generating units with new ones or by superimposing high pressure machines on the old units.

It was recognized early that the adaptability of the old plant for increased capacity and the amount of it salvageable with rehabilitation would be important factors in the final choice of plan. Studies showed that in the turbine room space was sufficient and foundations adequate to replace the old 20,000 and 45,000 kw units, respectively, with modern 30,000 and 60,000 kw machines. Furthermore, with minor changes the condensers of the old units, with their auxiliaries, were entirely adequate for the new larger units. By a relatively small building addition space could be provided for 2 additional 60,000 kw generating units. In the boiler room it was found that column spacing and foundations were such that the old boilers rated nominally at 10,000 kw could be replaced by new high pressure units having more than 3 times this capacity. These new boilers needed greater head room which would require raising the boiler room roof 32 feet. With this replacement program, the plant generating capacity could be increased to 330,000 kw or nearly double that of the old plant, and the plant structure and foundations, stacks, canals, coal handling and condensing equipment, and numerous parts of apparatus could be salvaged at a comparatively small cost. Because of the general rearrangement necessary, little of the piping even of the service type could be retained.

In considering the desirability of providing added capacity in a new separate plant these facts were weighed: First, because of its age the old plant would have to be replaced in a relatively few years, and during this time it would be used as little as possible because of its high heat rate. Operating and maintenance costs would be high, and reliability would be not of high degree. In general, this plan was not attractive from an operating standpoint.

Of the 2 methods of rehabilitating the old plant, that by which the old generating units were replaced by new ones gave the better heat rate and provided greater ease in operation. With the other method, by which high pressure units would be superimposed on the old machines, high maintenance and lower reliability, inherent in old equipment, would be retained. With either plan the boilers would have to be replaced completely.

Economic studies covering several years of estimated future operation were made of the several plans. As a result of this work, and by the application of what seemed to be common sense values to such intangibles as reliability and operating features, it was decided that in the long run the best procedure would be to rebuild the old plant and to replace the old generating equipment with new.

With this major decision made detailed plans were developed which provided in plan a layout as shown

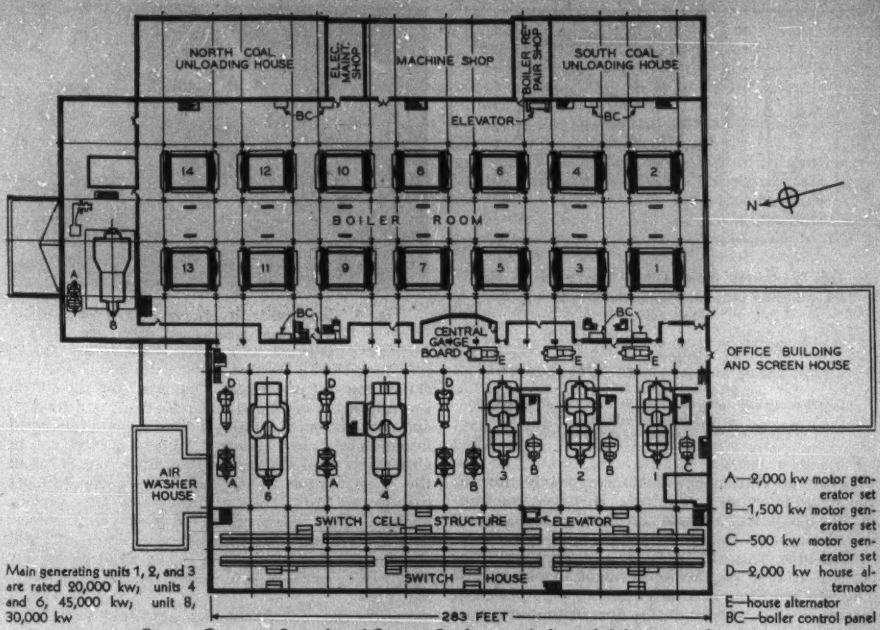

Fig. 2. Operating floor plan of Connors Creek station before rehabilitation was begun

in figure 1. Figure 2 is a similar plan of the old plant presented for comparison. In the new layout units 8, 9, and 10 occupy the positions of units 1, 2, and 3 of the old plant; units 11 and 12 replace units 4 and 6 of the old plant; and units 13 and 14 are located in an extension of the turbine room. Space occupied by unit 8 of the old plant will be used for house service machines in the new layout.

Schedule of Rehabilitation

With the rehabilitation plan developed, a time schedule for the work was established. This was extremely important in order to provide for the growth of industrial load expected in the area. As each replacement step temporarily reduces the plant capacity, and as each of these steps requires nearly a year for completion, the schedule and load growth curve had to be co-ordinated carefully. Obviously, it was highly desirable to start the work during this period of reduced load.

Load growth in the area in preceding years was studied, and from these data and other furnished by the statistical and sales departments of the company the load curve was predicted for 10 years hence. At any time the area firm capacity rating should be somewhat higher than the load in the area. This rating is equal to the sum of the ratings of the machines in the plant less the sum of the ratings of its 2 largest machines, plus the help that can be obtained through the system ties. This assumes that one machine is out of service for maintenance and that a second is lost through accident. It should be noted that it is not assumed that 2 machines can be out of service simultaneously in all power plants. Instead, the system firm rating is based upon 2 of its machines being out of service, and these *may* be in one plant or area.

The economics of all the sequences of replacement were studied. As a result of this work it was determined that the first step would be the removal of old 30,000 kw unit 8 and 20,000 kw unit 1, the latter to be replaced by a new 30,000 kw machine. This was to be followed by the replacement, in sequence, of the remaining 2 20,000 kw machines by 30,000 kw units. This work constituted the first phase of the program. As load requirements dictated, a new 60,000 kw machine would be installed in the turbine room extension, the two old 45,000 kw machines would be replaced in sequence by 60,000 kw units, and finally a second new 60,000 kw machine would be installed in the turbine room extension. Figure 3 shows how this sequence is matched with the load growth curve and indicates that nominal maintenance should be scheduled so that machines are not out of service for this reason during certain periods. This plan will be adjusted in accordance with actual load development. The first phase does not add any capacity but does replace machines nearly 20 years old with more efficient units. As an isolated case

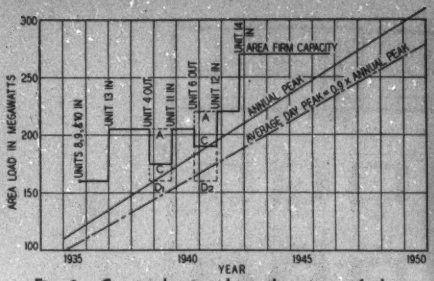

Fig. 3. Curves showing how the steps of the rehabilitation program are correlated with expected load growth

A—Firm capacity with one 60,000 kw generator out of service

C—Firm capacity with one 60,000 and one 30,000 kw generator out of service

D_1—Firm capacity with one 60,000 and one 45,000 kw generator out of service

D_2—Firm capacity with 2 60,000 kw generators out of service

this gain in efficiency will not completely warrant the added investment required. However, considering the project as a whole this sacrifice is necessary in order to meet the time schedule.

With the sequence program settled, work was started in 1933 on the replacement of old unit 1. The new machine, now called unit 8, was placed in service in 1934. Old unit 2 is now in the process of being replaced by new unit 9.* The first phase of the program will be completed during this year by the replacement of unit 3 by new unit 10. The work on these units was started somewhat earlier than was absolutely necessary, but this was justified by the fact that usually some operating time is necessary to work out minor difficulties in such new equipment, and because existing economic conditions permitted some modifications of the usual methods of justifying construction expenditures. For instance, it was recognized that this work would be of distinct benefit to the community and that it should be started immediately if it were to be helpful in relieving unemployment. This is an illustration of one of the many factors that affect rehabilitation programs.

Preparations are now under way for the second phase of the program. The extension to the turbine room is built and the first of the new 60,000 kw units has been ordered for delivery in the middle of 1936.

Features of Generating Plant

One feature of the new plant will be the amount of equipment salvaged from the old. This resulted from close scrutiny of the old equipment and through co-operation of the manufacturers. Also, as a result of much study, several processes, new at least to The Detroit Edison Company, have been worked out which it is believed will make the plant outstanding.

Generating Units. For 2 of the new 30,000 kw units the generators have been obtained from machines now out of service. One was from the 30,000 kw unit of the old Connors Creek plant and the second was obtained from a similar machine installed in old Delray power house 2. The generators are in good shape and are entirely suitable. Included in the construction of the turbines are the exhaust casings of the 20,000 kw units which they replace and the pillow blocks of the old 30,000 kw turbines. The appearance and performance of these units will equal that of new machines. The third 30,000 kw unit will be entirely new except for the turbine exhaust hood.

Condensing Equipment. A series of studies and tests made on the condensers of the 20,000 kw machines showed that with a different arrangement of tubes they would be adequate for the new 30,000 kw units. Actually, this arrangement uses fewer tubes than were used for the smaller machine. Further investigation showed that by the same process the condensers from the old 30,000 kw units from which the generators were obtained could be used for the new 60,000 kw units to be installed in the turbine room extension. Similarly, it was found that the condensers of the 45,000 kw units would be adequate for the 60,000 kw machines replacing them. As a result of these investigations no new condensers and practically no new condenser auxiliary equipment will be purchased for the new plant.

Welded Piping. Experience gained from the experimental 1,000 degree machine at Delray station brought out the weakness of bolted joints subjected to wide temperature changes; hence for Connors Creek it was decided to weld all of the main steam piping and most of the other high pressure piping including pipe-to-valve connections. This decision was based upon the development over a period of years, by the company's construction staff, of technique and men to produce high-class welds.

Each weld is checked with a device called an "archronograph" by means of which defective work may be detected. In addition the welds are stress-relieved in place by means of an induction coil developed for the purpose. This coil is made up of heavy flat conductors hinged on one side to permit slipping over the pipe. Current at 60 cycles and low

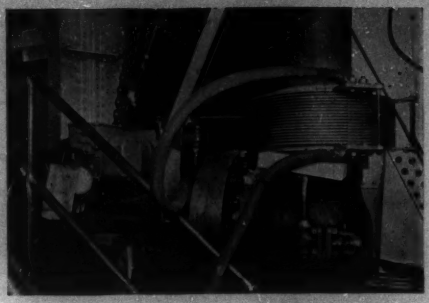

Fig. 4. Stress-relieving coil on welded joint in 10 inch main superheated steam line

*Replacement completed since paper was written.

voltage passed through the coil induces a circulating current in the weld which raises its temperature to 1,100 degrees Fahrenheit in a relatively short time. The coil is separated from the pipe by an insulating sleeve. Figure 4 shows the stress-relieving coil in place.

Models. A modern steam plant is a very complicated assembly of equipment, and it is difficult to visualize from drawings exactly what the final physical appearance of the product will be. In designing the Connors Creek plant this difficulty was overcome by the construction of exact scale models in wax and wood. Such models are particularly helpful in designing clean cut piping layouts as they eliminate to a great degree the necessity of making expensive changes as the work progresses. Figure 5 shows a model of units 8 and 9.

Boilers. The new boilers each have a nominal rating of 33,000 kw and occupy the same floor space as the old boilers rated nominally at 10,000 kw. This increase in rating has been obtained by the use of water walls (which permit higher combustion chamber temperatures), by the installation of economizers and air preheaters, by a slight increase in grate area, and by the use of a type of forced draft control that permits a high rate of coal burning.

The forced draft control used is such as to distribute the air uniformly through the fuel bed. The space below the grate is divided into 72 air chambers all supplied from a plenum compartment. Each chamber is equipped with a damper and a Venturi throat which measures the air flow and acts through a control system on the damper to hold to a predetermined value the air supplied through each chamber. By adjustment of the control, the amount of air supplied can be regulated to suit the fire conditions. With this system a uniform fire is obtained with the possibilities of burning holes in the fuel bed practically removed. A continuous check of the air distribution is indicated by a bank of meters in front of the boiler.

Superheaters. In other plants of the company the temperature of the steam varies considerably with the boiler load, that is, the superheat is not constant. As considerable extra money is being spent at the Connors Creek plant for high temperature equipment and piping, it is highly desirable that the superheat be maintained constant in order to realize the maximum return on the investment.

The superheaters as designed for the new boilers will maintain essentially a constant steam temperature over the ordinary operating range. This is accomplished through control of the path of the boiler gases. On leaving the combustion chamber the gases divide into 2 paths, one on each side of the boiler, and meet before entering the economizer. In each path is a radiant superheater directly over the fire, and back of one of these is a convection superheater. A damper in each of these paths varies the relative flow of gas in such a manner as to increase or decrease at will the convection effect of the combination, thus affording control of the resulting superheat.

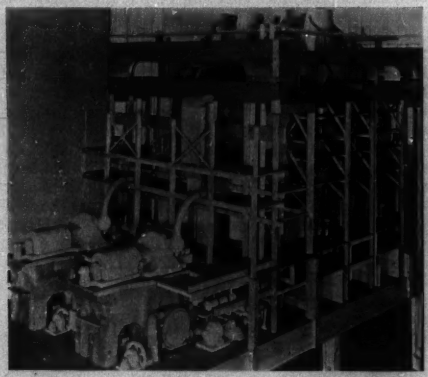

Fig. 5 (above). Model of new generating units 8 and 9 with boilers and other associated equipment

Fig. 6. View on fan room floor of boiler room showing forced draft fan control. Note d-c auxiliary bus construction overhead

Auxiliary Power. In accordance with past practice of The Detroit Edison Company, essential auxiliaries are supplied from a 240-volt d-c bus fed entirely independently of the main electrical system. One exception is made in that the boiler feed pumps are driven by slip ring induction motors supplied from the a-c house service. These, however, have stand-by steam driven pumps. The d-c system was adopted partly because of the motor drives salvaged from the old plant, but mainly because the company's experience indicates that the small increase in cost of the d-c system is warranted by the better and simpler speed control obtained.

The d-c bus used is single and not sectionalized, but is so constructed that it is practically proof against failure. The positive and negative sides each consist of 2 aluminum channels as shown in figure 6 and are spaced as far apart as possible, never less than 5 feet. The exposed surface of each channel is covered with a protective shell of formed horn fiber which does not obstruct movement of air for ventilation between the 2 channels. Because of the spacing and covering, short circuits between positive and negative busses are practically impossible. As the system is not grounded, ground faults are of no consequence. All taps taken from the busses are made through copper link fuses installed in small housings attached directly to the bus. Thus, although the leads may be brought together at the equipment, these fuses protect against a short circuit of the bus.

Costs and Comparisons

Costs of the project are summarized in tables I and II. Table I shows the book value and capacity for the old plant and for the various stages of rehabilitation. This table also gives the heat rate of the old plant and that estimated when the project is completed. Table II shows the make-up of the increase in book value for the completely rebuilt plant.

The following comparisons of design and performance of equipment in the old and new plants show the progress that has been made since the original plant was built.

Turbines. Engine efficiency of the new 30,000 kw units is 10 per cent higher than that of the old 20,000 kw machines. This increase is attributable partly to better design and partly to the higher steam pressure and temperature. The turbine heat rate of the 20,000 kw units at best point was 14,200 Btu per kilowatt-hour; that for the 30,000 kw units is 9,850 Btu. The future 60,000 kw units will show a similar advantage.

Besides being more efficient, the new turbines will be better operating machines. Turning engines are installed, and the design utilizes all knowledge of minimizing the effect of expansion in the turbine metals caused by temperature variations. The result will be machines that can be put into operation quicker and with less chance of trouble.

Condensers. The condensers as used with the old 20,000 kw units had 1.63 square feet of surface per kilowatt. As redesigned for use with the new 30,000 kw units the total surface, including the extraction heaters, is 1.07 square feet per kilowatt and for the condenser alone it is 0.90 square foot.

Boilers. Although the rating of the new boilers is slightly more than 3 times that of the old, the heat absorption is only twice as great because of the better water rates of the new turbines and because the feed water temperature is increased by the use of extraction heaters. The old boilers had 26,000 square feet of boiler and superheater surface. The new units have 48,000 square feet of boiler, water wall, economizer, and superheater surface. In addition, the new boilers each have 30,000 square feet of air preheater surface. Through the use of boiler water walls and metered air control the new boilers will burn 60 pounds of coal per hour per square foot of grate surface at nominal full load. In the old boilers the corresponding rate was 40 pounds. The temperature of the stack gases from the new boilers will be 325 degrees Fahrenheit; that from the old boilers was 650 degrees.

Although it is recognized that data obtained from

Table I—Values, Capacities, and Heat Rates of Connors Creek Plant During Various Stages of Rehabilitation

		Net Cumulative Book Values Including Overhead	Capacity, Kw	Average Btu per Kwhr
Old plant		$16,482,445	180,000	19,000
First phase of rehabilitation	3 20,000 and 1 30,000 kw units of old plant replaced by 3 new 30,000 kw units 4 old boilers replaced by 4 high pressure units Roof at boiler room raised. Extension made to turbine room	20,114,200	180,000	
Second phase of rehabilitation	1 new 60,000 kw unit added in turbine room extension 2 old boilers replaced by 2 new high pressure units	23,312,200	240,000	
Third phase of rehabilitation	2 old 45,000 kw generators replaced by 2 new 60,000 kw units 4 old boilers replaced by 4 new high pressure units	27,409,200	270,000	
Fourth and final phase of rehabilitation	Second new 60,000 kw generator installed in turbine room extension Remainder of old boilers removed and 2 new high pressure boilers added	30,367,200	330,000	Less than 13,000

Table II—Summary of Construction Costs and Retirements for Complete Rehabilitation Project

Old plant book value			$16,482,445
Total new cash		$20,367,610	
Value of old equipment from other locations re-used		459,000	
Total rebuilding account		$20,826,610	
Credit to property	$6,005,950		
Cost of removals	935,905		
Total charge to retirement reserve		6,941,855	
Net addition to book value			13,884,755
Total book value of completed plant			$30,367,200

Book value of old plant includes $2,576,663 for switch house.
Book value of completely rebuilt plant includes $3,028,663 for switch house.

the first section of a new plant may not be entirely reliable, figures obtained during the short time that the first new machine has been in operation indicate that the average heat rate of the new plant will be less than 13,000 Btu per net kilowatt-hour delivered to the bus; for the old plant the average was about 19,000 Btu. In addition, the new plant will show a decided labor saving, being consistent in this respect with the Trenton Channel plant.

Not a Made-Over Job

In the program developed it is believed that fuel efficiency, reliability, and operation have been properly evaluated and balanced. The steam cycle and conditions chosen will provide an excellent heat rate and the arrangement of equipment made will produce low operating costs. Due recognition was given to the possible advantages of other cycles and methods, but these were abandoned after careful consideration of all the factors involved.

In appearance the plant will be comparable with a new one and will not have the characteristics of a made-over job. Equipment will not be crowded, and the piping layout will be particularly clean cut. Suffice to say, this program represents the company's best judgment of procedure under the conditions prevailing.

Reference

1. Switching at the Connors Creek Plant, A. P. Fugill. Elec. Engg. (A.I.E.E. Trans.), v. 53, Jan. 1934, p. 162–8.

Protective Signaling

Protection of life and property may be secured by electrical signaling systems which have been developed to give protection against damage to property by fire, burglary, and other causes, and to supervise the activities of night watchmen and the operation of different types of mechanical equipment, and to perform other services. This paper consists of a general outline of the types of service available and the electrical systems for accomplishing them.

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THE function of the protective signaling systems described herein is to detect hazards to property and to life involved in fire, burglary, robbery, and related risks, and to summon automatically the necessary aid for overcoming them. Speed in detection and transmission of the alarm is often a vital factor in combatting successfully a fire or robbery. A few minutes, or even seconds, may mean the difference between little or no loss, and disaster.

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Insurance considerations have been such powerful factors in determining the pattern of all protective measures that frequent references to insurance rulings are made herein. Insurance premium savings account for many protective signaling installations but even more are made for the preservation of intangibles not covered by insurance.

The functional technique of such systems is similar to that employed in the code signaling and communication fields. The infrequency with which these emergency systems operate, and the danger of catastrophe attendant upon their failure, demand a reliability far higher than that of most commercial signaling systems. Self-supervision and organized maintenance are essential. Malicious tampering with the protective systems has to be checkmated. False alarms must be held to a minimum.

Protective signaling is accomplished through the following main services:

1. Sprinkler supervisory and water flow alarm service.
2. Automatic and manual fire alarm service.
3. Night watchman supervisory service.
4. Miscellaneous supervisory services.
5. Burglary and holdup alarm service.

Protective signaling systems for fire protection are classified by the National Board of Fire Underwriters as:

1. *Central Station Systems.* These systems transmit coded signals to a central station for dispatching the fire department, salvage corps, police department, central station guards or "runners," or other agencies as prescribed by the insurance regulations. These systems are owned and maintained by the central station organization but supervised by the Underwriters through routine reports, periodic inspections, and surprise tests. Figure 1 shows a typical central station.

2. *Proprietary Systems.* These are similar to central station systems but have signals transmitted to a station located on the protected premises and are manned by a prescribed quota of full time attendants. Figure 2 shows one type of proprietary control equipment.

3. *Local Alarm Systems.* These consist of devices for sounding audible signals within the premises for the notification of occupants,

mainly as a protection against loss of life. They are generally considered of relatively small importance in the protection of property (industrial and mercantile) since they are ineffective during the unoccupied periods.

4. *Auxiliary Systems.* These systems are, in effect, local systems connected to municipal fire alarm telegraph lines for direct transmission of alarms to fire headquarters. The questionable propriety of directly associating municipal circuits with extensive private local wiring, with divided responsibility for maintenance and the fact that municipalities are not regularly organized to care for supervisory services, limits greatly the field for auxiliary systems.

Sprinkler Supervisory and Water Flow Alarm

The value of automatic sprinklers in fire control depends upon their being in perfect operating condition at all times. For this reason, protective signaling is effectively combined with sprinkler systems to insure their reliability.

Water flow alarms are of great importance because in reality they are fire alarms, and, because serious water damage may be incurred should the flow continue after the extinguishment of an incipient fire or through an undetected leak in the system. The signals are initiated by electrical switches actuated by the clapper of an alarm check valve when lifted by a flow of water in the system; by a differential pressure operated device actuated by a sudden decrease in the system pressure following the opening of a sprinkler head; or, by a movable vane located directly in the flow stream of sprinkler piping. Figure 3 is a diagram showing the principle of a differential pressure type water flow detector. The vane type is shown in Figure 4. To avoid freezing, sprinkler systems installed in unheated buildings usually have the piping filled with air instead of water. The opening of a sprinkler head permits the air to escape which opens a "dry valve" admitting water to the system. The admission of water pressure to an intermediate chamber in the dry valve actuates a switch which initiates the water flow alarm.

To minimize false alarms from water hammers and pressure surges the alarm valve and vane type of flow detectors usually have retarding elements of the mechanical clock work, electrostatic condenser, or thermoelectric type associated with them. The differential pressure type overcomes such conditions hydraulically.

The most efficient sprinkler system obtainable would be valueless if on the occasion of a fire no water were available, through lack of normal supply pressure, or inadvertent closing of a water supply valve. Supervisory service provides a constant check on the condition of all essential elements of the sprinkler system by means of actuating devices, attached to these elements, which initiate signals in case of any derangement.

Automatic Fire Alarms

Automatic fire detection is accomplished by elements classified as "continuous," that is, those which are heat sensitive throughout their entire length, or "spot type" thermostats which are localized heat sensitive units. A further distinction is made between "rate of rise" systems and fixed temperature systems.

The pneumatic type of continuous fire detecting system shown in figure 5, which operates on the "rate of rise" principle, consists of a continuous small copper tubing attached to the ceiling of the protected area, the 2 ends terminating in chambers closed by thin diaphragms. This tubing normally contains air at atmospheric pressure and room temperature. In case of fire, the sudden rise in temperature expands this air, pressing the diaphragms against contacts which initiate the signal. To prevent false signals resulting from a rise in temperature produced by a change in weather, vents are provided in each diaphragm chamber which compensate for such slow changes. Having a diaphragm on each end insures operation even though the tubing should become open at some intermediate point. The internal fric-

Fig. 1. A typical central office

Direct wire burglar alarm circuits are terminated on the drops in the switchboard in the background. Coded signals are recorded, timed, and checked on the tables in the foreground

tion of 20 feet or more of tubing builds up sufficient pressure to operate with an open end.

Systems which are actuated by the rate of temperature rise can be made to respond to a fire more quickly than a system actuated by a fixed high temperature. The speed is further increased in the pneumatic continuous type because of the cumulative effect of all tubing exposed to the heat.

Electrical types of "continuous" fire detecting systems operating on the fixed temperature principle are available. One type consists of insulated conductors of fusible material which is melted by a fire, opening the circuit and initiating the alarm. In another form 2 separate circuits are contained within a single sheath. A fire melts a fusible element which initiates an alarm by making a connection between the 2 circuits.

"Spot type" fixed temperature thermostats are available which open or close a circuit when the heat

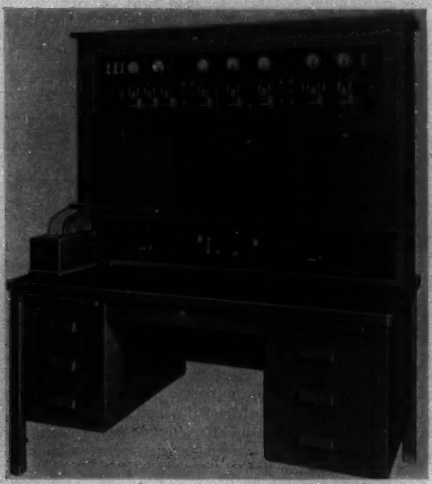

Fig. 2. A proprietary system control desk of the annunciator-recorder type

The annunciator in the center of the superstructure provides a continuous indication of the condition of the sprinkler system. Night watch, fire alarm, water flow, and sprinkler supervisory signals are recorded in printed words and numbers by the printing recorder at the left, and in punched code by the automatic punch register set in the desk top

of a fire melts a fusible element. Another form utilizes bimetallic or linear expansion thermostatic elements. Still another form has a number of thermopiles assembled in series which when heated generate an operating current. The cold junctions of these thermostats being partially shielded, slow changes in temperature are ineffective, thus giving a "rate-of-rise" characteristic. Pneumatic types of rate-of-rise spot thermostats are also available.

A recent example of the effectiveness of automatic fire detecting service plus effective patroling and fire fighting service is the "Century of Progress" Exposition. Despite the flimsy character of the construction and the fact that 37,000,000 persons in

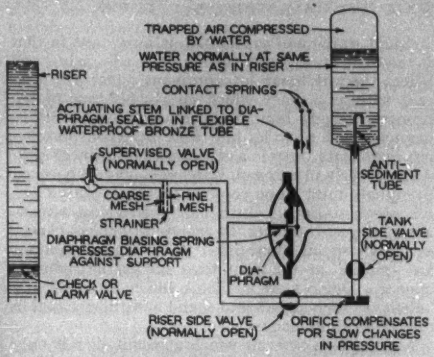

Fig. 3. A diagrammatic sketch of a differential pressure type of water flow detector

Increases in pressure, or slow decreases, have no effect. Sudden decreases in pressure as caused by the opening of a sprinkler head anywhere in the system, initiate an alarm

festive mood surged through the buildings and grounds, the fire losses were less than $5,000 for the 2 years. This is in striking contrast to the record of the Columbian Exposition in 1893.

Manual Fire Alarm Systems

To be effective, automatic fire alarm systems must cover the entire area to be protected. The somewhat higher cost of automatic systems provides a definite place for the manual fire alarm system in protecting large patrolled areas of less concentrated value. Manual fire alarm boxes on each floor of an industrial building offer good life and property protection by sounding local gongs to warn the occupants and simultaneously signaling a central station which calls the fire department.

Two types of local alarm systems are available, coded and noncoded. The former are further divided into the general alarm system which sounds all gongs for all alarms, and the presignal system which sounds its first alarm on "pilot" bells located in the superintendent's office or other designated places. After investigation, an authorized person can "condition" the fire alarm box to sound a general alarm. The presignal system is required for theaters, hotels, hospitals, and other public buildings where there is danger of panic.

Combination night watch supervisory and manual fire alarm systems are in common use. In these systems, the alarm box is arranged to transmit one round of signals when operated by the watchman's key, but to transmit from 4 to 7 rounds when oper-

ated by means of the pull-lever in case of fire. In proprietary systems the combination boxes are often equipped with a telephone connection and calling signal to provide communication means between the watchman and his supervisor.

Night Watchman Supervisory Systems

Night watchman supervision is important in that it removes the isolation which ordinarily exists and places the watchman in continuous direct-wire contact with an agency which checks his tour of the property, keeps him alert, investigates his delinquencies, and provides him with means of summoning immediate outside assistance in any emergency. As previously mentioned, watchmen may be checked by signals initiated on combination night watch and fire alarm stations. With such systems an attendant at the central office (or proprietary office) checks each code signal transmitted to see that all stations are "pulled" at the right time and in the right sequence. Devices are available which automatically "analyze" such signals and sound a warning signal in case of a delinquency.

Night watch systems which transmit signals only in case of a delinquency have been proposed but have not been commercialized because insurance underwriters prefer positive rather than negative signals. They require a signal from at least every tenth station visited. This requirement is met by a system having a maximum of 9 purely mechanical preliminary stations for each transmitting station. The transmitting station, shown in figure 6, cannot be operated until the watchman's key has been operated in each of the preliminary stations in predetermined sequence.

Fig. 4. A water flow detector operated by the movement of water in the pipe deflecting a flexible, hinged vane

A slight flow deflects the vane sufficiently to operate electrical contacts; greater flow flattens the vane against the inside of the pipe, offering very little resistance to water flow

Attempts to defeat the purpose of this system are indicated to the central station and investigated. Should an intruder compel the watchman to "ring in" on time in order to preclude outside investigation, he can readily transmit an emergency call without detection.

Miscellaneous Supervisory Systems

The supervision of automatic heating systems is among the more important of the miscellaneous supervisory services relating to fire hazards. Oil burners are supervised against flame failure, automatic stokers against the shearing of the safety pin on the fuel feed system, etc. Boilers are supervised against low water, high pressure, high temperature, etc. Rooms are supervised against low or high temperature or humidity. This latter service has quite a distinct field in cold storage vaults, curing vaults in various production processing, greenhouses, chicken hatcheries, etc.

The fine bore of the tubing offers such resistance to air flow that a break in the tubing affects the speed of fire detection only slightly

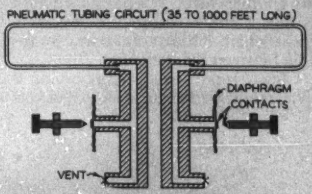

Fig. 5. The principal elements of a continuous, pneumatic, rate-of-rise, automatic fire alarm system

Other interesting applications of supervisory services are: transformer tanks against high temperature or pressure; the position of network switches or breakers; machinery against over-heating; etc.

Burglary and Robbery

A discussion of burglary and robbery protection requires an understanding of the nature of these hazards. The National Bureau of Casualty and Surety Underwriters define "burglary" as "an attempt forcibly to enter private property unlawfully for the purpose of gain." "Robbery," which in common parlance is termed "holdup," they define as "associated with an attempt to obtain securities or valuables from an institution or its representatives by threats of personal violence if resistance is offered," and "theft, although closely related to robbery, implies an attempt to steal property or valuables without threat of personal violence."

Burglar Alarm Systems

The Underwriters classify burglar alarm systems as:

1. Bank safe.
2. Bank vault.
3. Mercantile premises.
4. Mercantile safe.
5. Mercantile vaults.
6. Residence.

A "safe" is a portable, self-contained structure. A "vault" is an individually built-in structure.

Fig. 6. The watchman's key of a suppressed signal night watch system being inserted in the transmitting station

A maximum of 9 purely mechanical preliminary stations, visited in predetermined sequence, set up the combination of the key to operate the transmitting station

Protection may be "complete" or "partial" according to the degree of coverage.

Safes or safe cabinets are protected by means of an enclosure, usually of wood lined with foil strips, built permanently around all sides except the front, which may be removable or fitted with hinged doors. Opening of the front or breaking into any portion of the enclosure breaks the foil circuit and initiates an alarm. In some cases the external enclosure is not used and the foil lining is installed on the inside of the safe.

Earlier practice has been to "lace" vault structures with lead covered insulated conductors on 3 inch centers embedded in the concrete at the time it is poured. These are under continuous electrical supervision and so arranged that any attempt at forcible entry will initiate an alarm by causing either a break, a short circuit, or ground. The expense of this type of protection, and the difficulty in applying it to vaults already constructed, are obvious from figure 7.

Present day vaults are protected by a sound actuated alarm system which is responsive to the noises resulting from attempts at forcible entry. False alarms, resulting from extraneous shocks and sounds, are overcome through the use of "sound accumulators" or retard elements which require a series of impulses to operate the system.

Vault doors are also protected against torch flames or electric arcs by heat actuated units installed in the vault door or vestibule. Alarm contacts are provided to indicate movement of the door and door bolts.

Mercantile establishments require a totally different type of protective equipment. Window glass is protected in most cases by narrow strips of foil which form a conductor for the electrical current. Screens constructed of wooden dowels containing hidden wires are also used for windows and doors. Similar wiring embedded in half-round wooden molding run in strips 3 to 4 inches apart is used to protect walls and ceilings. Floors are protected by wires laid in concrete or in wooden moulding with a false floor to protect against mechanical injury. The floor trap, an effective supplementary aid, consists of a thin flexible conductor of low visibility stretched across the protected area at vulnerable points which initiates an alarm when brushed against.

A new development consists of photoelectric units which serve the same function as floor traps but go further in their applications. It is possible under favorable conditions to cover as much as 300 feet with a single straight beam of practically invisible light. The introduction of mirrors for directing the beam around corners reduces the range sharply. This rating considers the utilization of but 20 per cent of the optimum light value, which allows for supply voltage variations, and the intervention of haze, fog, rain, and snow, and deterioration of the light source with age. Such equipment is not yet adaptable to complete premise protection because the modern burglar thinks nothing of cutting through wall, ceiling, or floor to reach his goal. Complete protection must not only guard against actual entry but also against "fishing." The impracticability of such complete protection by means of light beams is apparent, particularly when one considers the losses in the reflecting mirrors required for full coverage. However, partial protection of a group of windows or doors is feasible by means of a single beam directed parallel to them at the correct height on the inside of the premises.

The most practical application of light beam detectors is in the protection of out-of-door yards and areas, although false alarms may be caused by birds, animals, or wind-blown papers intercepting the beam.

Considerable development work has been done on protective systems actuated by the approach of a person whose body capacity upsets the equilibrium of a finely balanced electronic system. The limitation to really complete protection by such means is that in making it wholly effective to expert attack of a single person, it becomes so sensitive that false

Fig. 7. A bank vault under construction, showing the protective "lacing" of several multicircuit cables embedded in the concrete

A break, ground, or short circuit between individual wires within the cable initiates an alarm

alarms may be initiated by one or more persons approaching the protected premises. This practically bars the utilization of such means for the protection of mercantile premises; it does hold some promise, however, for the protection of small safes, safe cabinets, and merchandise stock cabinets within the premises.

Other interesting possibilities which have been investigated for burglar alarm systems are pneumatic or atmospheric systems, wherein the opening or closing of doors or windows or even the entry of a human body so disturbs the air in the room as to initiate an alarm. The great sensitiveness required and the effect of the infiltration of outside disturbances constitute problems of first magnitude in such developments. The possibility of using a thermal detector actuated by the approach of the human body has also been the subject of much investigation.

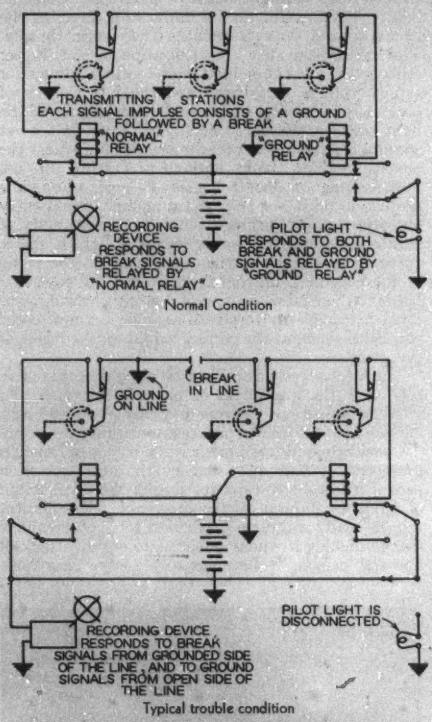

Fig. 8. The McCulloh circuit for transmission of coded signals to a central station or proprietary control desk

This circuit is self-supervised against breaks and grounds, and is rearranged by manual or automatic switches to transmit signals in spite of any break, ground, or combination of the 2

While these newer methods may present definite possibilities for covering certain portions of a risk or in providing some degree of partial protection, no cure-all has yet been found to displace completely the older methods which have proved their value over many years.

Holdup Alarm Systems

Robbery or holdup alarm service has many forms but the main objective is to make it possible for the victim to initiate a silent alarm without the knowledge of the robber who invariably cautions against an outcry or alarm. The fear of reprisal, of course, discourages many from utilizing available alarm facilities. Alarm initiating stations have been developed which make it possible to summon outside aid inconspicuously while actually following the commands of the robber or even by permitting the robber himself to initiate the alarm. Connections to a central station or a nearby vigilante station instead of to an audible signal outside the door render the alarm silent and eliminate the fear of reprisal. Use of police radio broadcasting facilities with cruising patrol cars ready for immediate response has measurably increased the value of central station holdup alarm systems during the past few years.

Circuits

With most electrical systems simplicity and directness of operation is desirable but with burglar alarm systems they are purposely complicated by providing feed backs, multipaths, electrically balanced elements, dummy conductors, etc., and the avoidance of any identifying means on terminals or conductors. For obvious reasons the detail of such arrangements are not being disclosed.

Grade *A* burglar alarm and holdup alarm systems are connected to a central station by a private wire to each subscriber, so circuited that a break, ground, short circuit, or change in resistance will initiate a signal. Other burglar alarms and the protective systems heretofore mentioned are usually connected to the central station by means of a series loop circuit to which several subscribers may be connected.

Central station loop circuits are operated on the McCulloh principle illustrated in figure 8, which permits transmission of signals despite a single break or ground or a combination of a break and ground. This is accomplished by having the code wheel on the transmitting device arranged to send the code signal in "break" impulses and in "ground" impulses. Under "normal" and "ground" conditions the "break" impulses are recorded. With a broken line, the "ground" impulses are recorded. The switching which is necessary to meet these different conditions may be accomplished manually or automatically.

All code signals transmitted to the central station are recorded on a paper tape by means of inking registers. A storage battery with suitable stand by facilities provides energy for all central station circuits. The entire central station equipment is in-

stalled, operated, and maintained in accordance with the Underwriters' requirements.

A new type of central station which is practically automatic in its operation has recently been established in Utica, N. Y. Automatic selection equipment on each circuit accepts and records all signals as they come in and routes them properly for such further attention as they should receive. Thus a fire or waterflow sounds a special attention signal at the central station and the alarm is simultaneously transmitted to fire headquarters. Similarly an emergency call, burglar alarm, or holdup alarm would be transmitted to police headquarters. Sprinkler supervisory and watchman's delinquency signals sound the special attention signal. Routine night watch signals are merely recorded.

Considerable study has been given to the possibility of transmission to central stations through the use of short wave radio. The complications arising from licensing transmitting stations at each subscriber's premises, together with the Underwriters' antipathy to systems less positively supervised than present land line circuits are definitely against such practice. This latter point applies also to carrier current transmission which has been given considerable study.

Proprietary Central Stations

Proprietary central stations are usually equipped similarly to those of the commercial operating companies. A new type of proprietary central station includes an annunciator with a simple multiple circuit to actuating contacts on each device or station being covered. The associated "drop" instantly indicates any activity at that station. Each annunciator "drop" is connected to a selector and through it to a transmitter which causes the corresponding signal to be recorded on an automatic printing recorder. This device transposes the code signals into printed figures and words indicating the source of each alarm and the time of recordance. The arrangement is such that these recordings are noninterfering and successive. A further feature is that fire alarms, for instance, are given preference over supervisory signals in the order of recordance.

Another type of proprietary equipment makes use of a separate unit transmitter at each device or station. This system operates over a 3 wire loop. The transmitters are energized from a central power source. Their operation is noninterfering and successive. The system will operate with a "break" or "ground" anywhere on the loop. Even if the cable is completely severed, it will still operate and preserve the noninterfering and successive feature.

In this discussion it has been attempted to give only a general outline of the application of electrical protection of life and property. Though the subject of protection against fire and burglary is, of course, a very old one, many new angles are constantly being projected into it by new hazards resulting from the complexity of modern living, and the ingenious audacity of the modern crook, all of which contribute greatly to the interest and possibilities in this field of protective signaling.

Sunrise Lodge and cabin area on the north side of Rainier National Park with Mt. Rainier in the background, which may be reached by a scenic highway but 2 hours from Seattle, Wash., scene of the Institute's 1935 Pacific Coast convention to be held August 27—30. Emmons Glacier, largest of the 28 glaciers on the mountain, may be seen winding its way down the snowy slopes

Insulation for High Voltage Alternators

Recent developments in mica tape insulation and stator winding construction for a-c rotating machines of large capacity wound for standard and appreciably higher than standard voltages are considered in this paper. Methods of improving composite mica tape insulation are discussed and the advantages of graded insulation are considered. Two types of windings for graded insulation are proposed for 33,000 volt machines. Special designs involving the insulation and construction of the end windings are presented, and methods of avoiding corona in the end winding zone are analyzed.

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THE development of improved insulating materials and of new methods of stator winding construction in recent years has opened the way for the construction of large capacity a-c rotating machines of higher voltage rating than are ordinarily in use in the United States. Furthermore, the difficulties involved in handling alternating currents of large magnitudes at the generating stations emphasizes the need for larger capacity generators of 27,600 to 33,000 volts rating.

As a result of the recent developments described in this paper, which include not only new insulating materials having promising characteristics, but also new methods of applying the insulation and in constructing the stator coils, the following general conclusions may be drawn:

1. The breakdown strength and dielectric loss of mica tape insulation have been improved materially by developing a bonding compound with more desirable characteristics, by exercising more effective control of the quality of the component materials, and by improving manufacturing processes for making the tape and applying it to coils.

2. Present mica tape insulation is adequate for stator windings of 33,000 volt generators. By using graded insulation (i. e., heavier insulation on the coils subjected to the higher voltages than is used on the coils near the neutral) on the stator winding of such machines, the costs can be reduced materially without any sacrifice in winding reliability, provided an arrester is installed at the junction of the 2 insulations. Two types of windings are available for building 33,000 volt machines with graded insulation. With one type corona can be eliminated at normal voltages, whereas with the other it can be eliminated at approximately test voltage.

3. Specific methods of end winding construction have been investigated and are proposed as adequate solutions for avoiding corona discharges between end winding conductors of different potentials, and creepage over the conductor surface to ground.

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General Discussion of Insulation Problems

The operating records of companies engaged in the generation and consumption of electrical energy and the records of companies which provide insurance coverage for dynamo machines classify the majority of the troubles on motors and generators as winding failures. However, an analysis of these data indicates that the larger percentage of the troubles is confined to relatively small industrial types of machines, which generally do not have mica insulation on the stator windings and which are subject to either unfavorable operating conditions or are given inadequate maintenance. Of the failures properly chargeable against large capacity machines in which mica insulation is used, the larger portion is on the field or excitation winding, in which the voltage is relatively low. The actual number of failures on stator windings on this class of machines is small and is appreciably lower at the present time than it was 15 to 20 years ago. The decrease in stator winding failures on the large capacity machines can be attributed to an improvement in the quality of insulation furnished by the manufacturer; a reduction in operating temperatures; operation with the closed circuit system of ventilation; and more effective protection from lightning and switching potential surges. It is anticipated that stator winding failures will occur still less frequently when more complete insulation co-ordination practices are adopted.

It has been recognized practice for a number of years for the manufacturer to determine the amount of insulation deemed necessary and sufficient for any given standard voltage. The actual thickness of insulation used by each manufacturer for a given voltage has been determined from the operating experience with machines over a long period of time. An increase in the insulation wall thickness for a given voltage would result in a larger and more costly machine. It rarely occurs that a purchaser specifies a greater amount of insulation than that normally required for the voltage class under consideration. In view of the fact that there are relatively few stator winding failures on machines with mica insulation, and that the purchasers do not feel justified in increasing the investment expense for an increased amount of insulation over that normally furnished, it can be concluded that the present mica insulation and insulation thickness standards are satisfactory at least for present standard voltages. It can be

concluded further that purchasers are not interested in better insulation performance for this class of machines, unless the improvement can be obtained at a cost comparable with the cost of obtaining the equivalent improvement from improved operating schedules, better maintenance, and more effective protection. Both manufacturer and purchaser are mutually interested in improvements in insulation which can be obtained without an increase in the cost of the product.

A relatively large number of new materials and compounds have been developed during the past few years. Some of these products, such as the new resins derived from rubber, synthetic waxes, cellulose acetate, cellophane, and solventless compounds, have promising characteristics for insulation applications. A few of these materials have actually been applied as insulation on magnet and general purpose electric conductors. The use of these new materials as bonding and carrier elements in the construction of composite mica insulation deserves consideration. The writers of this paper in conjunction with other associates have been investigating the properties and characteristics of these materials, alone and as fabricated composite mica insulation, in order to keep the insulation development apace with that of materials and with the general improvements in the design of the electric and magnetic circuits and structural parts.

Functions of Insulation

The primary function of insulation on the stator winding is to confine and direct the flow of electrical energy along prescribed channels so that the maximum useful input to or output from the unit can be obtained. Not only must the insulation withstand the potential stresses imposed upon it, but the amount of corona at normal operating voltages should be kept small. With the closed circuit system of ventilation, the continuous discharge of corona from the stator winding is more objectionable than in the case of the earlier unit which was continuously provided with a fresh supply of cooling air. The resulting increasing amount of nitrous oxide which is retained in the enclosure, in the presence of an excess amount of moisture, forms weak acids which attack the fins and tubes of the air cooler and deteriorate the organic insulation on the end-winding connectors, paralleling rings, and bracing members. In the case of older machines, the straight part of the coil in contact with the stator iron was the principal source of corona. This source of corona has been eliminated by applying asbestos tape to the straight part of the coil, treating to make it semi-conducting, and permitting this semi-conducting surface to be in direct contact with the stator iron. The remaining parts of the stator windings can be made practically corona free at normal voltages by grading off the resistance of the coil surface beyond the end of the core and properly spacing the coil ends.

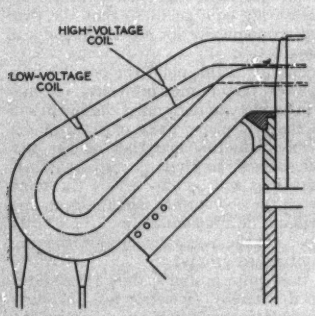


Fig. 1. A method of providing graded insulation for stator windings by using standard types of coils of rectangular cross section, with 2 coil sides per slot

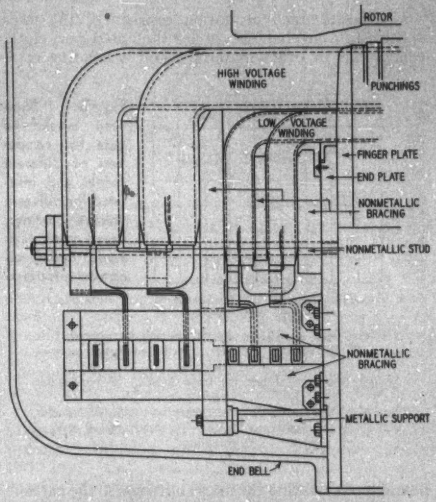


Fig. 2. A method of providing graded insulation for stator windings, by using 2 superimposed single layer windings

The problem of increasing the average breakdown strength of composite mica insulation is augmented by the fact that fundamental theory for and data on the mechanics of breakdown are not available. Until this kind of information is available, it will be impossible to determine the most effective procedure to follow in making insulation improvements. It is logical to expect that the fundamental concept and knowledge of insulation characteristics and limitations should be known sufficiently well that the quality of the insulation could be determined quantitatively from insulation test specimens taken from any section of a completely insulated coil. Although a rather limited effort is being made to obtain fundamental data on composite mica insulation, it is felt that the problem is of sufficient importance to

justify an even wider consideration by the research departments of some of the better equipped technical schools and universities than is being given at the present time.

Tests on Composite Mica Insulation

Composite mica insulation consists of the mica splittings, a mechanical carrier such as paper, cloth, cellophane, or other materials, and a bonding compound for cementing the mica splittings to the carrier, and adjacent layers of insulation to each other. The investigation to improve this type of insulation involved 3 principal items, namely, investigation of the characteristics of suitable materials for bonds and mechanical carriers; development of methods and processes for fabricating the insulation and applying it to stator coils; and an investigation of the characteristics of the insulation when applied to bar samples and actual coils. In comparing the bonding materials, high breakdown strength, low dielectric loss and good adhesiveness are the most vital factors. From the test data obtained on a large number of test specimens with different kinds of bonds, the following generalizations can be made: on step-by-step tests under oil, in which the voltage is raised in steps of 5 kv at the end of each minute, the puncture strength seems to depend almost directly upon the dielectric loss; and on short time tests where the voltage is raised quickly, and at an approximately uniform rate to failure (say in 10 to 30 seconds to failure), the absence of air pockets in the insulation seems to be the most important attribute. Power factor, or more correctly dielectric loss, seems to furnish one measure of the quality of the material used.

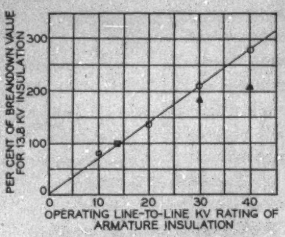


Fig. 3. Short time breakdown data for copper bars of different shapes and insulated for different voltage ratings, based upon tests made under oil on new mica tape

Circles—Tests on 1/2 by 3 inch rectangular copper bars insulated for voltages indicated. Protected against corona by shielding

Square—Average of tests on large number of rectangular bars

Triangles—Tests on 1/2 by 3 inch copper bars with semi-circular contour at top and bottom edges. Protected against corona by shielding

For comparing built up coil samples using different mica bonds, the dielectric losses at elevated temperatures give a measure of the relative abilities of these different armature insulations to withstand long-time or step-by-step over-potential tests. In this connection, where thermoplastic materials are used, it is well to note that the losses increase rapidly once the "melting" or softening zone is reached, yet the hardness and tendency to brittleness at room temperatures must also be considered, so that a reasonable balance must be arrived at in selecting the mica bond.

As between different built up insulations using the same mica bonds, power factor against voltage at a given temperature can be used to give a measure of the relative presence or absence of voids, because when the voltage is reached at which internal corona starts, the power factor increases much more rapidly with voltage than at the lower voltages. Power factor or loss measurements can be used to show the average condition of the insulation on individual stator coils, and thus can serve as a check on the quality and uniformity of materials and manufacturing processes. However, it cannot be concluded that such measurements can be relied upon definitely to determine the breakdown value of a particular coil because local inperfections may not show up sufficiently large in the dielectric loss values, even when relatively small effective electrodes are used and special precautions are exercised in making the measurements. Dielectric loss measurements are being made at different voltages on coils as they come through on customers' orders, to determine whether the relation between dielectric loss and breakdown strength can be used as a quality check on insulated coils during normal manufacturing operation. In checking the variations in the dielectric loss of the insulation on a coil, it is necessary to make the loss measurements on relatively small incremental lengths and traverse the entire coil. With the most up-to-date equipment available, an appreciable amount of time is required for each loss measurement, and thus considerable time and expense are involved in covering the entire coil. If the results from the present investigation indicate that dielectric loss values can be used as a reliable measure of insulation breakdown strength for finished coils, it will be necessary to develop special electrodes and reliable indicating or recording measuring equipment so that the data can be obtained economically for an entire coil and not handicap production.

It is well to consider at this point the possible uses of dielectric power factor measurements on machines already in service, to determine the quality of insulation. In the first place, these older machines do not have semi-conducting materials on the outside of the coil surface, so that on such windings dielectric loss readings will be affected by the small air spaces between the coil surface and the iron, and thus the data will not be a fair measure of the quality of the insulation. On the newer machines with semi-conducting materials to ground the coil surfaces to the punchings, it is quite probable that a technique can be developed whereby dielectric loss measurements on the insulation will tell much about the average condition of the insulation. The development of this technique should be undertaken jointly by the operators and insurance engineers who have the service experience, and the manufacturers who have spent much time on all phases of fabricating built-up insulation.

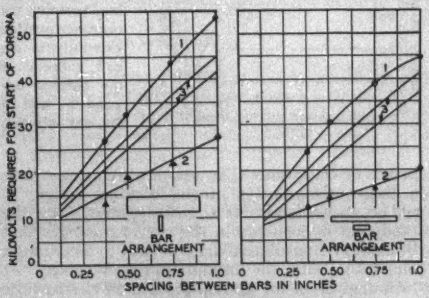
Up to date, the effort put forth on this insulation

development program has resulted in a material improvement in the average breakdown strength and dielectric loss of mica tape insulation by using a bonding element with more desirable characteristics; controlling the quality and condition of the component materials; and improving the technique of making the tape and applying it to coils. Although the improvements in mica tape insulation are of importance for stator windings at both standard and appreciably higher than standard voltages, the search for a bonding element with dielectric, thermal, and mechanical properties more nearly approaching the ideal requirements, is being continued.

Increased Voltages for A-C Generators

In the United States a number of generators have been built for potentials of 16,500 to 24,000 volts. There has been no marked increase in the magnitude of the generated voltage during the past 5 years. In Europe, the number of turbogenerators built for direct generation at 33,000 volts is steadily increasing. The disadvantages and difficulties associated with switching equipment, cables, and station structures[10] in handling alternating currents of large magnitude, emphasize the importance and need for building larger capacity generators for voltages of 27,600 to 33,000 volts.

Generators wound for voltages appreciably higher than the present standards are larger, longer, and more costly than units wound for the most economical voltage, which is usually nearer the standard voltage value. All of the high voltage generators built in the United States have had the same insulation on all of the coils, whereas in Europe practically all of the 33,000 volt generators have had the



Figs. 4 and 5. Voltage required for start of corona, for 2 different bar arrangements

Fig. 4 (left)—Bars crossed edgewise at 90 degrees

Fig. 5 (right)—Bars crossed flatwise

For both bar arrangements, bars were $^5/_8$ by $3^1/_4$ inch copper bars insulated for 13,800 volts with mica tape and finished as follows:

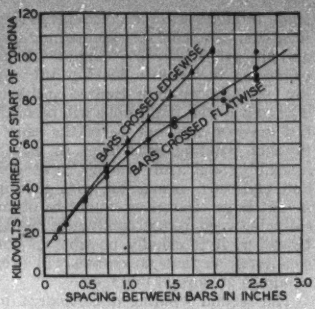
1—Butted treated cloth tape sanded and varnished 5 times to get smoothest possible finish

2—0.015 inch asbestos tape specially treated to make it electrically nonconducting but not made smooth

3—Commercial range

Fig. 6. Voltage required for start of corona, for 2 different bar arrangements

For both arrangements, bars were $^5/_8$ by $3^1/_4$ inch copper bars insulated for 33,000 volts, with mica tape finished as for a commercial machine



stator coil insulation graded in 2 or more steps in progressing from the neutral to the terminal leads. In connection with the increase in weights, dimensions, and costs of the high voltage generators with graded insulation, consider a machine having the armature winding insulated throughout with one wall thickness equal to the average of the various insulations to ground of another machine insulated with graded insulation. If these 2 machines are of equal kilovoltampere ratings and speeds, they will have approximately the same weights, dimensions, and cost.

The performance characteristics of stator windings with graded insulation differ from windings with uniform insulation only in regard to the over-potential tests and protection against over-potential surges. In making over-potential tests, each of the 2 windings will have to be tested separately at a potential corresponding to its class of insulation. In order to protect the winding with the reduced amount of insulation against over-potential stress to ground, an additional arrester is required at the junction between the low and high potential windings.[7,9] The cost of the additional protective equipment required by the high voltage generator with graded insulation is relatively insignificant as compared to the reduction in the cost of the generator. From the standpoint of generator costs and dimensions, the use of graded insulation is a very attractive proposition and deserves serious consideration by the purchasers of high voltage generating equipment.

Two methods of providing graded insulation for stator windings have been investigated by the writers of this paper and are offered as practical solutions to the problem. The first is a by-product of the double winding development for a-c generators. (This type of winding was proposed by C. W. Guth of Westinghouse Electric and Manufacturing Company.) The winding uses the standard type of coils with rectangular cross section for open slots as shown in figure 1. In each slot there are 2 coil sides, one insulated for full generated voltage and the other for half or approximately half terminal voltage. The coil sides are placed alternately in the top and bottom of the slots for alternate slots or alternate groups of slots. The respective coil sides of each insulation grade are connected in series and the

1. For all numbered references see list at end of paper.

leads brought out for 2 independent windings, one insulated for half or approximately half voltage and the other for full voltage. The 2 windings are connected in series to develop full voltage, with the low voltage winding located nearest the neutral. The coils of the 2 windings will be of the same width but may or may not be of the same depth. This type of winding introduces no new difficulties in assembly, coil end bracing, inter-coil connections and end turn insulation. Its principal limitation is that large clearances cannot be obtained economically between phase conductors on the end turns. However, it is usually possible to obtain sufficient clearances so that no corona will exist on the end windings at normal voltages.

The second winding development for graded insulation consists of 2 superimposed single layer windings as shown in figure 2. The winding in the bottom of the slots is insulated for $^1/_2$ normal voltage and the one at the top for full voltage. The windings are normally approximately full pitch, and further chording effects are obtained by displacing one winding circumferentially with respect to the other. This arrangement of the windings gives twice the center to center spacing between coil sides in any conical layer and approximately 3 times the air spacing when compared to the conventional 2 layer winding. With the greater separation, it is possible to build 33,000 volt generators which are essentially free of corona at the final test voltage of twice normal plus 1,000 volts. This problem will be discussed later in the paper.

Special Design Problems

The special problems involved in the design of high voltage rotating machines naturally fall into 2 separate groups, namely:

1. Those problems which are introduced by the possibilities of connecting high voltage machines directly to overhead lines so as to reap the fullest benefit of such higher voltage apparatus where this is possible. This phase of the subject has been adequately discussed in earlier papers[5–9] and, consequently, will not be considered in this paper.

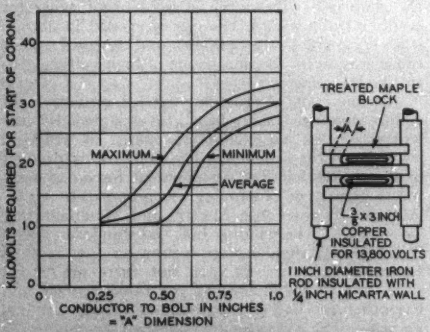


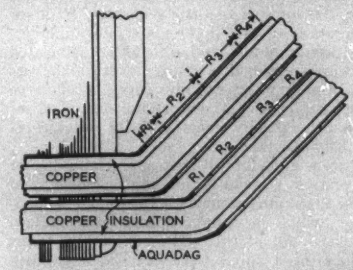
Fig. 7. Model of phase connecting rings and supporting structure, showing voltage required for start of corona, versus distance from conductor to bolts for 13,800 volt insulation on the connecting rings

2. Those problems which are introduced by the use of higher generated voltages (22 kv to 33 kv) which cannot be solved by ordinary design methods.

Under the second group there are again 2 main problems. The first is to design a slot insulation to obtain the minimum space occupied by the insulation, yet sufficient to withstand the over-voltage tests. The second is to design the end windings and the end winding insulation so that trouble due to corona or electrostatic discharges will be avoided.

Design of Slot Insulation

In higher voltage rotating apparatus, 22 kv and above, the slot insulation begins to occupy a very large percentage of the slot-tooth zone of the stator core. It obviously becomes desirable and necessary to use as few slots as possible without introducing excessive iron losses in the stator teeth and in the



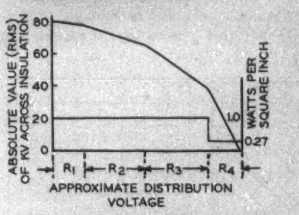


Fig. 8. A method of terminating the grounding surface by increasing the resistance applied externally to the coil surfaces as the distance beyond the end of the slot increases

surface of the rotor. The use of fewer stator slots facilitates the solution of end winding design, as will be shown later. It is also apparent from the standpoint of economy in the use of materials that the amount of insulation must be held to a minimum compatible with the insulation requirements.

An analysis of the general problem of electrostatic stress concentrations in rectangularly shaped coils for high voltage generators and methods for reducing the stress concentrations have been considered in a previous paper[4] and these features will not be discussed further. The curve in figure 3 shows the breakdown strength obtained on bar samples with square corners for insulation thicknesses corresponding to 10,000, 20,000, 30,000, and 40,000 volts and for 2 bars with half-round edges insulated for 30,000 and 40,000 volts. It was expected that the bars with the half-round edges would have a higher breakdown strength than those with square corners.

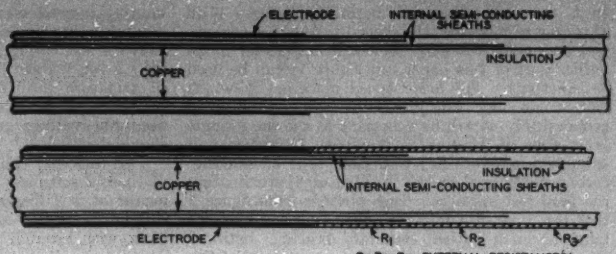


Fig. 9. A second method of terminating the grounding surface beyond the end of the slot by the use of an end shield with internal semi-conducting sheaths only

Fig. 10. A third method of terminating the grounding surface by using an end shield with internal semi-conducting sheaths and also external resistances, thus combining the methods shown in figures 8 and 9

The bar with half-round edges insulated for 40,000 volts had flashed to ground at 160 kv previous to the breakdown test and this may account for the decreased breakdown strength. These test results indicate that electrostatic stress concentration is not a limiting factor in the performance of well built mica insulated coils of conventional design for voltages well above any value considered feasible at present. The satisfactory operating records of 16,500 to 24,000 volt generators in service in the United States, and the added knowledge that has been obtained on the performance characteristics of composite mica insulation on bar samples, gives assurance that the present mica tape insulation is entirely adequate for higher voltage windings. It is obviously desirable and necessary to give more care and supervision to the manufacture of the insulation and its application to the coils, handling the coils through the respective manufacturing processes, assembling the coils in the machine, making insulation tests, and conditioning the machine prior to going into service.

Design of End Windings

The next major problem is the design of the end winding for the elimination of corona. These problems are by far the most difficult to overcome in the design of high voltage machines. There are 2 types of discharges to be guarded against, namely, discharge directly between 2 conductors, as between adjacent coils of different phases, and creepage to ground over the surface of one conductor.

Before considering the design possibilities, it is well to note some of the physical phenomena which affect the discharge between coil sides. Humidity up to the dew point has very little effect, perhaps 10 per cent at the most. Temperature and pressure variations existent in ordinary machines have a negligible effect. Ionized air left from a preceding test may reduce the discharge voltage on a test made almost immediately following, by as much as 10 per cent. The most important factor is roughness. In extreme conditions, this can cause a variation of 2 to 1. These data were obtained by visual observations in a specially made dark room. The voltage value at which corona was first faintly visible was used and was checked individually by several observers. All values were taken at 60 cycles on an increasing voltage, and several readings were taken for each point. See figures 4 to 7, inclusive. Thus, humidity, air density, and previous ionization have small effects, while surface roughness, by furnishing small points from which discharge may start, is by far the most important practical feature.

Of the several methods available for raising the voltage at which corona will start in the air spaces between conductors, the most promising are: (*a*) to apply a conducting or a semi-conducting material to the external surface of the coil ends which will act as a relatively low resistance shunt to ground in parallel with the intervening air; and (*b*) to increase the air gap spacing.

The proposition of applying a ground sheath of semi-conducting material over the entire winding to the machine terminals, or to points in the end winding where adequate separations are attainable, is the most desirable solution of the problem due to the fact that it simplifies the stator winding end construction and bracing, reduces the spacing requirements between coils, and thus results in a reduction of the axial length of the coil extensions. All of these advantages contribute to a reduction in the over-all length and cost of the unit. With the external coating of semi-conducting material on the end turns, the insulation must withstand approximately normal ground potential that exists for each particular coil, and the semi-conducting surface material must conduct the charging currents to ground without overheating. The corona problems thus become insulation and surface conduction problems. Therefore, it becomes necessary to make the end turn insulation as effective as that on the straight part of the coil. This is difficult to accomplish because the contour of the end turns is such that it is hard to apply the insulation so that it is free of air voids. In order to obtain the required insulation strength, it would be necessary to apply more insulation, desirable to find a more satisfactory bonding material, and essential to develop manufacturing methods and processes for applying the insulation to curved surfaces so that the final insulation is solid, free of voids, and reasonably flexible at normal operating temperatures.

In the case of large capacity, high speed turbogenerators which can be designed with relatively large stator slot pitches, it usually will not be necessary to take special steps in designing the end wind-

ings, to avoid corona at normal voltages. With this class of machines the special type of the conventional 2 layer winding, previously discussed in an earlier part of this paper (see figure 1) can be used satisfactorily. For lower speed machines in which sufficiently large slot pitches cannot be obtained economically, it will be necessary to use the 2 single layer type of winding as previously described and as shown in figure 2. With this type of winding, corona discharges can be avoided at approximately the final test voltages. It is obvious from figure 2 that this type of winding requires long end turn extensions, with rather elaborate bracing, both of which result in an increase in the size and cost of the unit.

At some point along the coil surface in present day designs, the grounding surface terminates. At present this is only a slight distance beyond the end of the slot. At this point something must be done to prevent excessive voltage gradients which will result in corona discharges along the surface of the coils.

Two or 3 methods present themselves for the solution of these difficulties. One of these is shown in figure 8, where, reading outward from the slot iron, successively increasing resistances are applied to the coil surfaces. The case shown is the electrical equivalent of 4 miniature cables connected in series. There is distributed resistance on the coil surface, distributed capacitance to copper through the insulation, and at 60 cycles, negligible inductance per unit of length. The voltage distribution may be calculated exactly as would be done for the cables. Semi-conducting paints have been developed, and

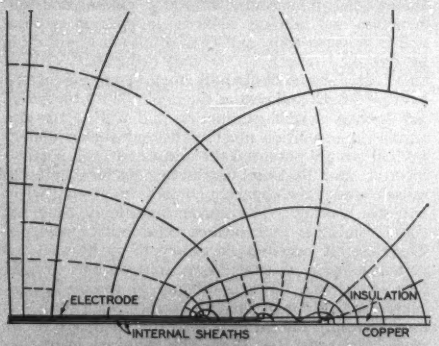


Fig. 11. A 2 dimensional flux map used for obtaining a simplified solution for the voltage gradient beyond end of slot, with internal sheaths but not external resistances

such a corona shield built which was capable of sustaining test voltages up to 70 kv with no corona or serious heating on a one minute test.

Another possibility is shown in figure 9, in which internal sheaths are used as in the case of condenser bushings, except that the sheaths are of semi-conducting instead of metallic materials. An experimental design similar to this has been built successfully for test voltages up to 90 kv. It is undesirable for a given voltage to use as many of these sheaths in armature insulation as are used in condenser bushings. If a sufficient number of sheaths are not used, the voltage gradient is not as uniform as it should be.

This difficulty can be overcome by a combination of these 2 schemes, as illustrated in figure 10. By means of a 2 dimensional flux map (figure 11), a simplified solution is obtained for the voltage gradient with internal sheaths, but no external sheath. The calculated distribution with external resistance added is shown in figure 13. A shield of this kind built with a total length of 24 inches plus 18 inches

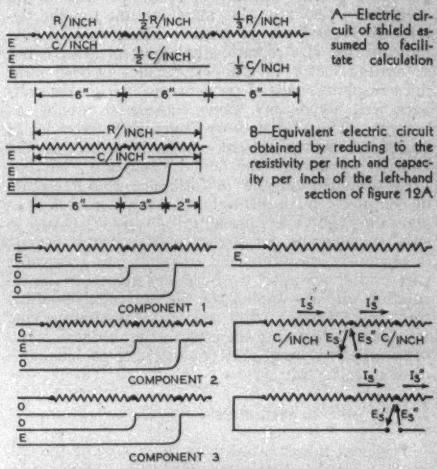


Fig. 12. Equivalent circuits used in calculating values of external resistance beyond end of slot for the end shield of figure 10

free creepage distance at the ends, when tested in air, withstood 155 kv without corona and flashed over at 160 kv, as mentioned above.

Appendix—Design of End Shield

It is intended in this appendix to discuss in somewhat more detail, methods for designing an end shield similar to that shown in figures 9 and 10.

The shield shown in figure 9 will be discussed first. These internal sheaths act similarly to those in a condenser bushing. In this case, they must be extended sufficiently well into the slot zone that they will take on very approximately the potential corresponding to their relative location in the insulation between the copper and iron. It is desirable to use as few sheaths as possible to avoid sacrificing too much space which otherwise would be used for insulation.

Figure 13 shows the voltage distribution expected with such a

shield in comparison with the voltage distribution when no shielding is used. Figure 11 shows the approximate electrostatic field for the shield of figure 9. Two-dimensional boundary conditions and a single dielectric constant assumed for both insulation and air, introduce definite discrepancies. However, these simplifying assumptions should not introduce very large errors, and the calculated distribution should be somewhere near the actual.

An interesting feature in this map (figure 11) is the manner in which the potential surfaces leave the semi-conducting sheaths fairly well back from the outer ends. This results in a fairly high density at the outer end of the embedded sheaths. It is probably desirable to use fairly high resistivity material at least at the ends of these sheaths. However, in drawing figure 11, the sheaths were assumed to have no appreciable voltage drop along them. The justification for this will be brought out later.

This brings up the question of the resistivity which should be used in these sheaths. Obviously, a solid sheet of metal foil could not be used, because the electromagnetic flux would set up eddy currents in it which would result in excessive heating. A wire or very thin ribbon could be wound on in a spiral to overcome this difficulty. However, possible air pockets and certain electrostatic stress concentrations within the insulation make these solutions doubtful. Therefore, semi-conducting paints were developed with which in a thin coat of suitable material practically any resistivity from a few ohms to infinity could be obtained for the surface resistivity per square inch of surface.

To calculate the desired resistivity, the largest desired voltage between layers was assumed, and the resistivity of the sheath taken as zero for the moment. From this, the maximum possible charging current from the overlap of one sheath to the next inner sheath was computed for test voltages. The resistivity was then so determined that with this current the temperature rise in 10 minutes was only about 4 degrees centigrade. To simplify this computation, the insulation can be treated as infinitely thick, because only a small amount of heat will reach the outer surface in 10 minutes. The details of this calculation will not be given. It is only necessary to know the heat conductivity and the heat storage capacity for the insulation and to use well-known methods of calculation (see page 294 of reference 2). The current and resistivity determined for the internal sheaths by this method of calculation are such that the assumption of no very large voltage drop along these sheaths becomes justified.

Calculation of Voltage Distribution

By referring to figure 13, it will be observed that the voltage distribution is greatly improved by means of the internal sheaths, but it is not all that might be desired, due to the rather steep gradients at certain points. It is probably sufficiently good for most commercial tests on high voltage coils, but should be improved so as to prevent flashovers or severe static up to the puncture voltage.

Continuous and connected layers of semi-conducting paints of suitable resistivities applied to the outside surface will give the desired results. (If coatings of different resistances are used in series, the higher the resistance the greater the distance at which it should be from the iron.) The resistivities of these materials will be much greater than those on the internal sheaths. Hence, the voltage drop and resistance along the inner sheaths may be neglected in the calculations.

If the resistance per unit length on the outside surface is a particular constant value in each of the zones directly above one of the inner sheaths, the problem is comparable to that of several cables connected in series, in which the resistance and capacitance per unit of length is to be considered, but in which the inductance is negligible at normal frequencies. Calculations have been made on this basis.

To indicate about what values of resistance to use on the outside surface, the following more simple method of calculation has been employed, although it has the disadvantage of involving slightly decreasing resistances as the distance from the iron increases. The resistivity was so chosen that the resistance and capacitance per unit of length were in a fixed ratio, as shown in figure 12*a*. The equivalent electric circuit was drawn as shown in figure 12*b*, where the resistivity and capacity per inch of length are all put in terms of those of the left-hand section of figure 12*a*. The voltages may be divided into 3 components as shown in figure 12*c*, and the equivalent circuits for each component are shown in the right half of figure 12*c*. Component 1 is applied on an open end line. Component 2 must be divided into 2 parts such that $E_s' + E_s'' = E$ and $I_s' = I_s''$, where all values are vector quantities. It is seen

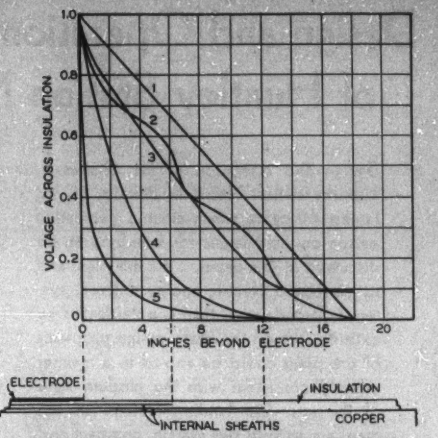


Fig. 13. Calculated voltage distributions beyond end of slot, for different combinations of internal sheaths and external resistances

1—Desired voltage distribution
2—Voltage distribution with internal sheaths only
3—Voltage distribution with internal sheaths and external resistances proportional to the capacitance from outside surface to sheath
4—Voltage distribution with a particular value of external resistance only
5—Distribution with no protection against corona

then that E_s' acts on a grounded end line and E_s'' on an open end line. Component 3 is treated in a manner similar to that used for component 2. The reals and imaginaries of each component are added to obtain the final distribution of voltage magnitudes and relative power factor angles. The resulting distribution is shown in figure 13 for comparison with the previously obtained data. The details of the calculation of these component voltages are omitted because the calculation is lengthy and because well-known methods are employed.[1]

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Design and Operation of Huntley Station No. 2

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Design and operation of the Charles R. Huntley station No. 2 in Buffalo, N. Y., largest 60-cycle steam-electric generating station on the Niagara-Hudson System, are discussed in this paper. As the plant and its associated electric energy delivery system replaced rather than supplemented an existing system, the basic design problems of the plant could be solved in a manner entirely consistent with the modern state of the art. Outstanding features of the plant are its split bus system, compact and flexible electrical layout, all-electrical auxiliary drives supplied at a single voltage, slag tap furnaces, and automatic furnace lighters; no coal is stored in the station building. Excellent results have been obtained by direct firing with pulverized coal and good over-all economy has been achieved under adverse load conditions.

BUFFALO'S first electric lighting was supplied by d-c series arcs in 1881. This was followed by 110/220 volt d-c Edison lighting and 125-cycle single-phase a-c lighting. In November 1896 Niagara Falls power was transmitted to Buffalo at 11,000 volts, 3 phase, 25 cycles. By 1898 motor generator sets were being installed to supply the existing d-c lighting, and frequency changers to supply $62^1/_2$ cycle a-c lighting. The 3 existing steam plants with belted generators then were scrapped, and Buffalo, for 18 years, depended entirely on transmitted Niagara Falls power.

Power for lighting the Pan-American Fair, in 1901, was supplied at 25 cycles. For several years the load on the frequency changer sets was kept constant by taking the growth in lighting load on the 25 cycle system. This resulted in changing large sections of Buffalo from $62^1/_2$ cycles to 25 cycles. From then until 1930, both of the a-c systems and the Edison d-c system grew side by side. In 1916 the 25 cycle Huntley steam plant of the Buffalo General Electric Company (now a subsidiary of the Niagara-Hudson System) was built and put in service in October of that year. It is situated in the town of Tonawanda, on the east branch of the Niagara River, $1^1/_4$ miles from the northwest corner of Buffalo. It is connected with the hydroelectric generating plants at Niagara Falls by 2 66 kv transmission lines, each 10 miles long.

Rapid development of the electric light industry was responsible for the simultaneous presence of these 3 systems of lighting in Buffalo. The development of satisfactory equipment for 60-cycle low-voltage network systems made conditions favorable for the adoption of a common 60 cycle system for all classes of service. The formation of the Niagara-Hudson Power System with its transmission ties to the 60 cycle steam and hydroelectric generating stations in the central and eastern parts of the state, and its proposed tie with the large 60 cycle generating plants in New York City, furnished additional justification for the decision to launch the 60 cycle change-over in Buffalo. The major items of this program consisted of building a 60 cycle steam plant, installing 3 large variable-ratio frequency-changer sets between the 60 and 25 cycle systems, and building a complete new 60 cycle delivery system to serve a population of 700,000 people in the metropolitan area of Buffalo.

Selection of the Site

In August 1929, engineers of the Buffalo General Electric Company were authorized to design and erect, under the supervision of N. R. Gibson, vice president in charge of engineering for the Niagara-Hudson System, a 60 cycle steam plant for Buffalo and the western division of the system. Several sites were considered for comparison with the existing 25 cycle station location. Those on Lake Erie, to the south and west of Buffalo, were eliminated because of higher cost. They required breakwalls to protect the circulating water intakes, more subtransmission to the load areas of Buffalo and the Tonawandas, and more transmission to the trunk lines to the east. Two sites to the north of Buffalo, on Ellicott Creek, were considered. One was eliminated because of the poor and limited amount of condensing water, and the other because of the longer subtransmission lines. Therefore it was decided to build the new 60 cycle station, known as Huntley station No. 2, just north of the 25 cycle station. The advantages of this site may be listed as follows:

1. It had an abundance of fresh relatively clean water for condensing purposes.
2. The load areas of Buffalo and the Tonawandas could be supplied directly from the plant by subtransmission circuits.
3. Coal receiving and handling equipment could be used jointly by both plants.

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4. Being adjacent to the 25 cycle plant, which has a capacity of 305,000 kw, would permit definite operating advantages, among which were: (a) joint supervision; (b) interchange of operating personnel to meet emergency conditions; and (c) joint use of machine shop, storeroom, first aid, and other miscellaneous facilities.

The relative locations of the steam plant, load areas, and transmission lines are shown in figure 1.

Design Requirements

In working out its design, the engineers considered that the station must meet the following requirements:

1. It must have rapid response to sudden changes in load. This need required a simple steam cycle and careful arrangement of controls.

2. Its reliability must be of the highest order. This requirement emphasized the need of rugged equipment with the possibility of some sacrifice in efficiency.

3. It must carry its full capacity continuously for months at a time, occasioned either by a low rate of water flow at the hydroelectric plants, or by large hydroelectric units being out of service for repairs.

4. The installation cost per kilowatt of capacity must be low as it was estimated that the capacity factor would not exceed 25 per cent for the life of the plant, although a combination of circumstances might produce an occasional annual capacity factor of approximately 50 per cent.

5. Operating and maintenance costs must be low for the same reason as given in item 4.

6. It must supply an expected load of 100,000 kw in the Buffalo area, and, in addition, supply energy to or receive energy from the Niagara-Hudson bulk power system.

7. Being part of a large bulk power system, the annual peak load of which already had exceeded 1,000,000 kw, would justify relatively large units.

8. Initial electrical ties would consist of: 21 22-kv 10,000-kva subtransmission feeders to the local load areas; 2 110-kv 60,000-kva transmission lines to the bulk power system; and 1 22-kv 25,000-kva frequency changer set.

9. The design of the station buildings must be such as to offer as little restriction as possible to the choice of equipment for future extensions.

The very fact that the designs of the steam station and the delivery system were not handicapped by the problem of having to fit into an existing system placed squarely upon the engineers the responsibility of selecting the best possible system consistent with the economics of the problem and the state of the art. How well this was accomplished is demonstrated by the fact that in the $4^1/_2$ years since the system was completed there has not been a single interruption to the low voltage network service or loss of voltage on the 22 kv bus of the generating station. On 2 occasions service was interrupted to the 60 cycle automatic substations because of faulty relay settings, both occuring within the first few months of operation.

Main Building

Figure 2 shows a cross section of Huntley station No. 2, from the coal pile to the outgoing transmission lines. A railroad track extends through the south end of the boiler and turbine rooms where hoists or the turbine room crane may lift machinery directly from the cars. The crane has a 100 foot span and a capacity of 150 tons. Monorails with trolley hoists are provided over the boiler feed pumps and mills. A motor operated crane in the central bay of the top floor of the boiler house is used as a means of transferring a $7^1/_2$ ton electric hoist with its load to the various monorails over the forced and induced draft fans and air preheaters.

The 5,213,000 cubic feet inside volume of the main buildings of Huntley station No. 2, costing 36.5 cents per cubic foot, is distributed as follows:

	1,000 Cubic Feet	Cubic Feet per Kilowatt
Administration building	108	0.7
Electric bay and control room	600	3.7
Turbine bay	1,500	9.4
Boiler bay	2,700	16.9
Coal machinery room	305	1.0
Totals	5,213	32.6

The steel frame of the building and the turbine foundations are supported on steel caissons extending 40 feet to rock. They vary from 48 inches to 89

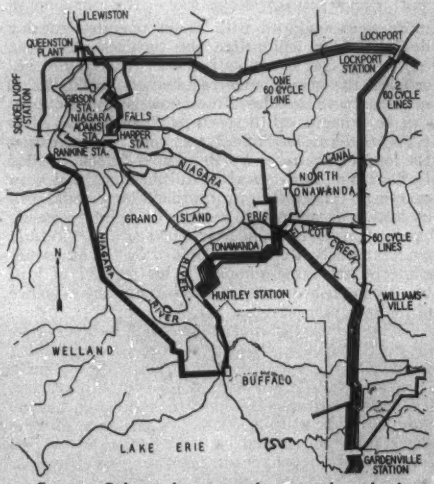


Fig. 1. Relative locations of steam plant, load areas, and transmission lines

inches in diameter and are filled with reinforced concrete. The turbine and building caissons are tied together by reinforced concrete beams poured integral with the concrete floor, which is 12 inches thick. The main operating floor is 32 feet above the basement floor. In this distance the turbine foundations are built of reinforced concrete and are independent of the building steel. The transformer and mill foundations are supported by concrete piles

poured in place. The coal bunker is supported on a continuous spread footing.

Turbogenerators

To meet the design conditions, 2 single spindle, turbogenerator units without direct connected exciters were selected, each rated 80,000 kw, 100,000 kva, 1800 rpm, 12,000 volts. A tandem unit of the same capacity would have given better efficiency, but the increased cost was not justified for so low a capacity factor. The building to contain these units, with their boilers and accessories, was designed so that units of 200,000 kva, tandem type, could be installed crosswise of the station if found to be desirable for future extensions. Figure 3 shows a view of the turbine room; note the turbine panels mounted in the wall. Rapid response to sudden changes in station loading (design requirement 1) often requires quick starting of the turbines. To facilitate this, the units were equipped with motor operated turning devices which will rotate the turbines at 1 rpm during idle but available periods. This device has reduced the normal time required to start from 90 minutes to 45 minutes; in an emergency, the units can be brought up to speed in 25 minutes. After trying several loading cycles, such as increasing the load 10,000 kw every 10 minutes, it was decided to determine how quickly a turbine that had been carrying 5,000 kw for an appreciable time could pick up load. Accordingly a test was made by increasing the load on one machine from 5,000 to 85,000 kw and simultaneously decreasing the load on the other machine by the same amount. This transfer of load was accomplished in 33 seconds without any evidence of undue strain on either machine.

Table I shows how the individual turbines have operated since the plant was started. Note the long hours of operation when the turbine loadings have been less than 7 per cent of their rated capacity. The annual capacity factors of the individual turbine units have varied from 6.4 to 34.7 per cent, whereas the station net annual capacity factor has varied from 5.7 to 25.8 per cent in the 4 years of operation.

Steam Generation

The use of one boiler per turbine was given serious consideration. Based upon experience at Huntley station, which showed that the availability factor of the boilers was less than that of the turbines, it was decided to install spare boiler capacity. Boilers at Huntley station are taken out of service once a year for insurance inspection and a general overhauling, whereas turbines are not taken out oftener than once in 2 or 3 years. National data[1] recently accumulated indicate an availability factor of 86.9 per cent for

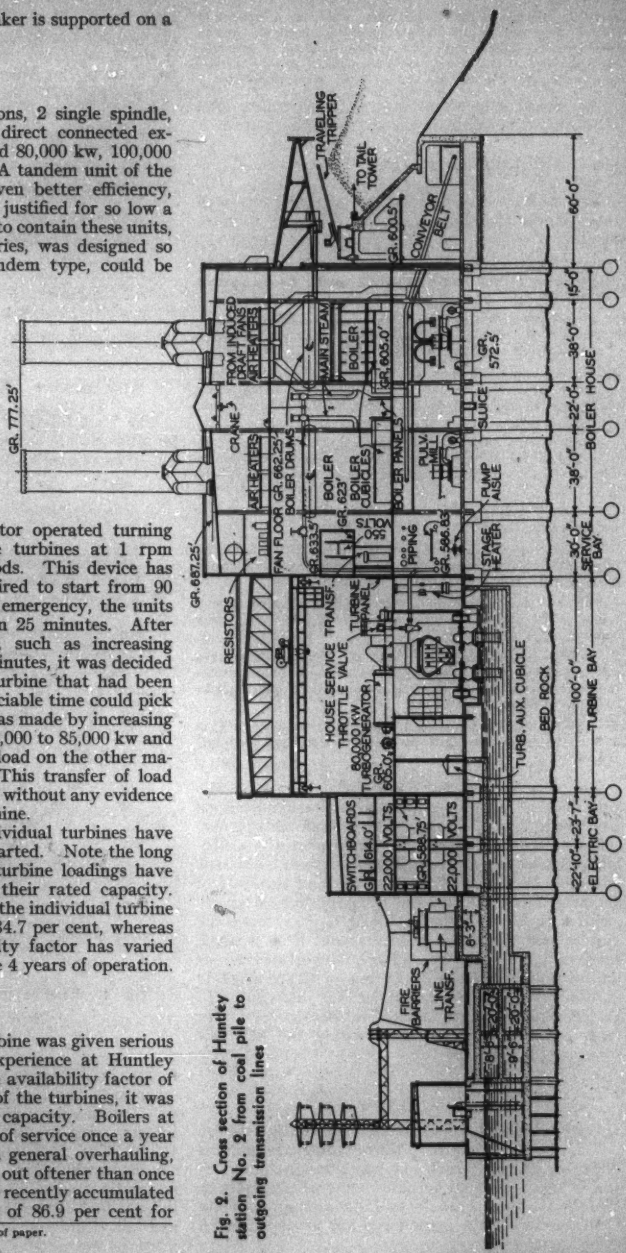


Fig. 2. Cross section of Huntley station No. 2 from coal pile to outgoing transmission lines

1. For all numbered references see list at end of paper.

pulverized fuel fired steam generating units and 92.8 per cent for turbines. This is equivalent to an over-all availability factor for plants having one boiler per turbine of 80.7 per cent minimum (86.9 × 92.8) and 86.9 per cent maximum. Accordingly, 4 boilers were installed, each of such capacity that 3 boilers could deliver continuously the required 1,640,000 pounds of steam per hour throttle flow required for 160,000 kw net station output. The fourth boiler, although regarded as a spare unit, would be of material assistance in picking up loads quickly during stand-by periods, and in addition would operate normally with the other 3 boilers for loads in excess of 120,000 kw.

Each boiler is 60 sections wide and 22 tubes high, and has 36,792 square feet of heating surface and a 9,350-square foot interdeck multiple-loop superheater. The 3,301 square feet of heating surface in the 4 furnace walls and the 900 square feet in the water cooled bottom surround a 22,900 cubic foot furnace designed for a heat release of 32,300 Btu per cubic foot at its rated capacity of 560,000 pounds of steam per hour.

The boiler units have operated continuously at 620,000 pounds per hour for a 3 hour period. The 4 lower rows of tubes in the boiler are double spaced, both vertically and horizontally, forming a slag screen to prevent the accumulation of slag on the main tube bank. The boilers and water walls each are supported independently at the bottom rather than hung in position.

Furnaces are of the slag tap design developed in Huntley station No. 1 in 1926 and 1927. The only limitation this design places on the purchase of coal is that the coal ash shall have a fusion temperature not to exceed 2,500 degrees Fahrenheit.

During long periods of operation of the plant at minimum load (5,000 kw), one boiler supplies the necessary 65,000 pounds of steam per hour. Two other boilers normally are held in hot reserve at a pressure not more than 100 pounds per square inch (gauge) below line pressure. A furnace that has been operating at this light load for days usually can be tapped within 2 hours after the loading has been increased to a rate of 120,000 pounds of steam per hour. It requires 4 tons of coal each 24 hours to keep one of the boilers within 100 pounds of line pressure.

Furnace Lighting Equipment

By means of special igniting oil burners the hazards and delays incident to hand lighting of powdered coal furnaces by torches have been eliminated. The oil is ignited automatically by an electric spark. A push button control station is mounted on the wing of each boiler panel as may be seen at the extreme left of figure 4. Within 3 seconds after the button is pushed 6 large oil flames are produced in the furnace, one in front of each of the 6 powdered coal burners, assuring effective ignition of the coal. During a 2 year period these lighters were used for approximately 6,000 boiler starts without causing a single puff. The lighters are withdrawn from the furnace, when the coal is well ignited, by pushing another button. The results obtained have been eminently satisfactory with but slight maintenance cost. The operating department considers the lighters one of the most valued features of the plant.

Method of Firing

The last stoker fired boiler was added to Huntley station No. 1 in 1924, and in 1925 additional boilers were purchased, equipped for direct firing of pulverized coal. This equipment operated so successfully that the decision was unanimous to use pulverized coal firing for the new plant. The direct fired system was justified as against the bin system of pulverized coal firing for the following reasons:

1. The installed cost was less.
2. The direct fired system had met successfully the exacting flexibility requirements in the 25 cycle plant.

Fig. 3. Turbine room looking toward boiler room

Fig. 4. Boiler control panels with master pressure controls on center panel

3. The hazards of bin fires and explosions when burning coals of high sulphur content were eliminated.

4. The nuisance resulting from the pulverized coal packing and caking in the bins were avoided.

5. No data could be found to prove that the direct fired system was less efficient or required more energy per ton of coal burned than did the bin system.

6. It was the opinion that the direct fired system could be made to have the same speed of response as the bin system.

Referring to the foregoing item 5, the efficiency of either system is made up of 2 parts: (1) the thermal efficiency of the fuel burning and heat recovery equipment, and (2) the mechanical efficiency of the pulverizing and transport equipment. For equal fineness of pulverization, the thermal efficiency should be the same for either system. Well designed efficient mixing burners are in use in both systems, and the method of preparation should make no differences. The bin system may use less energy for pulverization, but this will be offset by the additional energy used in transporting the pulverized fuel.

In further reference to the foregoing item 5, speed-of-response tests were conducted on one of Huntley No. 2 boilers, the results of which are shown in figure 5. During the tests with one mill in service, the steaming rate of the boiler was increased from 110,000 pounds to 320,000 pounds per hour in 2.7 minutes, or at the rate of change of 78,000 pounds of steam per hour per minute. Under this condition the control shut the feed water off entirely and the boiler water level rose $7^1/_2$ inches, thus demonstrating that in this station, where there are 2 mills per boiler, the limit to the rate at which the load can be picked up is set by the rise in boiler water level and not by the system of firing. The foregoing rate of pickup is equivalent to an increased station output of 7,800 kw per minute per mill.

As specified in design requirement 3, the plant must be able to carry full load continuously for long periods of time. It should be noted from figure 6 that on February 13 full load (160,000 kw) was carried for more than $15^1/_2$ hours. Full load also was carried for more than 12 hours on each of the 2 succeeding days. The load curve logs also illustrate the extreme variation in the station load.

Operating Procedure During Load Changes

Under normal operating conditions station load changes are made at the rate of 10,000 kw per minute. Load bulletins are provided in the turbine and boiler rooms which indicate the actual and anticipated load on the station. The actual-load hands of the load indicating instruments are positioned by means of a remote metering device, and the anticipating hands are positioned by the electrical operator in the control room through a selsyn sending and receiving device. Two horns, one in the boiler room and one in the turbine room, are sounded from the control room to announce a load change.

Thirty seconds after sounding the alarm for a load change, the electrical operator starts to change load at the rate of approximately 10,000 kw per minute. He does not hesitate to change load at this rate under normal conditions. However, if his steam gage shows the pressure to be less than 425 pounds and falling, he must change his procedure accordingly. Each turbine is provided with a load limit device to protect it against pulling water over from the boilers upon a sudden load increase resulting from a system disturbance. This device limits the load on the

Table I—Operating Record of the 2 80,000 Kw Generating Units Installed in Huntley Station No. 2

Year	Unit No.	Hours Operation at Various Loads (in Megawatts) 90	85	80	70	60	50	40	30	20	10	5	Hours Idle But Available	Hours Idle But Unavailable	Elapsed Time, Hours	No. Idle Periods	Unit Capacity Factor	Net Station Capacity Factor
1930	1	0	0	1	3	18	150	587	858	1,259	1,585	1,685	138	49	1,872*	9	32.8	—
1931	1	0	0	1	3	5	178	520	965	1,506	3,000	4,593	2,517	1,650	8,760	28	10.6	8.1
	2	0	0	2	3	18	41	126	306	546	1,451	3,121	2,182	298	5,601†	86	7.7	
1932	1	0	1.5	2	3	4	6	8	12	56	2,612	5,125	1,333	2,326	8,784	30	6.4	5.7
	2	9	14	54	67	123	150	348	385	470	2,154	3,837	239	3,741	8,784	41	7.0	
1933	1	18	72	266	770	1,544	2,362	3,013	3,472	3,947	6,795	8,396	1,206	125	8,760	26	34.7	25.8
	2	0	16	185	603	1,085	1,692	2,190	2,462	2,610	3,824	2,864	1,733	4,163	8,760	77	20.8	
1934	1	2	47	197	418	786	1,240	1,805	2,348	2,836	4,250	5,050	1,640	2,070	8,760	42	22.1	22.5
	2	1	41	198	418	868	1,421	2,185	2,812	3,461	4,882	5,869	2,600	291	8,760	83	26.1	

* Unit No. 1 started October 15, 1930. † Unit No. 2 started May 12, 1931.

turbine by means of an adjustable stop for the travel of the governor beam. The position of this limit is controlled from the control room by the electrical operator. The setting of these devices limits the increase in load to 12,500 kw for each active boiler. Immediately following the initial disturbance, the operator may raise the load limit and allow the machines to pick up more load, if needed, at a rate not to exceed 10,000 kw per minute per active boiler.

Air Heaters

There are 2 45,000-square foot regenerative air heaters per boiler. In selecting this type of heater a leakage factor of 10 per cent was allowed. To take care of possible corrosion troubles, the top or cold end of the 42 inch long heater section was made so that it could be replaced easily with corrosion-resistant steel. During 1932 the boilers operated for more than half of their active hours at outputs less than 70,000 pounds of steam per hour, and to date no corrosion can be detected in the air heaters.

A test was made that appears to explain the absence of corrosion. Fly ash was collected from the flues leaving the heaters, the collecting receptacle being arranged to cool the gases to various temperatures. The samples of fly ash so collected were mixed thoroughly with a measured quantity of distilled water and allowed to stand for a few hours. The water then was filtered off and its pH value (hydrogen ion concentration) determined. This water was strongly alkaline when the fly ash was collected at the temperature of the gases leaving the heater. As the temperature was lowered the alkalinity became less pronounced, but it was still alkaline at a temperature 100 degrees below the dew point of the flue gases calculated, taking account of sulphur content.[2] From this it was concluded that:

1. Pulverized fuel fly ash is strongly alkaline when it leaves the flue gases at temperatures above the dew point for the gases.

2. Pulverized fuel fly ash has a strong tendency to absorb acid moisture. This tendency enables it to carry off mechanically appreciable quantities of moisture, preventing it from depositing on metal parts and corroding them.

3. The temperature of the pulverized fly ash and flue gas may be reduced considerably below the dew point for the flue gas before its reaction becomes acid.

Draft System

Air and flue gas passes for the boilers are designed so as to keep down the friction in the system. Vanes are used in elbows where possible and streamlined enclosures are used around pipes passing through the air duct. Figure 7 shows how the forced draft air ducts are tied together at the discharge from the fans and again by a ring duct at the burners. The gas passages also are tied together on both sides of the induced draft fans; this permits operating the boilers at 70 per cent capacity with only one set of fans. The preheated air delivered to the primary air fans under pressure from the forced draft fans is tempered by a damper-controlled by-pass around the air heater. At full load on the boilers the flue gases leave the air heaters at 280 degrees Fahrenheit, and the secondary air enters the furnace at 600 degrees Fahrenheit.

Coal Handling

There are 2 methods of receiving coal. A rotating 100-ton car dumper with integral track scales was provided for rail delivery of coal, and a boat unloader with a capacity of 10,000 tons in 20 hours for the delivery of water-borne coal. From the car

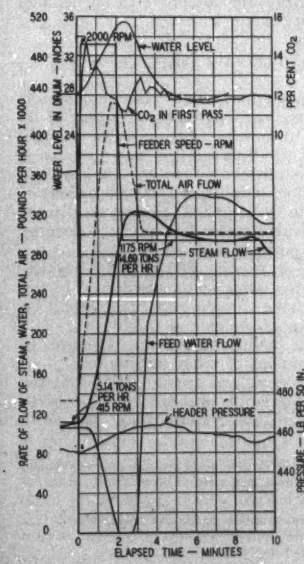


Fig. 5. Speed of boiler response with one pulverizing mill operating

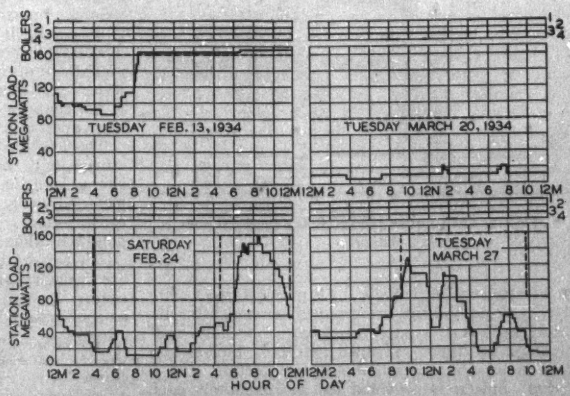


Fig. 6. Load curves for 4 typical days, showing boilers in service and total station load; dashed lines show rated capacity of turbines operating

dumper and dock, main belt conveyors of 750 tons per hour capacity (1,500 tons future) carry the coal to a balancing bin and thence to 2 rotating cylinder type breakers for the removal of foreign matter and the crushing of mine run coal to $1^1/_4$ inch size, thence over a magnetic separator to the storage piles.

Storage of coal at Huntley No. 2 is unique in that no raw or pulverized coal is stored inside the plant. The outside bunker is combined with the storage yard. Crushed coal is stored or reclaimed by a drag line scraper which operates between a movable head post and a movable tail car, both of which are operated electrically from a control cab.

Coal for the house enters through 8 48 inch square openings under the powerhouse end of the pile and through combined roll crushers and feeders to 18 inch belts which supply the individual mills. Each conveyor is started and stopped automatically by the automatic scales which weigh the coal in 400 pound lots, the number of starts being controlled by the rate of coal consumption.

The main conveyors are driven by high torque motors suitably protected from coal dust. These motors are started at reduced voltage in order to take up the slack in the drives and belts, and then are

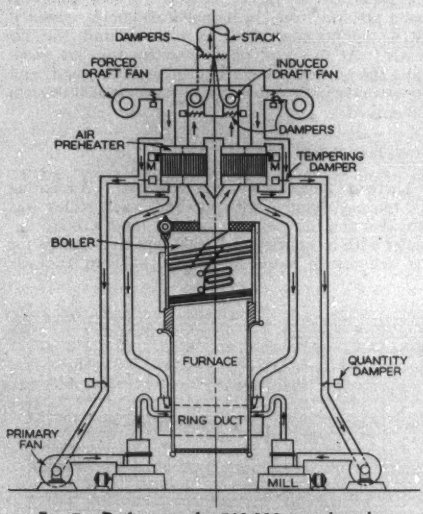


Fig. 7. Draft system for 560,000 pound per hour boiler

accelerated at full voltage. All motor starters, with accessory equipment, are grouped conveniently into "cubicles" and located in rooms especially constructed for them. A dust-tight push-button station is located at each motor for starting, and a "stop" button is provided for approximately each 100 feet of conveyor length. The usual interlocking is provided to prevent starting a conveyor out of sequence; and if a conveyor stops, all belts supplying it will stop.

Heat Balance

The heat balance diagram for one of the 80,000 kw turbines is shown in figure 8. The 17 stage turbine is bled at the sixth, eighth, eleventh, and fourteenth stages, for supplying steam to the feedwater heaters and evaporators. The evaporator equipment, which may be operated in either single or double effect, is floated on the system. The hot well pumps force the condensate through the 2 low pressure heaters and the evaporator condenser to the boiler feed pump suction header. These pumps force the condensate through the eighth and sixth stage heaters to the boilers under the control of 3-element feedwater regulators. The low pressure heaters can be by-passed as a unit, likewise the high pressure heaters. Push buttons to start and stop, and control the speed of the boiler feed pumps are mounted on the boiler panels together with the necessary indicating flow meters.

In conformity with the fundamental scheme for the essential auxiliaries, as described under the heading "Auxiliary Power," 2 boiler feed pumps are provided for each turbine unit, that is, one per boiler with a fifth pump as a spare unit. The fifth pump may draw water from the condensate header of either unit and feed into either boiler feed header. When a pump is not out of service for repairs both inlet and outlet valves are kept open so as to permit full control from the boiler room panel, the boiler feed pressure being held by check valves.

The saving of the heat from the generator air and lubricating oil coolers did not prove to be justified at the low capacity factor expected.

Condensers and Cooling Water

Each 45,000-square foot single-pass condenser is bolted solidly to the turbine casing with part of its weight supported by springs. Steam jet air removal is used. Each of the 2 circulating water pumps is driven by 2-speed squirrel cage motors. When both pumps are operating at full speed, 80,000 gallons of water per minute is supplied to the condenser. A horizontally divided water-box permits cleaning when operating at partial loads.

The location of an existing 305,000 kw plant upstream, with its circulating water discharged to the river where the intakes for the new plant would be located, necessitated a major undertaking of tunnel construction. The main tunnels are designed to handle a million gallons of water per minute.

The raw water cooling and general utility systems are designed for 3 separate pressure levels, so as to reduce losses when the requirements are more or less continuous:

1. The low service system at 20 pounds pressure provides cooling water for main transformers, generator air coolers, and turbine oil coolers.

2. The house service system at 65 pounds pressure supplies water for cooling the house service transformers and evaporators, and for general utility use around the plant.

3. The slag sluicing at 175 pounds serves for ash removal and boiler washing, also for the hydro-jet vacuum cleaning system.

One pump normally pumps all slag sluicing water. The same is true of the house service system. There is a third pump, however, which is duplicate of the slag sluicing pump and is driven by a 2 speed motor, permitting its use as a spare unit on either the house service or slag sluicing systems. Further interconnection between the 2 systems is provided through check and reducing valves to keep house service pressure on the slag sluicing lines at all times and for other emergencies. An elevated tank "floats" on the house service system. The low service is fed by a pump at each unit and a third as a spare pump. The importance of this service required interconnection through a reducing valve with the house service.

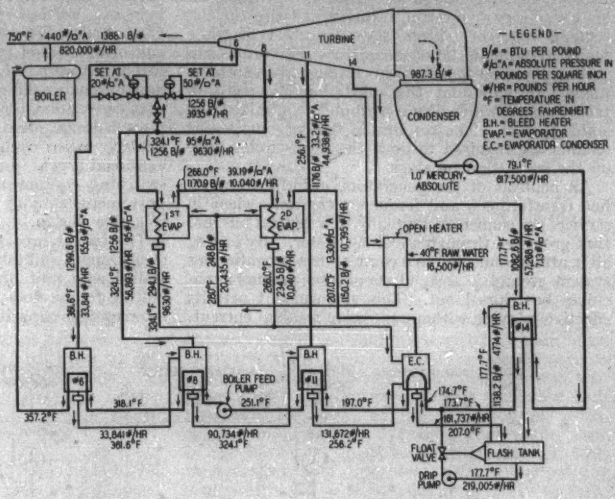


Fig. 8. Heat balance diagram for 80,000-kw 17-stage turbine

After giving consideration to experience in the 25 cycle station with a combination of a 12 kv generator and an autotransformer for obtaining 22 kv at the station bus, and after a careful study of the economics of the problem, it was decided that this method would give a greater degree of reliability than would a generator wound for 22 kv, with no increase in cost or sacrifice in efficiency. In addition the autotransformer could be designed to provide distinct operating advantages as explained in succeeding paragraphs.

Choice of Voltage

The station was built primarily to supply the distribution system of the metropolitan area of Buffalo. A thorough study of the economics of the problem indicated that the delivery of the energy should be at 22 kv by means of subtransmission underground feeders directly to the load areas. Ten years of experience in Buffalo with a similar 25 cycle subtransmission system of the same voltage had proved its reliability. To have transformed a portion of the energy for transmission, either overhead or underground, to a receiving station or stations in remote parts of the city with subtransmission circuits from these stations to the load areas, would have been far more costly and probably less reliable. A voltage of 22 kv was also suitable to supply large power consumers almost anywhere in the metropolitan area.

Electrical Connections

The scheme of electrical connections is known as the "split bus scheme." This scheme was evolved during the expansion of the 25 cycle system. It requires that each large transformer connected to the bus have the equivalent of 2 22 kv windings normally connected to opposite busses.[3] This gives a low through reactance between a generator or line to the busses, but a high transfer reactance between busses. For example, on the generator autotransformer the through reactance from generator to both busses is 5.46 per cent, but the transfer reactance between busses is 50.4 per cent. This design is very effective in limiting short-circuit current without excessive reactance to the load, it eliminates the use of large reactors in the busses, and provides highly satisfactory stability between machines because a comparatively high voltage is maintained on the "good" bus (actually the voltage tends to rise) during fault conditions on the other bus. Transformers for the outgoing lines and the frequency changer are also of the split winding type.

With all the equipment in service, including the 2

80,000 kw generators, 2 60,000 kva transformers from the 110 kv system, and the 20,000 kw frequency changer, the short-circuit value on one of the 22 kv busses is approximately 640,000 kva. If the station were extended to include 6 80,000 kw generators and 6 60,000 kva transformers, the short-circuit value could be held to 715,000 kva by sectionalizing the 22 kv busses and utilizing the split windings of the transformers for tying the bus sections together. From the connection diagram, figure 9, it should be observed that the various bus sections are tied together also through the subtransmission circuits and the substation and network transformers, which also contributes to a unified and stable system. The reactors in the outgoing feeder circuits are required to limit the short-circuit duty on the substation breakers.

All neutrals of the generators, autotransformers, line transformers, and frequency changer, when in service, are connected normally to a neutral bus and then grounded through a 5 ohm resistor. By having all neutrals connected to a common bus, a continuous system ground is assured should one or more machines be tripped out. This arrangement permits effective relaying without excessive residual current. There is no measurable exchange of harmonic current between the neutrals of the machines.

Switching Equipment

A thorough study of the types of switching equipment available led to the selection of simple and rugged equipment of the conventional type installed indoors. Vertical isolated-phase equipment, oil-filled vertical-lift switches with horizontal draw-out, and other related types of equipment were investigated, but were discarded either because of high cost or maintenance difficulties. It is the writer's opinion that conventional type switching equipment of improved design often is not evaluated properly, particularly when comparing it with the more unconventional types. In other words, conventional type switching equipment may incorporate all the improvements actually required over similar equipment of earlier design.

The circuit breakers were built at the factory in steel frames, suitably enclosed, and shipped and installed as a unit, the field work consisting only of bolting to the floor. The circuit breakers have an interrupting capacity in excess of the estimated

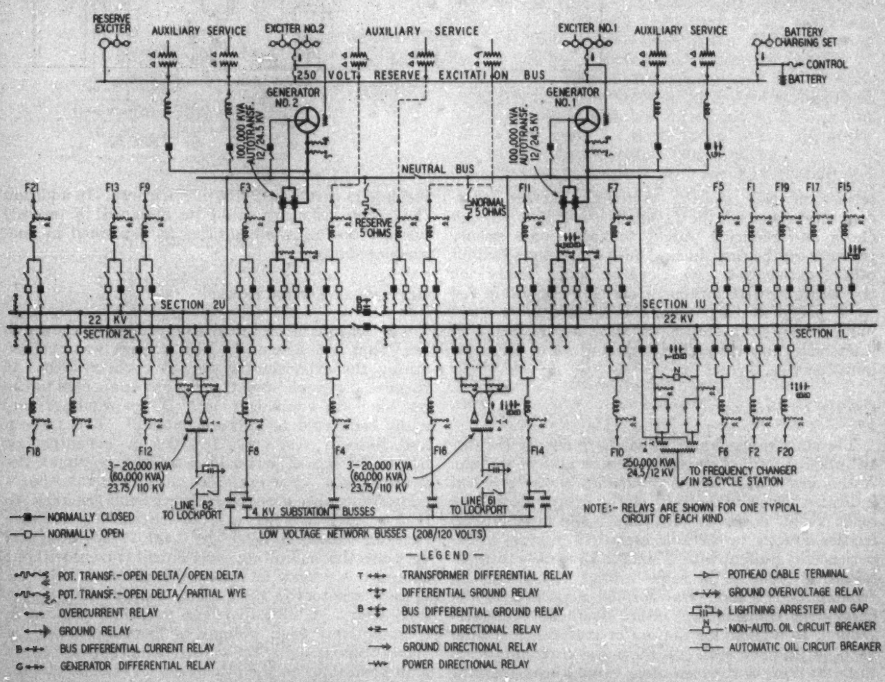


Fig. 9. Single line diagram of main electrical connections

The 4 feeders F4, F8, F14, and F16 illustrate the manner in which the 22 kv busses are tied together through the distribution system. All 22 kv feeders are connected similarly. Connections at the distribution systems are simplified for clarity

maximum requirements under normal operation. This margin was considered necessary to meet unexpected future requirements and to provide safe operation under abnormal conditions. Outgoing and auxiliary feeder breakers have a specified interrupting capacity (OCO plus OCO basis) of 1,000,000 kva, and the generator and transformer bank breakers 1,500,000 kva. The disconnecting switches are stick-operated and are mounted on strong supports inside steel and molded composition compartments; they have flashover voltages (110 kv dry) and creeping distances considerably in excess of ordinary standards. Dry type current transformers of the stud or through type, with suitable ground shields between the primary and secondary windings, are used.

The main busses and generator interconnections consist of rectangular copper bars with each phase divided into 2 parts, each part separately insulated for full voltage, and the 2 parts mounted on common insulated porcelain supports. Interconnections for the remainder of the circuits are insulated similarly. This method of phase protection is absolutely gas tight and need not be completely inclosed in compartments, the only protection required being reasonable isolation between adjacent circuits. The floors are suitably isolated from each other to prevent communication of trouble as are also the aisles on each floor.

Arrangement of Switch Bay

The switch bay (see figure 10) was constructed with flush wall spaces with no projecting columns, and with the bottoms of the ceiling beams all at the same level. This simplified the design and facilitated the work, there being no obstructions to interfere. The switching equipment occupies the first and second floors, and the neutral ground resistor switches, control battery, electric shop, control conduit terminals, etc., were placed on the third floor. It may be noted that the busses are located between, and inclosed by, 2 concrete bearing walls. The circuit breakers are bolted to the floor with their isolating disconnecting switches located directly above them. The door in the front of the disconnecting switch compartment is interlocked with the breaker mechanism. It is apparent from the diagram that 3 breakers, instead of 4, could have been used on the generators and transformer banks. However, 4 breakers simplified the layout and cost less than 3 breakers because of their lower current carrying capacity and, in addition, materially contributed to the flexibility of switching and security of operation. The potential transformers and fuses are housed in metal cells, and the feeder reactors in concrete cells.

An interesting feature is the use of 3-phase lead-covered cables on the 22 kv side of the generator autotransformers and 4-conductor single-phase cables for the line transformers. As may be noted from the wiring diagram the neutral of the line transformers is formed at the yoke end of the 4 conductor cables, which eliminated sheath voltage. These cables terminate in an oil-filled terminal chamber

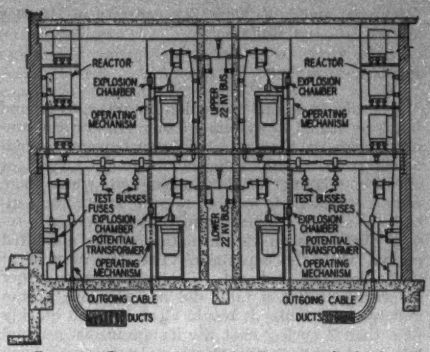


Fig. 10. Cross section of switch bay at 22 kv feeder equipment

equipped with a conservator at the transformer end, and in a similar manner in an oil-filled terminal chamber equipped with a pressure reservoir at the opposite end. The cables are wiped to plain brass sleeves to allow the oil in the terminal chamber to enter or leave the cables freely, thus assuring continuous oil saturation of the cable insulation with but little likelihood of the formation of voids. All remaining 11-kv and 22-kv 3-phase cables used in the station terminate in a similar manner, with the same degree of protection. Where required, the lead sheaths are armored with copper tape to withstand internal pressure which may be caused by a high oil head or by expansion of the oil during a heating cycle.

A forced ventilating system is provided which will cause air to flow from the outside into the electric bay and discharge it into the turbine room in the summer; in the winter it will cause heated air to flow from the turbine room into the bay and discharge it into the cable and piping tunnel under the transformers, where the heated air will prevent freezing of the water piping. The direction of air flow may be changed at will. Accumulation of smoke and gas will be dissipated quickly by the ventilating system.

Connections to Bulk Power System

Huntley station No. 2 is tied into the Niagara-Hudson bulk power system at Lockport, N. Y., through the 60,000 kva transformer banks, which have voltage ratio control, and the 110 kv transmission lines. The bulk power system extends across the State of New York and comprises the generating and transmission systems of the constituent operating companies. Through the bulk power system, interconnection is maintained with the power systems of New England and New York City—in fact, the Hell Gate steam station in New York City usually regulates the frequency of the system.

The bulk power system also is tied into the 25 cycle system through 3 variable-ratio frequency-changer sets, of which there are 2 of 18,000 kw capacity at

Lockport, and 1 of 20,000 kw capacity in Huntley station No. 1 at Buffalo.

Fault Protection

In order to secure protection for phase-to-ground faults on the 22 kv system a 5 ohm resistor was connected between the neutral of the system and ground, which permits only sufficient current to flow for effective relaying. A few years ago, when there were a considerable number of cable faults, the neutral was solidly grounded temporarily in order to reduce the stress on the insulation of the unfaulted phases, with the expectation that the number of faults could be reduced. The results were rather surprising; when a fault did occur in one of the underground cables it would clear itself so quickly (less than 3 cycles) that the instantaneous residual relays did not have time to operate, nor was it known that a fault actually had occurred. In several instances the cable inspectors entered a manhole to find an exposed live 22 kv conductor with fortunately no serious results. After a very short time the neutral again was grounded through the 5 ohm resistor.

In general, percentage differential relays are used in which the load current exerts an opening torque, allowing very sensitive settings. A generator with its autotransformer are protected as a unit; if a relay contacts it will trip the main circuit breakers, field breaker, neutral breaker, and throttle, and also initiate a transfer of the auxiliary motors as explained under heading "Auxiliary Power Equipment." Should mechanical trouble develop on a turbogenerator, the throttle will be tripped manually, which in turn trips the main circuit breakers, but the field breaker will remain closed in order to bring the unit to a quick stop.

A set of differential relays protects each bus section. These will trip all of the circuit breakers connected to the faulted section. On 2 occasions these relays have acted to clear a fault; once when the removal of a protective ground was overlooked; and once when a disconnecting switch was opened under load (before the interlocks were in use), causing a flashover to ground. Each time the relays functioned efficiently with a minimum of damage and without loss of any load or of stability.

Each of the house service transformer banks is equipped with a set of differential relays of the autotransformer type.

The 2 outgoing 110 kv lines with their transformer banks when operating singly are protected by distance impedance relays, in which the voltage drop through the transformer bank is compensated. When operating in parallel, instantaneous current

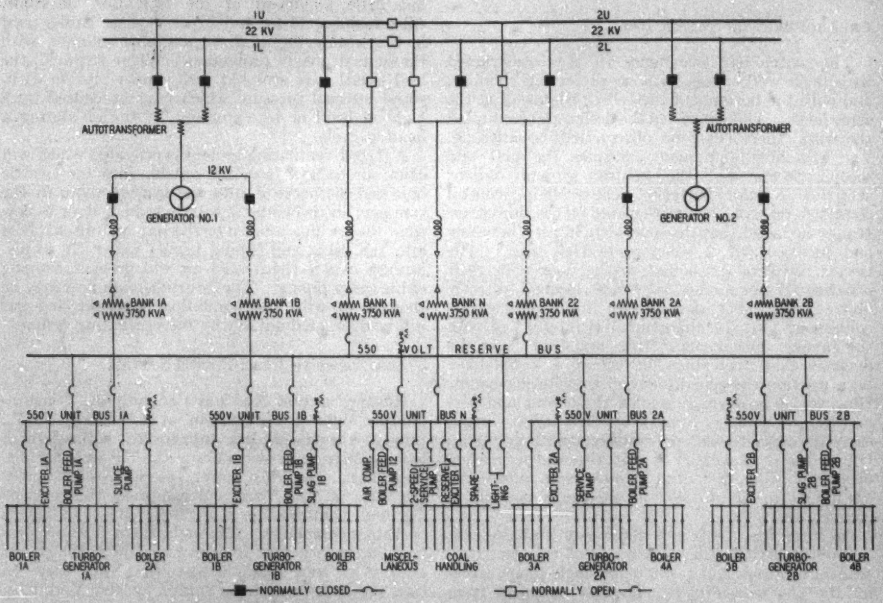


Fig. 11. Single line diagram of electrical connections for auxiliary power

Each group of boiler auxiliaries consists of: induced draft fan, forced draft fan, pulverizing mill, primary air fan, and miscellaneous units. Each group of turbogenerator auxiliaries consists of: a 2-speed circulating-water pump, 2 cooling fans, hot well pump, drip pump, and turbine turning motor. Coal handling auxiliaries consist of: conveyor, drag scraper, tail car, tripper, and miscellaneous units

balance relays select the faulty line. A voltage relay in the neutral of a 110 kv capacitor potential device will trip the line for a phase-to-ground fault. For grounds on the 22 kv windings of the transformers a directional ground relay is used.

Outgoing 22 kv feeder circuits are equipped with inverse-time-delay overcurrent relays for phase-to-phase faults and an instantaneous overcurrent relay for phase-to-ground faults. Inasmuch as the 22 kv feeders all consist of shielded-type 3-conductor lead-covered cables the fault is invariably of the phase-to-ground type, which is cleared instantly and without noticeable effect on the system. The

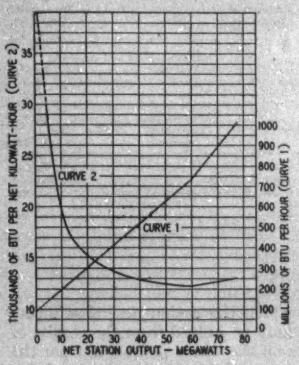


Fig. 12. Energy consumption curves obtained during over-all input-output tests

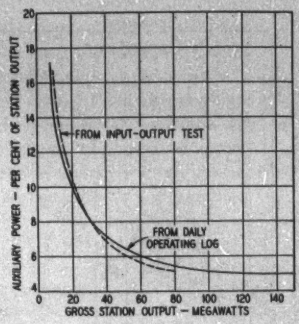
overcurrent phase relays serve principally as back-up protection for faults in the substations.

Auxiliary Power Equipment

Auxiliary power is obtained from the 12 kv terminals of the generators with a reserve supply from the main station busses. Where a station is a part of a large interconnected system with multiple ties to the system, this method of obtaining auxiliary service was considered justifiable in view of its advantages over other schemes, namely, low capital cost, low operating cost, and simplified operation. Figure 11 shows the connections.

The proper voltage for the auxiliary motors is usually a difficult problem to decide. Many elements influence this, among which are, motor sizes, motor and control equipment costs, the connection diagram, and the amount of reserve transformer capacity required. For this station a thorough

Fig. 13. Auxiliary power versus net station output



study showed that a single 550 volt system would have decided advantages over a 440 or 2,200 volt system, or a combination of both, especially in over-all cost, simplicity, and reliability.

Because of the large size of the turbogenerators and boilers, the auxiliaries for each were divided into 2 groups, for example, 2 induced draft fans per boiler, 2 circulating water pumps per turbine, etc., the groups being designated *A* and *B*. The miscellaneous motors make up the *N* group. There are 5 major groups of motors, namely, 1*A*, 1*B*, 2*A*, 2*B*, and *N*, each connected to a unit bus similarly named. A separate transformer supplies each of these busses, 2 of which are connected to the 12 kv terminals of generator 1, 2 to the 12 kv terminals of generator 2, and 1 to the 22 kv bus. Two additional transformers, each connected to a separate 22 kv bus, supply a 550 volt reserve bus to which any of the unit busses may be transferred. The control is arranged so that if the voltage on an *A* or *B* bus should fall to a value 50 per cent or more below the voltage of the reserve bus, an automatic transfer will be initiated after a period of 2 seconds; in this transfer the normal supply circuit breaker will

Table II—Over-All Operating Performance of Huntley Station No. 2

		Turbines						Boilers				
Year	Months	Net Megawatt-Hours	1,000 Pounds of Coal Burned	Avg Net Generation, Megawatts	Net Station Capacity Factor	Number of Starts	Net Turbine Water Rate	Number of Starts	Banked Hours	Active Hours	Evaporation, Pounds of Steam per Pound of Coal	Btu per Net Kilowatt-Hour
1930	2½	44,505	48,389	23.8	29.7		11.09		508	1,857	9.18	14,971
1931	12	94,934	136,302	13.2	8.3	114	11.80	2,578	12,215	8,890	8.52	18,721
1932	12	80,069	130,291	9.1	5.7	71	13.00	2,922	12,657	12,639	8.50	19,973
1933	1st 5	29,976	50,031	8.2	5.1	6	13.38	1,328	6,181	4,698	9.12	21,130
1933	Last 7	330,890	346,708	64.5	40.3	97	10.65	1,442	5,369	13,966	10.77	13,812
1933	12	360,866	396,739	41.2	25.8	103	10.88	2,770	11,550	18,664	10.31	14,467
1934	12	314,667	345,527	35.9	22.5	125	10.88	2,901	12,998	16,282	10.12	14,470

be tripped and the breaker to the reserve bus closed, thus retaining the auxiliaries in service and thereby maintaining the same rate of boiler steaming capacity.

A 550 volt system for the auxiliary motors permitted the use of simple and rugged equipment of

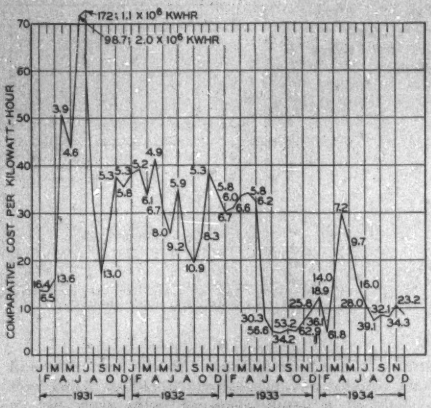


Fig. 14. Total monthly costs, including maintenance and fixed charges, for the first 4 years of operation of Huntley station No. 2. Figures at each point designate the monthly output in millions of killowatt-hours

the 600 volt class. Air circuit breakers with silver faced main contacts and phase barriers were provided for the transformers and for all the motors or groups of motors supplied directly from the main 550 volt busses. For the various motors in the subgroups special latched-in contactors were used, enclosed in steel cubicles and located near the load centers. One of the criterions in the layout of the auxiliary equipment was to locate the transformers and busses as close to the load as possible to avoid long feeders. It may be noted that the main transformers are placed directly below the 550 volt switch rooms and that the latter are located centrally within the cross section of the station.

Each motor was selected for its specific duty, fully enclosed or drip proof as required, with special insulation, etc. Motors on the air heater floor are cooled by drawing cool air from the roof and discharging it into the room.

Fault protection of the auxiliary motors is of the simplest possible type. Each 550 volt feeder was equipped with overcurrent instantaneous relays which operate on short-circuit current only. None of the essential motors have overload or thermal protection. No protection of any kind is provided for the individual motors in the boiler or generator subgroups; a fault in one of these motors will cause the opening of the main circuit breaker supplying the group. If a fault should occur on a 550 volt unit bus, overcurrent relays will trip the normal supply breaker and lockout relays will prevent an automatic transfer to the reserve bus. Ground detectors are provided for the 550 volt busses, which will indicate a ground and usually permit its removal before the development of more serious trouble.

Construction Costs

Construction costs of the 160,000 kw Huntley station No. 2 were divided as follows:

Item	Per Cent of Total Cost	Item	Per Cent of Total Cost
Land	1.4	Turbogenerator and condenser equipment	17.7
Ground improvements	1.3	Boiler house equipment	19.3
Intake and discharge tunnels	*4.4	Piping	3.9
Main buildings with their foundations	15.9	House service equipment	4.6
Coal handling equipment	†12.1	Miscellaneous equipment	0.8
22 and 110 kv electric feeders	8.4	Construction expense and overheads	10.2

* Intake tunnels were designed to handle the requirements of a plant with an ultimate installed capacity of 1,000,000 kw; also the figure includes the cost of extending the discharge tunnel of the 305,000 kw adjacent plant to the downstream side of the new intake.

† This figure includes the total cost of a car dumper, boat unloading tower, and necessary conveyors, which serve both plants.

Operating Results

The degree to which the design described meets the requirements may be judged from the results of input-output tests on the whole plant and from the records of 4 years' operation. During August 1932, an over-all plant test was made using 2 boilers and one turbine. The coal input was measured by the automatic scales located above the coal feeders,

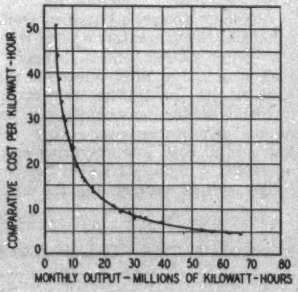


Fig. 15. Data of figure 14 replotted in different form

and the net electric output of the plant was read on station meters. These devices were carefully calibrated before the test. Raw coal samples were obtained in approved manner and carefully analyzed. Each of the 5, 10, 20, and 30 megawatt loads was held constant for 24 hours; the 40 megawatt load for 15 hours; and the 60 and 80 megawatt loads for 9 hours each. The results of this test are

shown in the curves of figure 12. No-load losses for one turbine and 2 boilers including station lighting and miscellaneous power amounted to 91,000,000 Btu total furnace input per hour. The auxiliary power required is shown in figure 13. It may be of interest to know that the power required by the pulverizers with full load on the station is $^1/_2$ of 1 per cent of the generated power (10 per cent of the total auxiliary power).

An idea of the wide range of loading imposed upon the plant can be obtained from figure 6, which shows typical daily loads, and from table I, which shows the turbine loading for the 4 year period. Table II shows how the plant has performed under these severe operating conditions. The year 1932, with a capacity factor of 5.7 per cent was the low output year for the plant. For the first 5 months of 1933 the average station output was 8.2 megawatts with a net heat rate of 21,130 Btu in contrast with the last 7 months of the same year, in which the average was 64.5 megawatts and the net heat rate 13,812 Btu.

The total monthly costs per kilowatt-hour (operation, maintenance, and fixed charges) for the entire period of operation to January 1, 1935, is shown in log form in figure 14. Figure 15 shows the data of figure 14 replotted using monthly output for one of the co-ordinates. While this station was designed for a relatively low capacity factor (25 per cent or less) the results indicate that the economy is well in line with plants having an even higher steam pressure.

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Photoelectric Control of Resistance Type Metal Heaters

Manually operated resistance type metal heaters, which heat the metal by passing current directly through it, have been in use for several years. Automatic machines of this type have now become practical due to the development of photoelectric temperature control. Results with photoelectric control are shown to be highly satisfactory.

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RESISTANCE type electric heaters, in which the material under treatment is heated directly by the electric current being passed through it, are coming into prominence for purposes of heating metal bars, rods, rivets, and other similar parts to a heat treating or forging temperature. The proper control of these heaters so that power is cut off and the part ejected at the proper temperature is important.

A resistance type heater consists of a power transformer which steps the line voltage down to a few volts, conducting electrodes for gripping the material and conducting the current to it, and mechanism for operating these electrodes. The control is very simple for a manually operated machine, but for fully automatic machines the use of more elaborate and accurate equipment may be necessary.

A photoelectric controller which has been developed for resistance type heaters is described in this paper. Radiation from the material being heated operates a photoelectric tube which, when the proper temperature has been reached, operates through an amplifying tube and other devices to shut off the current, eject the material from the heater, and start another cycle of operation on a new piece of material.

Features of the apparatus described in this paper are as follows:

1. The operation of the automatic heating equipment described herein proves that the photoelectric method of temperature control is entirely satisfactory.

2. Increased production above that possible with manually operated heaters may be expected. Consistency of temperature control including the normal variations in tube characteristics has been proved.

A paper recommended for publication by the A.I.E.E. committee on electrochemistry and electrometallurgy, and scheduled for discussion at the A.I.E.E. summer convention, Ithaca, N. Y., June 24–28, 1935. Manuscript submitted March 11, 1935; released for publication Apr. 2, 1935.

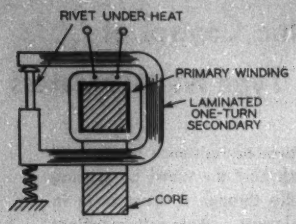
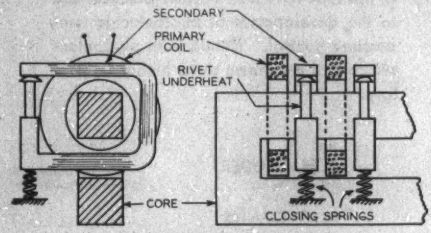


Fig. 1 (left). An early design of rivet heater

Fig. 2 (below). A present day rivet heater



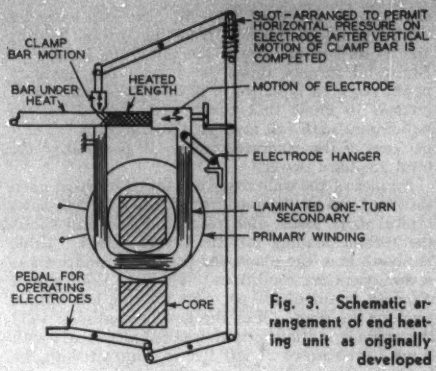


Fig. 3. Schematic arrangement of end heating unit as originally developed

Under average operating conditions the trip point may be expected to remain within 50 degrees Fahrenheit after having been set by use of a pyrometer as a standard.

3. It is obvious that better temperature regulation is possible than by manual control, for the human element is eliminated. Accordingly, less rejections caused by improper heating conditions may be expected.

4. Automatic operation of equipment reduces material handling time, thereby resulting in a proportionate production increase and lowered cost through reduction of labor charges.

5. The photoelectric method of control may also be used for control of other methods of heating such as furnaces and inductive heaters.

Development of Various Types of Heaters

The electrical heating of metals by passing current through the part to be heated is not a new process, but the development of satisfactory, and, at the same time, rugged equipment, has been tedious and difficult. The rivet heater brought out in 1913 by a manufacturer with which one of the authors is connected, has now been developed to the present fully automatic, temperature controlled heater for use in forging and heat-treating.

The original heater consisted of a transformer, having a low-voltage high-current secondary winding of one turn placed directly over the primary winding as shown in figure 1. The metal to be heated was inserted in the secondary circuit and held in place by spring pressure on the electrodes. This type of heater has been materially improved upon. The succeeding design makes use of several pancake type primary windings, while the one-turn secondaries are sandwiched between the primary coils, as shown in figure 2. This is the type of design in general use today in fabricating shops and for bridge construction where rivets are to be heated.

With the development and sale of the rivet heater, came that knowledge of the art which led to its application in other fields, principally in the heating of materials for forging, bending, heat-treating, etc. To meet the demands thus imposed, many heaters of different types were constructed, each meeting a definite requirement.

For example, heaters have been constructed for the end heating of the various length blanks used in cutlery manufacture, for the end heating of wheel spoke blanks and for upsetting bolt heads. Such heaters usually have embodied the side to end method, figure 3, or the 2 path secondary principle, figure 4. The heating current either enters the bar at a point or points on its perimeter and leaves at the bar end, or enters and leaves at different points on the perimeter only.

Heaters have been constructed for the forging of

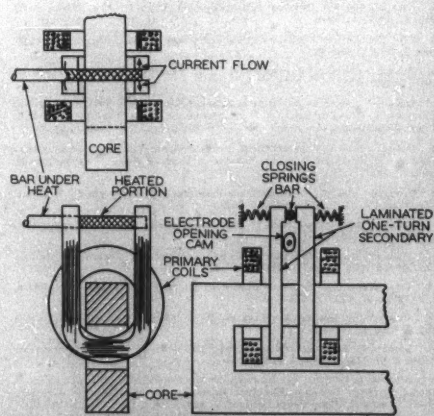


Fig. 4. Arrangement of principal parts of a 2 path heater representing the first design from which the present fully automatic machine has evolved

automobile valves, as well as the heat-treatment of valve stems and other intricate parts. However, in the heating of such stock—and it should be recognized that a satisfactory end heat is difficult to obtain—it is usually necessary to avoid the marring of the blank sidewalls. Particularly is this true on automotive and bolt blank stock. Marring or pitting is eliminated by the use of limit switches, mechanically operated, and actuating the main contactor in such manner as to assure no power being supplied to the transformer until the material has been securely gripped between the electrodes; and further, that power be cut off previous to any attempt to break contact between bar and electrode.

However, the use of the electric heater in the field of heat-treating and in the forging of alloy steels demands a definite control of temperature. This can be accomplished best by shutting off the current to the primary of the transformer at the instant that the proper temperature is reached. Various schemes proposed heretofore are:

1. Magnifying leverages operated by expansion of the bar under heat.
2. A bimetal strip located close to the side of the bar, which would bend and close contacts due to absorption of radiated heat.
3. A time delay relay connected to apply power to the transformer for a measured length of time only. This is unsatisfactory due to varying time, voltage, and electrode-bar contact resistance.

Photoelectric Scheme of Control

A fourth method, and the one to be described in this paper involves the use of a photoelectric controller which has been developed. The photoelectric tube, which is the sensitive element, is mounted so that the energy radiated from the bar is focused on it. This development has been very important in extending the field of heater application by making a fully automatic or semiautomatic heater practical for the first time.

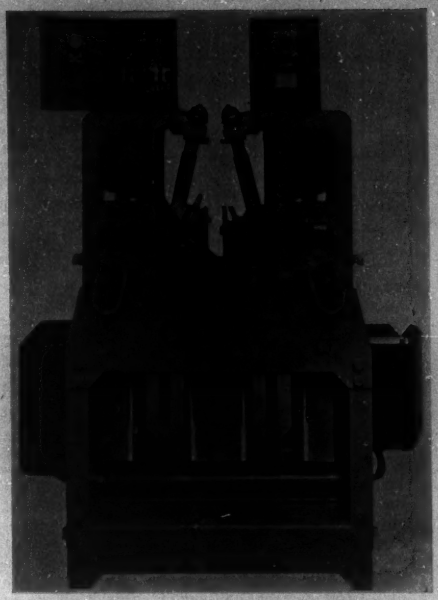


Fig. 6. A 2 unit automatic heater with photoelectric control

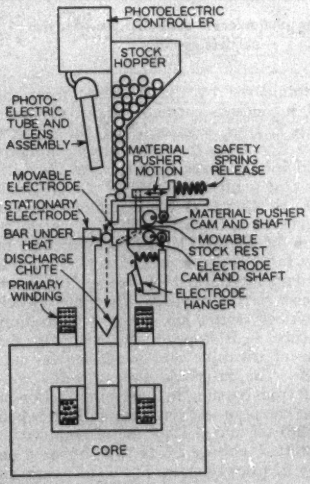


Fig. 5. Schematic arrangement of heater arranged for full automatic operation

A general idea of the principles involved in the automatic type of heater is obtainable from figures 5 and 6. The mechanical operations are rather simple. Material to be heated is loaded into a stock hopper, from which it is led vertically downward to a shelf, from whence, as needed, it is pushed laterally one piece at a time and falls to a movable stock rest between the open electrodes, which are then closed, and power is applied. Upon heating to the proper temperature, as determined by the setting of the photoelectric control, the power is cut off the transformer, the electrodes are opened automatically, the hot piece discharged, and another cold blank drops into place, and the cycle of operation is repeated.

Description and Characteristics of Equipment

The photoelectric tube is an electronic tube which conducts current in proportion to the quantity (lumens) of light projected on its cathode.

If the temperature of a body is raised, the total energy radiated to other bodies increases as a fourth power function of the absolute temperature. The spectral distribution of the energy radiated depends upon the temperature of the body. Much more energy of short wave lengths is radiated as the temperature of the body is increased. A continuous in-

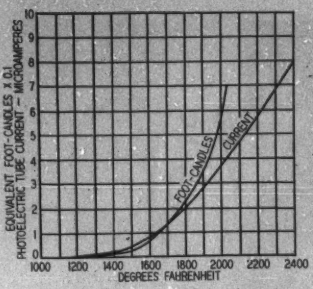
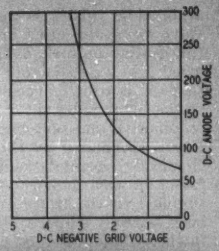


Fig. 7. Curves of test data showing photoelectric tube current for various temperatures and the footcandles from a standard lamp at 2,870 degrees Kelvin required to produce that current

All tests made on nichrome bar with an arbitrary optical system and an average photoelectric tube, all representative of the design of photoelectric controller in figure 9. Other metals less similar to a black body, such as aluminum, produce less response

Fig. 8. The grid control characteristic of the grid-controlled gas-filled tube used



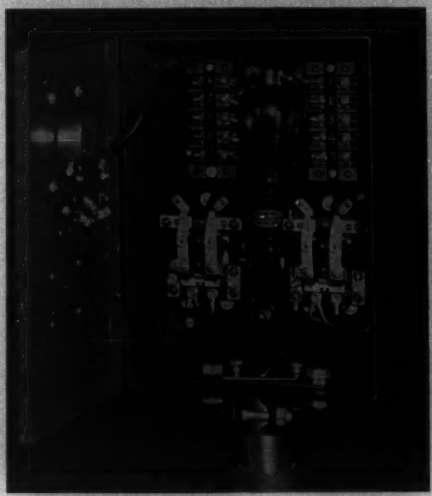


Fig. 9. The photoelectric controller used for temperature control

crease in temperature results in radiation of red light visible to the eye at a temperature of about 1,200 to 1,300 degrees Fahrenheit.

Commercial photoelectric tubes have a color sensitivity curve such that the first appreciable photoelectric current due to radiated energy received from a heated body occurs at a body temperature of about 1,150 degrees Fahrenheit. As the temperature of the body is increased further, the equivalent light on the photoelectric tube cathode increases rapidly as a power function of the temperature rise above 1,150 degrees Fahrenheit; this is shown in figure 7. The same figure shows the photoelectric tube current in microamperes. This curve was taken using a photoelectric tube of average sensitivity connected in series with a 10 megohm resistor and with a supply voltage of 90 volts direct current. These conditions are identical with those in the photoelectric control equipment.

Since the photoelectric current is not sufficient to operate a magnetic relay, an electronic tube of the grid-controlled gas or mercury vapor filled type is connected to function as a sensitive relay. When the proper temperature is reached, the voltage drop over the resistor in series with the photoelectric tube causes the grid-controlled gas-filled tube to conduct and energize the control contactors.

The grid-controlled gas-filled tube has a grid control characteristic as shown in figure 8. This characteristic shows the grid voltage which will cause the tube to start and conduct current for various values of anode-cathode voltage. It is seen from the circuit of the photoelectric controller, figure 10, that the anode voltage E_a is alternating current. The critical grid voltage which will permit the grid controlled tube to start at various times during the half cycle of anode voltage when the anode is positive with respect to the cathode is shown in figure 11, curve e_c. When the photoelectric tube T_2 is dark, there is no voltage drop over resistors R_1 and R_2, and the voltage e_g between grid and cathode consists of the adjustable d-c voltage E_b plus the phase shifted voltage E_{ps}. The voltage divider P is so adjusted that the total grid voltage curve e_g does not intersect the critical bias curve e_c. When the photoelectric tube T_2 is illuminated by the radiation from the heating metal, it conducts current and thus produces a voltage drop E_r over resistor R_1 of the polarity shown. When E_r reaches the value shown in figure 11, the net grid voltage curve E_{ps} intersects the critical bias curve e_c at point C and causes the grid-controlled tube T_1 to start. T_1 then conducts current during the remainder of the half cycle as shown in the shaded portion of figure 11. The conduction of current by the tube T_1 energizes contactors 1 and 2 which close and are interlocked by contacts 1 through the "reset" push button PB_1 and the limit switch LS_1. The interlock circuit has low enough voltage drop so that tube T_1 is stopped, thus reducing the operating time of the tube and increasing its stability and life. The interlock also prevents contactors 1 and 2 from opening because of reduction of illumination on the photoelectric tube cathode when the power is shut off and the hot metal removed.

The phase shifted voltage E_{ps} is superimposed on the d-c voltage E_b to cause tube T_1 to start early in

the positive half cycle of anode voltage. Without E_{ps}, tube T_1 would start at the middle of the half cycle as E_s would intersect e_s at its midpoint due to increase of E_s. This is not desirable as maximum current will not flow in the coils of contactors 1 and 2 until the photoelectric tube T_1 is illuminated enough more to shift the point of intersection of E_{ps} with E_s to point C.

Sequence of Operation

The complete sequence of operation of one unit of the 2 unit automatic heater, figures 5 and 6, is readily visualized by reference to figure 10. Let it be assumed that the machine is being started with the electrodes closed but with no material between them, and that contactors 1 and 2 are open. The bar pusher is under the hopper spout and a bar is in position in the spout. When the push button PB_2 is depressed, contactors 1 and 2 are closed, thus energizing the motor through contacts 2. The motor is directly coupled to the electrode cam shaft. As this shaft starts to revolve, the electrodes are forced open against spring pressure and at the same time the bar feed cams, mounted on a shaft geared to the electrode cam shaft, drop off their high points permitting springs to force the pusher bar forward. The bar stock being pushed out reaches the edge of the shelf at the same instant that the electrodes reach their fully open position. When the bar is pushed past the edge, it falls between the electrodes. As the pusher bar moves forward, a movable stock rest attached to the pusher bar moves forward with it, but slightly in advance, so as to be in position to catch the bar.

As the shafts continue to revolve, the electrode cams drop off their high points, permitting springs to close the electrodes and grip the bar. At the same time, the bar feed cams return the movable rest and the bar pusher to their original positions, thus leaving the way clear for the bar to drop to the discharge chute when released by the electrodes.

As soon as the electrodes have gripped the bar and the movable rest is under the shelf, the motor switch cam which is mounted on the electrode shaft breaks the contact in a normally closed limit switch *LS-1*. The opening of *LS-1* de-energizes contactors 1 and 2 thus stopping the motor and energizing the transformer by operation of contactor 3. The motor is stopped almost instantaneously by a magnetic brake. A 5 or 6 degree drift of the motor permits *LS-1* to reclose.

The bar now heats to a predetermined temperature which will cause the photoelectric controller to operate as previously described, energizing contactors 1 and 2. Their closure opens contactor 3, de-energizes the transformer and closes the motor circuit, thus starting a new cycle of operation.

As the electrodes release the bars, the limit switch *LS-2* is closed by a cam on the electrode shaft. This energizes the kicker solenoid which forces a plunger

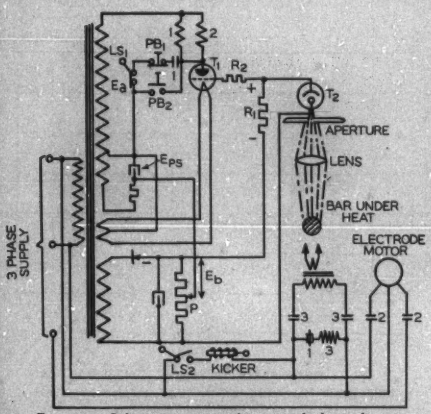


Fig. 10. Schematic circuit diagram of photoelectric controller and heater control

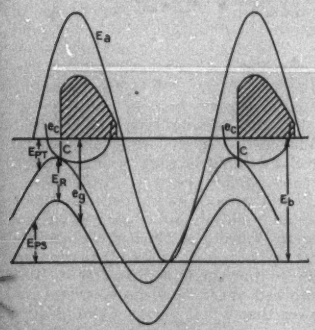


Fig. 11. Voltage relations in circuit of figure 10

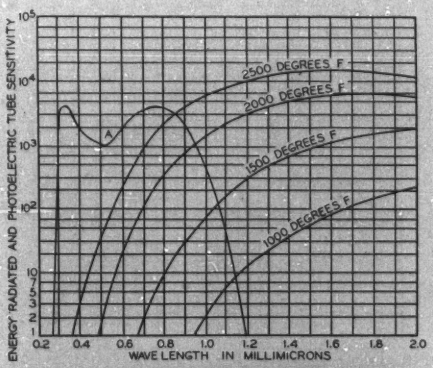


Fig. 12. Curves showing relative energy radiated by a hot body at various temperatures and wave lengths. The color response curve A of the photoelectric tube is also shown. All curves are to an arbitrary scale of ordinates

against the bar at the moment of its release. This prevents any trouble which might be caused by occasional sticking of the bar to the electrodes.

Range of Operating Temperature

There is practically no upper limit of operating temperature as this is readily increased by masking a greater portion of the light from the photoelectric tube. The unit shown in figure 9 will operate reliably at temperatures as low as 1,500 degrees Fahrenheit and has an approximate range of adjustment as shown in figure 14 when no mask or aperture is used.

The minimum operating temperature is established by the lack of sensitivity of commercial photoelectric tubes to the radiated energy at long wave lengths beyond 1.2 millimicrons. (One millimicron represents a wave length of one-millionth of one meter.) The color characteristic of an average photoelectric tube of the caesium-oxide type is shown in curve *A* of figure 12. The spectral distribution of energy radiated from an ideal black body at various temperatures is given in the same figure to show how rapidly the energy radiated at wave lengths to which the photoelectric tube is responsive is reduced as the temperature of the body is decreased. The parts of the curves which overlap represent the sensitive range of wave lengths. The product of the ordinates of the photoelectric color response curve and the spectral energy curve at a given wave length is proportional to the photoelectric sensitivity for that wave length. The products obtained at various wave lengths form a spectral luminosity curve for the photoelectric tube as shown in figure 13 for various temperatures. The product of the area under the spectral luminosity curve and an empirical constant gives the photoelectric current for a given temperature, photoelectric tube, and optical system.

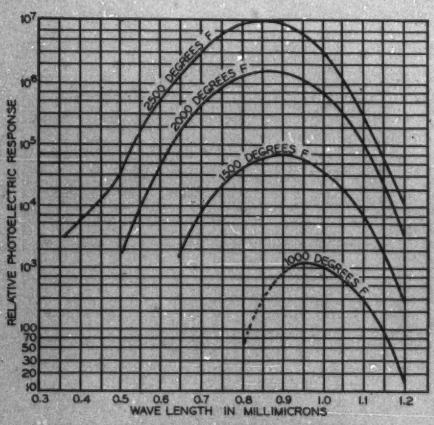


Fig. 13. Relative response of a caesium-oxide photoelectric tube at various temperatures and wave lengths. Calculated from data in figure 12

Considerable improvement in the response of photoelectric tubes to light of wave lengths up to 1.2 millimicron has been made. However, the threshold wave length of 1.2 millimicron has not been extended appreciably in any commercial photoelectric tube. Unless the threshold wave length can be extended into the long wave length region beyond 1.2 millimicron, the lower limit of operating temperature for any photoelectric device will be between 1,150 and 1,500 degrees Fahrenheit. The practical lower operating limit depends entirely upon the color sensitivity of the photoelectric tube used and the permissible amplification. Sufficient safety factor is included in the rating to insure operation with tubes having limiting color and sensitivity characteristics.

Other light sensitive devices such as the selenium cell and the "thalofide" cell have been investigated but do not appear to be as satisfactory as commercial caesium oxide photoelectric tubes.

Indicating elements other than the photoelectric tube have been considered, especially thermocouples mounted so that the radiation is focused on them by a lens. The thermocouple has the advantage of being responsive to the total energy received, and is not selective. The disadvantages of the thermocouple are numerous and appear to eliminate it from application at the present time. The thermocouple equipment is more expensive than the photoelectric control within the range of sensitivity of the latter. The thermocouple has considerable time lag, causing inaccurate control for rapid heating of small parts. At low temperatures outside the range of the photoelectric system, the thermocouple apparatus is not simple to design and build because of the low energy output from the thermocouple which must operate a contact making instrument. If a suitable system of thermocouple, contact making instrument, and control can be worked out, it may prove useful for temperatures lower than 1,500 degrees Fahrenheit.

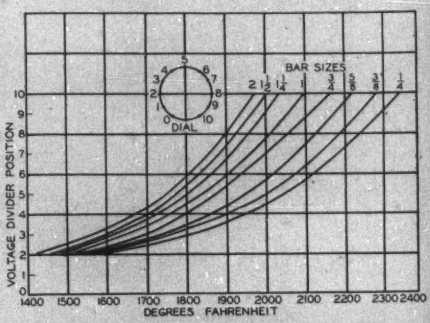


Fig. 14. Typical curves of voltage divider position versus temperature for several sizes of stainless steel round bar

The Sparkless Sphere Gap Voltmeter

Sphere gaps may be used for measuring very high voltages by holding them at a separation greater than spark-over distance, and measuring the force between them. The voltage may then be calculated easily and accurately from well known electrostatic principles. Among the advantages of this type of measurement over the conventional spark-over methods are: no corrections are necessary for air temperature, humidity, and pressure; effective voltage values are given; measurements are not erratic; and numerous difficulties in taking measurements are avoided.

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THE sphere gap may be used as a Kelvin electrostatic type of voltmeter rather than a spark gap voltmeter, if the spheres are mounted so that the forces between them, due to applied differences of potentials, can be measured; and the authors of this paper believe the data presented herein indicate greater convenience and accuracy for sphere gaps thus used than can be obtained with gaps used in the conventional manner. The reasons for this statement are:

1. Accurate methods are available for calculating the relation between potential differences of 2 isolated spheres and the forces due to these potential differences when sphere dimensions, spacing, and the dielectric constant of their ambient medium are known.

2. Since the dielectric constant of air is not appreciably affected by temperature, air density, or humidity, no corrections for these factors are necessary.

3. The tests showed complete freedom from erratic readings so noticeable in the spark gap voltmeter.

4. Test planes of large size placed as near as possible to the spheres without causing sparking from spheres to plane had little influence on the readings.

5. The sensitivity of equipment used is such that a change in force of $^1/_3$ gram or less can be detected easily, and forces from 100 to 400 grams were available in the tests. This degree of sensitivity is such that the instant of contact of the spheres at zero spacing can be noted by a movement of the free sphere more readily than by noting the electric contact or any other means known.

Apparatus Used

The apparatus used in the experiments is shown in figures 1, 2, and 3. The only large spheres available at California Institute of Technology for making these tests were a pair of 100 centimeter cast aluminum spheres made at the same time and as exact duplicates of the pair used by Carroll and Cozzens[1] in their tests; and these spheres show, on spark-over tests, the same erratic performance as reported by them. The right-hand sphere is supported by a rigid insulating frame suspended from the roof structure of the laboratory and is mounted in such a way as to provide for adjustment of the sphere gap for spacings from 0 to 150 centimeters. Changes in the sphere gap setting are made by means of a motor-driven mechanical system, the motor being placed on the floor and attached to, but insulated from, the sphere driving mechanism by a long rope belt. The left-

Fig. 1. A view of the sphere gap and other principal pieces of apparatus comprising the sparkless sphere gap voltmeter. The sphere in the foreground is the hot sphere. The measuring apparatus, shown in more detail in figure 3, may be seen at the far end of the shaft of the grounded sphere

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The authors acknowledge the assistance of Gilbert D. McCann, Louis T. Rader, Jack M. Roehm, and others working in the high voltage laboratory at the California Institute of Technology.

1. For all numbered references see list at end of paper.

Fig. 2. Another view of the apparatus, showing the relation of the sphere gap to the other equipment in the laboratory, and showing the large clearance available around the gap. The grounded sphere is in the foreground of this view. Note the long V suspension ropes

hand or free sphere is suspended by 4 ropes arranged in 2 pairs, each pair forming a letter V, the apex of which is attached to the shaft supporting the free sphere. This suspension with the upper ends of the V attached to the roof structure provides horizontal force components which prevent lateral motion of the sphere and at the same time allows very free motion along the axis through the center of the 2 spheres. In the tests made, this free sphere was grounded by very flexible connections from its supporting shaft to ground. Mounted on this supporting shaft near the end away from the sphere, is a fine wire which serves as a pointer, any motion of which may be observed through a cathetometer telescope. Also at this end of the shaft, there is attached a cord which passes over a bicycle wheel used as a pulley and supports a weight pan on which weights may be placed to balance the pull between the spheres. With this arrangement the natural damping was sufficient to prevent oscillations.

A water tube resistance of about 2 megohms, made of $^3/_4$ inch garden hose through which tap water is run for cooling, is connected in the circuit between the transformers and the insulated sphere to prevent burning of the spheres when the gap flashes over. This resistance is kept insulated from ground by having the flowing water fall into a funnel at the top of the hose and from the outlet into a tank on the floor. The hose is protected from corona burns where necessary by pie tins used as disk shields spaced about 18 inches apart.

Taking Test Readings

In the work to date, readings of voltage have been made by setting the sphere gap just above spark-over distance for each voltage measured and enough weight put on the pan to balance the pull on the spheres and keep the free sphere from moving, as noted by the cross hair. With voltage held constant by means of a voltmeter in the transformer tertiary "volt" coil, the sphere gap distance was then decreased until the gap flashed over and the length of gap at the time of flashover noted. The potential difference for this spacing, as indicated by use of the A.I.E.E. sphere gap curve, may then be compared with the voltage calculated by the equation

$$V = 9{,}405\sqrt{F/S}$$

where F is the weight in grams on the pan, and S is the spacing factor shown in figure 8. Results of these measurements are shown in figure 4, typical data for which are given in table I.

V in the above equation is the effective value of voltage; hence, to compare it with the A.I.E.E. sphere gap curve, the wave form must be known. No difficulty was encountered at any time in duplicating readings showing the relation between the force readings as determined by the weights on the pan and the voltmeter readings as obtained at the "volt" coil; and the sensitivity and precision of the force measurements was found to be much better than the degree of accuracy obtainable in reading the voltmeter and setting the voltage control regulator. Figure 5 shows two 2 wave forms, the lower, the input volt wave to the testing transformer, and the upper one, the output voltage wave. The output wave was recorded by using a water tube resistance of about 5 megohms in series with an oscillograph; one end of the resistance being connected to the supporting shaft of the ungrounded sphere, and the other end connected through the

Table I—Typical Test Data for Voltage Measurement With One-Meter Spheres

Temperature "T" = 13 degrees centigrade
Barometric Pressure "b" = 747 mm of mercury

$$\delta = \frac{0.392\ b}{273 + T} = 1.023$$

Reading Number	Gap Setting for Force Measurement	Force in Grams	Tertiary Voltmeter Reading	Spark-Over Distance	Spark-Over Distance Corrected	S	Calculated Voltage*
2	35 cm	346.1	150	31.1 cm	32.1 cm	0.11082	526,000
3	40 cm	376.6	170	36.6 cm	37.9 cm	0.09174	603,000
5	50 cm	354.7	190.5	43.8 cm	45.4 cm	0.06592	690,000
7	55 cm	362.5	202	51.7 cm	53.7 cm	0.05693	750,000
10	65 cm	338.9	220	62.7 cm	65.4 cm	0.04363	829,000
13	70 cm	309.1	224	65.8 cm	68.4 cm	0.03863	840,000

* Calculated by equation: $V = 9{,}405\sqrt{F/S}$

oscillograph element to ground. An analysis of the output wave, using 50 ordinates, shows its root mean square value to be 99.25 per cent that of a true sine wave having the same crest value. Figure 5 shows the wave form is practically a sine wave.

Relation of Force to Voltage

The use of inverted images for calculating the force between 2 spheres may perhaps be more readily understood by considering the case for a point charge in the presence of a grounded conducting sphere isolated in space.[2,3,5]

When no other body is present, the potential at any point a distance r from the point charge q is $V = q/r$ which equation satisfies the one boundary condition that the potential be zero at an infinite distance from the charge. When the grounded sphere is introduced, the equation for potential at any point in space must satisfy the additional condition that the potential is zero at every point on the sphere. Simple geometry provides the equation for V which will satisfy these conditions.

In figure 6, o is the center of a sphere of radius a; charge q is a distance f from o; p' is a point on the line op at a distance d from o; s is any point on the surface of the sphere. From the figure,

$$r = \sqrt{a^2 + f^2 - 2af\cos\theta}$$

and

$$r' = \sqrt{a^2 + d^2 - 2ad\cos\theta}$$

If d is made equal to a^2/f:

$$r' = \sqrt{a^2 + \frac{a^4}{f^2} - 2\frac{a^2}{f}\cos\theta}$$

$$= \frac{a}{f}\sqrt{a^2 + f^2 - 2af\cos\theta}$$

and

$$\frac{r'}{r} = \frac{a}{f} \quad \text{or} \quad \frac{1}{r} = \frac{a}{f}\cdot\frac{1}{r'}$$

With a charge q at point p and another charge $q' = -\frac{a}{f}\cdot q$ at point p', the expression for potential at any point in space a distance r from p and a distance r' from p' would satisfy the condition that the potential be zero on the surface of the sphere; since

$$V = \frac{q}{r} + \frac{q'}{r'} = q\left[\frac{1}{r} - \frac{a}{f}\cdot\frac{1}{r'}\right]$$

and

$$\frac{1}{r} = \frac{a}{f}\cdot\frac{1}{r'}$$

everywhere on the sphere.

Point p' is the inverted image point of p and the above expression for potential completely defines the field outside the sphere. The field outside a grounded sphere due to an adjacent point charge is the same as the field caused by the original point charge and its image point charge. The image charge is always $(-a/f)$ times the original charge and is located a distance a^2/f from the center of the sphere.

This analysis can be extended to show the field about a sphere A at a potential V in the presence of another sphere B at ground potential. The field outside an isolated sphere A at a potential V is equal to that due to a charge $q_1 = aV$ at the center of the sphere, where a is the radius which for a sphere is equal to its capacitance. If, as in figure 7, another sphere B, of the same radius and grounded, is brought into the field with its center a distance c from the center of A, the field will be distorted. But, as has been shown, a charge $q_2 = -\frac{a}{c}q_1$ at a distance $d_2 = \frac{a^2}{c}$ from the center of the grounded sphere B will, together with the original charge q_1 in the equation, give zero potential over the surface of sphere B. This new expression, however, no longer satisfies the condition that the voltage be equal to V over the surface of sphere A and it is necessary to cancel the effect on sphere A of the added charge q_2 by placing its image charge q_3 at a distance d_3 from the sphere center. If q_3 is the inverted image of q_2, that is, if $q_3 = -\frac{a}{c-d_2}q_2$ and $d_3 = \frac{a^2}{c-d_2}$ the resulting potential on sphere A due to q_2 and q_3 will be zero and the sphere potential will be the desired value V due to q_1 only. To keep B at zero potential under the influence of q_1, q_2, and q_3, this new charge q_3 must be imaged by a charge q_4 in B at a distance $d_4 = \frac{a^2}{c-d_3}$

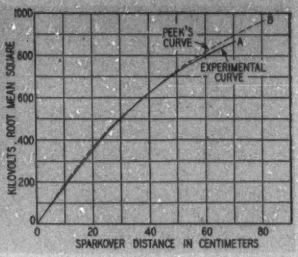


Fig. 4. Relation between sparkover voltage (effective) and sphere gap setting at sparkover distances

Curve A from force measurement data
Curve B from Peek's values for 100 centimeter spheres

Fig. 3. A closeup view of the measuring apparatus

Fig. 5. Oscillogram of voltage, showing wave form

The upper curve shows the form of the voltage applied to the sphere gap

The lower curve shows the form of the voltage applied to the primary of the transformer

from the center of B. The value of q_4 is $-\dfrac{a}{c-d_3}\,q_3$ to satisfy boundary conditions. Thus a double series of images is set up, all those in sphere A having the same sign and all those in sphere B having the opposite sign to the original charge q_1.

In general $q_n = -\dfrac{a}{c-d_{n-1}}\,q_{n-1}$ and $d_n = \dfrac{a^2}{c-d_{n-1}}$

The total force on sphere B is then the sum of the attractions on each charge in B due to every charge

Table II—Calculated Images

Radius "a" = 50 centimeters Spacing = 30 centimeters

Sphere A (Potential V)	Sphere B (Potential Zero)
$q_1 = Va \ldots d_1 = 0$ cm	$q_2 = -0.385\ Va \ldots d_2 = 19.2$ cm
$q_3 = 0.174\ Va \ldots d_3 = 22.6$ cm	$q_4 = -0.086\ Va \ldots d_4 = 23.2$ cm
$q_5 = 0.0378\ Va \ldots d_5 = 23.4$ cm	$q_6 = -0.0177\ Va \ldots d_6 = 23.45$ cm
$q_7 = 0.00833\ Va \ldots d_7 = 23.5$ cm	$q_8 = -0.00393\ Va \ldots d_8 = 23.55$ cm

in A. Since the attraction between 2 charges q_s and q_t a distance f apart is $\dfrac{q_s q_t}{f^2}$ the total force on B may be expressed as a summation:

$$F = \sum_{2\,(\text{even})}^{\infty}{}_{s} \sum_{1\,(\text{odd})}^{\infty}{}_{t} \frac{q_s q_t}{(c-d_s-d_t)^2}$$

Since c, even for very small gap settings, must be at least twice a, the nth image charge is much smaller than the $(n-1)$th charge. The inclusion of more pairs of images contributes rapidly diminishing amounts to the total force. In any case it is necessary to take only as many images as are required to make sure the total force of all the neglected images will be less than the allowable error.

A calculation for a 100 centimeter sphere gap with a setting of 30 centimeters will illustrate the method. The first 4 pairs of images and the distance of each from the center of its respective sphere is given in table II.

The force, due to these 4 pairs of charges only, is then:

$$F = \frac{q_1q_2}{[130-d_2]^2} + \frac{q_1q_3}{[130-d_2-d_3]^2} + \frac{q_1q_4}{[130-d_2-d_4]^2} + \frac{q_1q_5}{[130-d_2-d_7]^2} +$$
$$\frac{q_3q_4}{[130-d_4]^2} + \frac{q_3q_6}{[130-d_4-d_5]^2} + \frac{q_3q_4}{[130-d_4-d_6]^2} + \frac{q_3q_4}{[130-d_4-d_7]^2} +$$
$$\frac{q_5q_6}{[130-d_6]^2} + \frac{q_5q_8}{[130-d_6-d_8]^2} + \frac{q_5q_6}{[130-d_6-d_4]^2} + \frac{q_5q_6}{[130-d_6-d_7]^2} +$$
$$\frac{q_7q_8}{[130-d_8]^2} + \frac{q_7q_2}{[130-d_8-d_2]^2} + \frac{q_7q_2}{[130-d_8-d_3]^2} + \frac{q_7q_8}{[130-d_8-d_7]^2}$$

Which, for $q_1 = aV$ (a being 50 centimeters) reduces to, if V is expressed in statvolts:

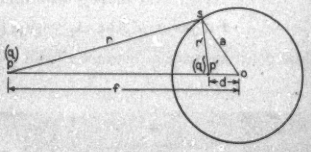
$F = 0.137V^2$ dynes

In general, $F = SV^2$ dynes for V expressed in statvolts or; $V = 9{,}405\sqrt{\dfrac{F}{S}}$ for V expressed in practical volts, and F in grams. With charges 7 and 8 neglected, the constant S would be reduced about one per cent, and, as their contribution to the total force is less than half the contribution of charges 5 and 6, the error made by neglecting all charges beyond 8 cannot exceed one per cent. The values for S, correct to the 5th decimal place, given in table III were computed with enough image charges to give this accuracy for spacings from 0 to 100 centimeters. These tabulated values are plotted in figure 8, and were used in conjunction with the force measurements to calculate the voltages for the one-meter spheres.

Since the larger the force measured, the smaller the experimental error, the gap should be set as small as possible without permitting flashover for each measured voltage. For flashover gap settings, using F. W. Peek's data[4] for the flashover of one-meter spheres, forces approximately those shown in figure 9 will be obtained.

Figure 10 shows for one-meter spheres the force as a function of voltage for sphere gap spacings of 15, 30, 50, 75, and 100 centimeters.

Fig. 6. Diagram representing a sphere and a point charge



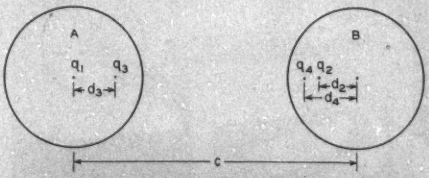


Fig. 7. Diagram representing 2 spheres, sphere A being at a potential V, and sphere B being at ground potential

Influence of Ground Planes

In like manner, images may be used for the calculation of the influence of ground plane effects on the force between the spheres. The accurate calculation of such influence is possible, but laborious. To compute the change in the force caused by an infinite ground plane (for instance, a laboratory floor or wall), each charge of the original 2 infinite sets of images must be imaged to a position as far behind the plane as the charge lies in front of the plane. These 2 new sets of images must in turn be imaged back into the spheres following the law for sphere images presented above, each image being the origin of an infinite series of images in the spheres, and the procedure continued until the imaged charges become negligibly small. Consequently, the number of charges to be considered in calculating the force existing between the spheres is very much larger than for the case of isolated spheres.

Slide rule computations for the one-meter spheres set at 25 centimeters gap, were made of the disturbing effect of grounded infinite planes, one 20 feet from the gap, parallel to the line of the sphere centers, representing the laboratory floor; and the other 20 feet from the gap, perpendicular to the line of the sphere centers, representing an end wall. Since only an approximate indication of the disturbance was desired, image charges less than one per cent of the original charge were neglected; and charges located within a few centimeters of each other were grouped in a mean position when considering the forces exerted on them by charges several hundred centimeters distant. The result of these calculations indicated the error due to the assumption of isolated spheres to be of the order of 0.5 per cent. For the number of images considered in the computation, this is within slide rule accuracy. These calculations and the experiments with test planes to date, are believed to warrant the conclusion that for the test conditions in this laboratory, the disturbing effects are negligible for gap spacings up to at least 30 centimeters.

Should further work indicate the need for more complete corrections for ground planes, when the gap settings are large compared to the sphere diameter, such corrections will be a matter only of more extensive calculations.

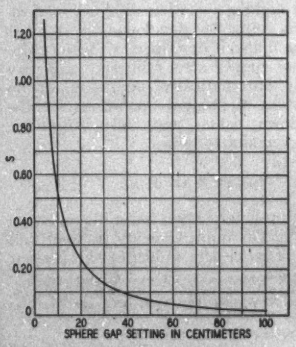


Fig. 8. Relation between sphere gap setting and the value of S used in the equation: $V = 9{,}405\sqrt{F/S}$

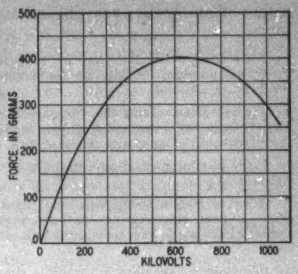


Fig. 9. Relation between force in grams and kilovolts with spheres set at Peek's values of sparking distances

Résumé

Curve A of figure 4 has been drawn as a mean curve through the test points without the points being shown, because, when all the points were shown, they made the curve, at the scale drawn, look like a broad ragged line. This is due to the well-known erratic behavior of the sphere gap when used to measure voltage by the spark-over method. The deviations in the test carried out by the authors had the following range from curve A: at 20 centimeters spacing, from about 1 per cent below to 1 per cent above; at 40 centimeters spacing, from about 2 per cent below to 1 per cent above; at 60 centimeters spacing, from 6 per cent below to 2 per cent above; at 70 centimeters spacing, from 6.5 per cent below to 1 per cent above.

Table III—Computed Value of the Spacing Factor S

(Sir W. Thomson—"Papers on Electrostatics and Magnetism," p. 96)

Sphere Gap Setting—Cm	S	Sphere Gap Setting—Cm	S	Sphere Gap Setting—Cm	S
0	∞	35	0.11082	70	0.03863
5	1.13844	40	0.09174	75	0.03441
10	0.52852	45	0.07720	80	0.03084
15	0.32917	50	0.06592	85	0.02775
20	0.23159	55	0.05693	90	0.02509
25	0.17432	60	0.04963	95	0.02278
30	0.13696	65	0.04363	100	0.02075

It is interesting to note that curve A is practically coincident with the curve shown by Meador[5] in his figure 8.

Attention is directed to the form of the curve in figure 9 which shows that the maximum force between the spheres, when they are used as close as possible to spark-over voltage settings for the force measurements, occurs at a spacing of about 40 centimeters which is just the minimum spacing at which trouble from erratic sparking commences. Perhaps this is an indication that difficulties will be encountered if 100 centimeter spheres are used at spacings above this value for voltage measurements by the spark-over method.

The advantages of using force measurements

rather than spark-over distances for sphere gaps are:

1. No corrections are necessary for temperature, humidity, and barometric pressure, the only air characteristic of influence being the dielectric constant.

2. For any given spacing the relation between force and voltage may be calculated accurately from fundamental electrostatic theory without the use of any empirical data.

3. From (2) this method appears to have value as an absolute standard.

4. Adjacent bodies, floors, walls, etc., have at least no greater effect on force measurements than on spark gap measurements and their influence on force measurements is subject to exact calculation.

5. In making voltage tests on apparatus, the use of force measurements permits continuous voltage application and avoids the well-known difficulties incident to the spark gap method, not the least of which are the oscillations sometimes set up.

6. No series resistance is required if care is exercised to keep the spheres at all times separated far enough to avoid spark-over.

7. Less care is needed in making the spheres capable of withstanding spark-over and in maintaining a highly polished surface free from dust, lint, etc.

8. Absence of polarity effects, and effects due to the state of gap ionization.

9. Applicable to continuous potential, and to alternating potential of any frequency, without any change in the force-voltage relation.

10. Readings are always root mean square or effective values regardless of wave form.

The authors request the interest and co-operation of other laboratories in checking the results obtained for spheres in air and in extending this method of measurement to spheres of different diameter and to spheres mounted in dielectrics other than air, such as oil or other liquid dielectrics.

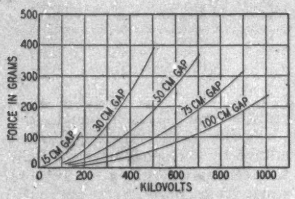


Fig. 10. Relation between force in grams tending to pull the spheres together and kilovolts (effective) for several gap settings (centimeters)

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Automatic Control for a Roughing Mill

Automatic screw-down equipment recently built for a 3-high roughing sheet bar mill represents one of the most recent advances in steel mill control equipment. This equipment, together with other control equipment designed for this mill and a semiautomatic screw-down control recently installed on another 3-high roughing mill, is described here.

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STEEL mill operators are analyzing production costs today more carefully than ever before and, as a result, are continually looking for improved labor saving devices as well as means for increasing production. In this search for improved equipment and methods electrical control is playing an increasingly important part. The object of this paper is to outline briefly some of the most recent designs in steel mill control equipment. Particularly, the operation, extreme flexibility, simplicity, and reliability obtainable from automatic screw-down controllers are emphasized. While the application of automatic screw-down controllers to sheet mills is described in this paper, it is worthy to note that this same type of controller may be readily adapted to practically any type of steel mill from large breakdown mills to almost any finishing mill.

In addition to the automatic screw-down controllers and other equipment developed specifically for a typical 3-high roughing sheet bar mill, a semiautomatic screw-down controller developed for another 3-high roughing mill also is described. These equipments are built for rugged steel mill duty and may be operated fully automatically, manually, or by using a combination of manual operations for the first few breakdown passes and fully automatic operation for the remaining passes.

Modern Roughing Sheet Bar Mill

A modern 3-high roughing sheet bar mill represents one of the most recent improvements in steel mill rolling practice. This clearly indicates the present

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* Application pending for re-election to grade of Member.

tendency toward more prevalent use of automatic magnetic control in the operation of steel mills. For the sake of simplicity, the description here will be confined to a 5-pass roughing mill schedule and will be based largely upon an equipment actually being installed in a steel plant. This mill, with its tables and control, embodies many special features which, based upon the judgment of the consulting engineers, were justified in order to operate the mill at a high sustained rate of production.

The 3-high roughing mill being installed in this plant, which has top and bottom rolls 52 inches wide and 33 inches in diameter and a middle roll 20 inches in diameter, operates at 29.3 rpm and is designed for roughing 12 inch bars in 5 passes to 15 or 16 gauge sheets. The first 2 passes will be rolled single thickness; then the sheets are matched, and the last 3 passes are rolled double thickness. Steel bars are fed to this roughing mill, shown in figure 1, by a single-width continuous furnace 100 feet long. An interesting feature of this new 3-high mill is the middle roll, which is balanced and is actuated up and down by the raising and lowering of the catcher's table.

Automatic Screw-Down Equipment

A special feature of this roughing mill is an automatic screw-down equipment. The screws are operated by 2 15-horsepower mill-type d-c motors, mechanically connected by a spline. On movements in the down direction, the motors are connected in series; on the upward movement of the screws, they are connected in parallel. A Clark 14-inch d-c series-wound high-speed-operating brake, with the inertia of its brake wheel reduced to a minimum, is mounted on each motor shaft.

The master switch, shown at the top of figure 2 and marked "manual-off-automatic" is, in normal operation, left in the "automatic" position. On the master panel the only items, besides the master switch, that have anything to do with the screw-down mechanism are the 4 buttons at the extreme right. The top button, which has a horizontal operating mechanism, is operated once for each pass; that is, as soon as the operator sees the end of the metal going through on pass 1, he momentarily presses this button which automatically sets up the mechanism for pass 2. After the metal has gone through pass 2, he again presses this same button and automatically sets up the mechanism for pass 3. No matter how long an operator holds down this button, it will not skip a pass but will move only to the next pass. The next to the top button is used to reset the screw-down mechanism, if it be found that the steel bars have to be taken off the table after making 1 or 2 passes, and the operator wishes to set up the mechanism again for pass 1.

This automatic screw-down equipment may be operated manually by simply moving the master switch handle to the "manual" position and then operating the 2 lower right-hand buttons. These 2 lower buttons provide inching in the manual operation but are inoperative when the master switch is in "automatic" position. One of these buttons is for down travel and the other for up travel. In manual operation, as long as the "down" button is depressed the screws will move downward, while pressing the other button moves the screws upward.

If the screw-down mechanism has been operated manually and it is desired to place the equipment again in position for automatic operation, all the operator need do is to inch the screw-down mechanism to pass 1 setting, return the master switch to "automatic" position, press the reset button; when the light for pass 1 shows up on the screw-down

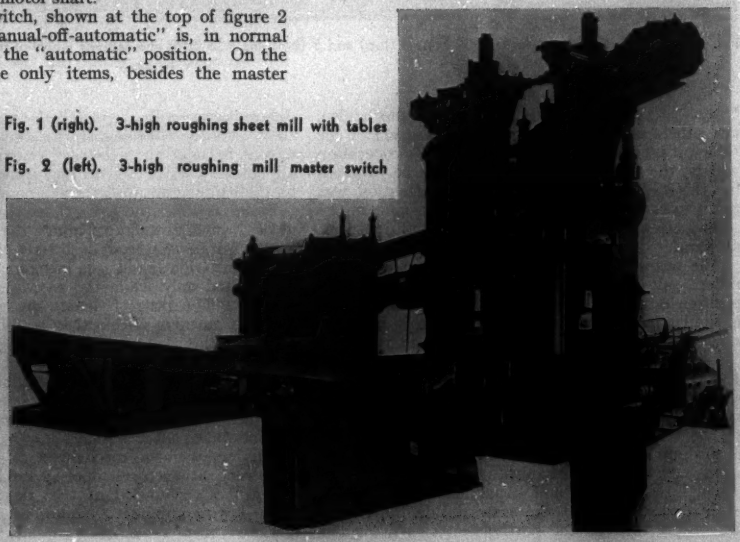


Fig. 1 (right). 3-high roughing sheet mill with tables

Fig. 2 (left). 3-high roughing mill master switch

position indicating device, the control is ready for automatic operation. The automatic screw-down control panel, shown in figure 3, is relatively simple considering that it handles 2 motors in series-parallel and provides reversing dynamic-braking duplex control.

In this installation, the screw-down limit switch is of the "preset" type, positively driven from the screw-down motors. The screw-down operation is made automatic for the various passes and, as mentioned before, the control is so arranged that the operator need only to press the top button to set the screw-down mechanism for each pass. Considering all the safety features on the screw-down mechanism and others in connection with the operation of the tables, it is expected that the mill's cycle of operation will be the fastest that could possibly be attained for this type of rolling. Particular attention was given to the speed on the upward movement of the screws after the completion of the last (fifth) pass, preparatory to entering a new bar in pass 1.

The screw-down limit switch is mounted on the roller's side of the mill, immediately in front of the position occupied by the roller. This limit switch is similar in construction to that shown in figure 4, except that fewer dials are used since this is only a 5 pass mill, whereas with the switch shown in figure 4, a setup could be made for 15 passes. The switch is mounted on the mill housing with its long axis vertical, and the shaft extension is geared directly to the screw-down mechanism so that the motion of the limit switch shaft is in proportion to the motion of the screw-down mechanism itself.

The interior of the limit switch, shown in figure 5, is illuminated so that the scales inside the switch are visible through the portholes, which are small windows with clear celluloid panes. A stationary wire inside these windows makes it possible to read directly on the scales. The row of hand wheels below the scales determine the stopping position of the screw-down mechanism for each pass and give micrometer adjustment so that the stopping position for any pass may be varied at will. In making a setup, the individual handwheels are turned until the indicating scales read the desired positions for stopping for each pass. If some one pass must be altered after the setups are made for a given schedule, to make the correction it is merely necessary to turn the handwheel corresponding to that pass. When different sized rolls are installed, another handwheel, shown on the coupling end of the limit switch, is moved to make the necessary general correction for all passes. With this arrangement the calibration on the scales is not disturbed.

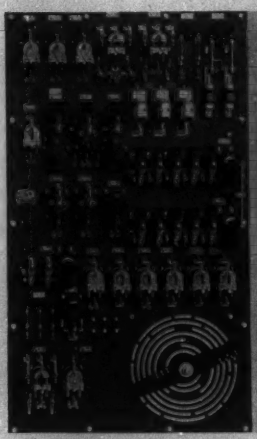
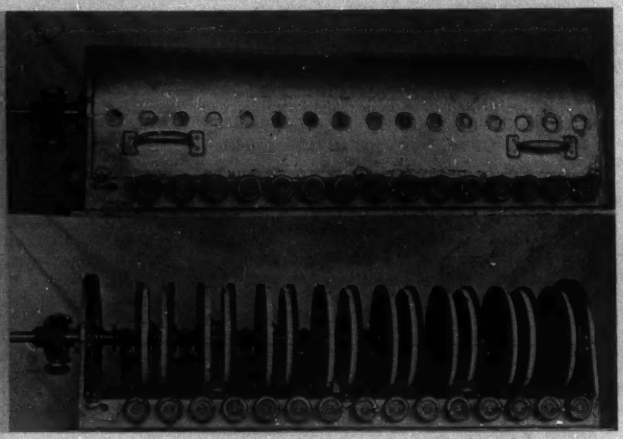


Fig. 3. Automatic screw-down control panel



Figs. 4 (top) and 5 (bottom). Exterior and interior views of the screw-down limit switch

Figure 6 shows the screw-down position indicating device, which is mounted above the mill housing so that it can be seen from both sides of the mill. The lower lens (right-hand lens in figure 6) is red and is illuminated only while the screw-down motors are moving. The other 5 lenses are green and have numbers on them so that they read from top to bottom, "1, 2, 3, 4, and 5" (left to right in figure 6). For instance, when the screw is set for pass 3, the green lens showing number 3 is illuminated. In this way, on both sides of the mill, operators know at all times whether the screw-down mechanism is set and for what pass it is set.

This screw-down mechanism is extremely fast, gives very satisfactory stopping, and is, to the best of the author's knowledge, the simplest automatic screw-down equipment that has been placed on the market.

Roughing Mill Tables

Roughing mill tables, shown in figure 1, are another special feature of this 5-pass roughing sheet bar mill as a unit. The catcher's table is of the tilting type with manually operated magnetic control and 3 hand controlled stops. The control on the catcher's table is operated manually in preference to any automatic control by flag switch, photoelectric cell, or other mechanism, investigation having indicated that faster operation of this table could be obtained by manually operated control than by any other method.

The front table is stationary and carries 2 sets of chains: one is an ordinary set for feeding packs into the mill on passes 3 and 5; the other carries 2 dogs and a special safety stop each, for feeding the bars into the mill on pass 1. The front table is equipped with 3 stops, 2 of which are of the motor driven type operated with rotating magnet type motors, and the other is of the "knockdown" type. The motor operated stop nearest the mill is stationary relative to the mill, while the other is adjustable for different lengths in order to re-enter in the minimum time after delivery from pass 2. The knockdown stop, located farthest from the mill, is also adjustable in position for the minimum time in rematching the pair after delivery from pass 4. In entering the pair for both passes 2 and 4, the end of the pair hits the rotating stop next to the mill for front end matching. This stop then disappears, permitting the pack to enter.

The opening of the furnace door, the starting of the furnace chains, and the delivery of a pair of bars down a driven conveyor to the front table are tied in definitely and positively by electric control at some predetermined point in the cycle of 5 passes on the previous pair. The timing for the delivery of the second pair is such that, after the tail end of the preceding pair has left the rolls on pass 5 and the operator has pressed the button to set the mill for pass 1, the time between the release of the pack on pass 5 and the entry of the new bar on pass 1 will be the absolute minimum.

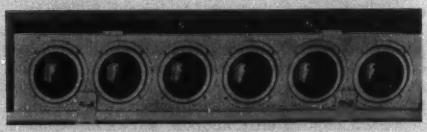


Fig. 6. Screw-down position indicating device; it is mounted vertically on the mill

Control of the screw-down mechanism, the preset arrangement for the various passes, the interlocking of the motor operated stops, and the delivery of the second pair of bars from the furnace are other most essential features in connection with the fast operation of the unit as a whole. Without proper interlocking of all of these factors, the unit never would be able to function within the time limits specified.

There are many other interesting special features in the control arrangement. For instance, if the operator has the screw-down mechanism set for pass 5 (which is the last pass and therefore the lowest screw-down setting) and then tries to enter new bars, the reduction would be too great and roll breakage would be likely to occur. In order to prevent this, the control is so arranged that if the screw-down setting is not right for pass 1 when the bars get down to the front of the table, they will stop automatically and will not enter the mill until the screw is set for pass 1.

When the catcher table is tilted, it is impossible to run the chains on the roller side toward the mill. Therefore, it is impossible for a bar to be entered through the mill when the catcher table is in the "up" position, as this would permit the bars to come through under the catcher's table. This same interlocking system also prevents the entering of bars between the top roll and the middle roll at the same time that bars are going between the bottom roll and the middle roll. Whenever this occurred in the past, roll breakage was almost sure to follow.

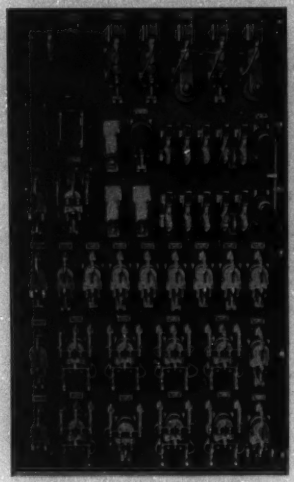


Fig. 7. Semi-automatic screw-down control pane

With this control system, the bars are delivered automatically from the furnace and are deposited automatically on the roller's table, ready to enter the mill as soon as the screw-down mechanism has been set for pass 1 after the end of the preceding pack has gone through. This entire control system is provided with adequate protective measures so as to prevent any mishap from an error on the part of the operator. For instance, if by any chance the operator has not pushed the button to set the rolls for pass 1, the bars will be carried up to within 15 inches of the mill and there they automatically stop. The bars will remain in this position until the operator

has pressed the button, but even then they cannot enter the mill until the rolls have reached the predetermined opening for pass 1. When the pack goes through on pass 5 the time elapsing until the new bars on pass 1 are entered, is much shorter than anything that has been accomplished previously on this type of mill. It is claimed that this particular unit should and will be the fastest operating roughing sheet bar mill of its kind that has ever been built.

Semiautomatic Screw-Down Control

Another type of screw-down controller, shown in figure 7 and recently installed on a 3-high roughing mill, is intended primarily for semiautomatic operation; it is made as simple as possible both in equipment used and in change-overs necessary from one schedule to another. This controller was designed for a maximum of 7 passes and is operated entirely from 2 foot switches, one of which is shown in figure 8. One of these is pressed for the up motion and the other for the down motion. The screw-down limit switch is mounted on the left hand side of the mill housing, within easy reach of the operator so that changes in any pass setting may be made readily by the operator.

This 7-pass screw-down control equipment consists of 1 entering, 1 matching, and 5 down motion passes. The down motion passes are arranged so

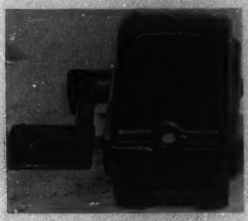


Fig. 8. Foot operated switch for semiautomatic control

that the first time the down foot switch is depressed, the screw-down limit switch will move to the setting corresponding to the first dial of the down travel. The next time it will go to the second setting, and then to the next, and so on. In one complete mill cycle, regardless of the number of passes, or where matching takes place, there are only 2 times in the cycle when the screw-down motors go up. The first time is when the matching takes place and the next time is when the pair of bars have been finished and the screws go up to prepare for the entrance of the next pair of bars. Therefore, on the screw-down limit switch there are 5 dials for the down travel and only 2 dials for the up travel.

In making a setup for the up travel, the first dial is adjusted for the matching pass and the second dial for the entering pass. This second dial limit switch mechanism stops the screw-down in its up travel after all other passes are finished. Therefore, regardless of the position of the screw-down mechanism, the first time in the cycle that the "up" foot switch is depressed the mechanism will go up to the matched setting. The next time in the cycle that the "up" foot switch is depressed, it will go to the first pass setting, thus making the screw-down setup ready for new bars to be entered. The next time this same foot switch is depressed it will go to the matched setting, and so on.

The screw-down position indicating device, likewise, has 5 numbered lenses for the down motions, and 2 lenses for the up travel. The up motion lenses are marked M and E, corresponding to matching and entering passes.

Since this control equipment was designed for semiautomatic operation of the mill, it permits any desired variations in the rolling practice. For instance, if after the third pass the operator presses the "up" foot switch, this motion automatically cancels all setups in the down direction so that the mill is ready to start with the first down setting, and so on. In this way any number of passes up to 7 may be had, and matching may take place on any pass and on either side of the mill that the operator desires. In changing over from one schedule to another it is only necessary for the operator to reset the dials to the proper positions, no operation of any transfer devices being necessary. Simplicity of operation may be shown best by outlining a typical sheet bar rolling cycle.

Suppose that a 5-pass schedule is being rolled with matching taking place on the roller's side of the mill after the second pass. It is assumed that the screws are set properly for the first pass. On the first and second passes the bars go through the rolls one after the other. After the rear end of the second bar has gone through on the first pass, the "down" foot switch is depressed momentarily. The 2 bars now are brought back through the second pass; after the rear end of the second bar has gone through, the operator momentarily presses the "up" foot switch, causing the screw-down mechanism to move up to the proper setting for the matched pair. After the steel has gone through on the matched pass the "down" foot switch again is depressed momentarily, causing the setup to be made for the fourth pass. When the match sheets have gone through the fourth pass, the operator again presses the "down" foot switch and the screws move down for the fifth and final pass. After the rear end of the sheets goes through the final pass, the "up" foot switch again is depressed momentarily and the screws move up to the proper setting for the entrance of new bars.

With all the variations possible in the methods of operation, this system is not restricted to any particular pass for matching or to any particular number of passes. It seems to be an ideal setup for many types of roughing mills. Of course, it must be realized that in this type of semiautomatic control arrangement the operator must press the "down" foot switch when the screws should come down and the "up" foot switch when the screws should go up; the whole system outlined here for this mill control is based upon the assumption that the operator is sufficiently intelligent to do this. The screw-down indicating device shows, each time, exactly for which pass the screws are set.

Transients in the Finite Artificial Line

Some of the results obtained and the conclusions reached in a study of the current at the end of any section of a nondissipative artificial line terminated at one end at midseries position by a physically realizable resistance and excited at the other end at midseries position by a unit continuous voltage are presented briefly herewith. This paper is a condensed version of a longer paper* on file in the Engineering Societies Library.

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IN SO FAR as their general operational formulation is concerned, the disturbing effects of terminal impedances in the transient response of the periodic artificial line to voltages suddenly applied at one end already have been treated.[1] However, even with the simplest terminations, the difficulty of determining useful explicit or time solutions of the complicated operational expressions formulating these disturbing effects is such that it has led investigators either to avoid these terminal effects entirely or to reduce them to relatively simple forms by the use of simplifying assumptions all of which are included as either special or limiting cases of the following ideal problem: The line is assumed to be terminated in impedances that for all frequencies exactly simulate, within fixed constants, its characteristic impedance as seen from both ends.[1,2] Such exactly simulating impedances, however, are not physically realizable;** moreover, the limiting cases of this assumption, such as the cases of open or short-circuited far end,[3] do not represent the manner in which the artificial line usually is terminated when used as a low-pass wave filter. It is evident, therefore, that previous studies of the finite artificial line in the transient state have been confined to either impractical or unrealizable terminal impedances.

It is the purpose of this paper to present a few curves and conclusions arrived at in a study of the current at the end of any section of a nondissipative artificial line of n sections when terminated at one end at midseries position by a physically realizable resistance $R = k\sqrt{L/C}$ and excited at the other end

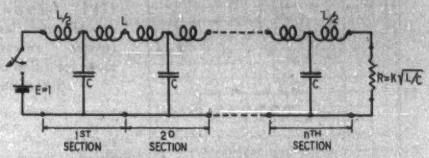
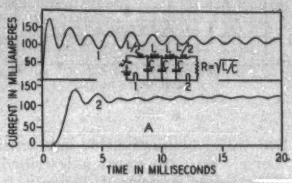


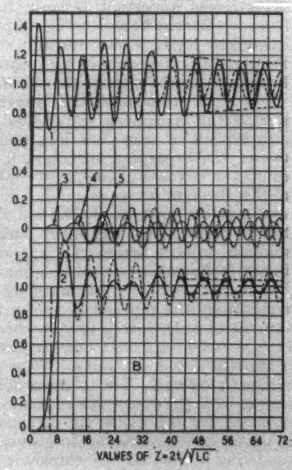
Fig. 1. Diagram of a nondissipative artificial line terminated into a resistance $R = k\sqrt{L/C}$

at midseries position by a unit continuous voltage applied at the time $t = 0$ (see figure 1). The solution of this problem is of importance in the study of the finite low-pass filter, and in establishing the relation between the response of the finite artificial line and that of the corresponding finite smooth line. (By the corresponding smooth line is meant here

Fig. 2. Indicial admittance of initial (1) and last (2) mesh for a line of 3 sections

Tracing of oscillogram (right)





——— Current in finite line as computed by means of expansion theorem

..... Current in finite line as computed by means of series treatment. Curve 4 is the first reflection in the initial mesh; curves 3 and 5 are the first and second reflections in last mesh

– – – – Current in corresponding mesh of infinite line

–·–·– Current in corresponding smooth line

Note: Multiply ordinates by $\sqrt{C/L}$

* A condensed version of a longer paper, now on file at the Engineering Societies Library, 33 West 39th Street, New York, N. Y., which is based almost entirely upon material developed in a thesis "Transient Oscillations in Low Pass Electric Wave Filters of a Finite Number of Sections" by M. J. Di Toro, Brooklyn Polytechnic Institute, June 1933; recommended for publication by the A.I.E.E. committee on communication. Manuscript submitted Oct. 25, 1933; released for publication Nov. 26, 1934.

** The authors are indebted to Drs. J. R. Carson and O. J. Zobel of the American Telephone and Telegraph Company for calling their attention to the physical possibility of closely simulating the characteristic impedances of the usual lumped lines used as wave filters. See the section on the simulation of wave filter impedances in the paper "Extensions to the Theory and Design of Wave Filters" by O. J. Zobel, Bell System Technical Journal, April 1931, v. 10.

1. For numbered references see list at end of paper.

that line that has the parameters L and C uniformly distributed per "unit length." The magnitude of this "unit length" depends, of course, upon the degree of approximation desired between lumped and smooth lines.) In addition, the solution is also, to a first approximation, a solution for the periodically loaded cable with a termination often used in practice. The nondissipative line considered here is, of course, ideal; the solution described here, however, is nevertheless important because the disturbing effects, which arise because of the impedance mismatch existing at the far end of the line, are brought out to the greatest extent and in the clearest manner when damping caused by dissipation is avoided.

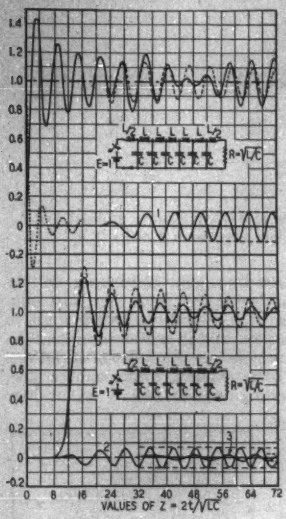


Fig. 3. Indicial admittance of initial (upper curves) and last (lower curves) mesh for a line of 6 sections

—— Current in finite line as computed by means of the series treatment. Curve 1 is the first reflection in the initial mesh; curves 2 and 3 are the first and second reflections in last mesh

– – – – Current in corresponding mesh of infinite line

–·–·– Current in corresponding smooth line

. . . . . Fictitious voltage causing first and second reflections

Note: Multiply ordinates by $\sqrt{C/L}$

For a line of not more than 3 sections, the conversion of the operational expressions of the problem into explicit or time functions was effected by the use of the expansion theorem of Heaviside. The enormous increase in complexity inherent in the use of this theorem for an increasing number of sections was avoided, however, by the use of an approximate but powerful series treatment which broke up the solution into a series of "apparent reflections." Figure 2 shows the current in a line of 3 sections, for $k = 1$, as obtained by means of the expansion theorem and by the approximate series treatment. Figures 3 and 4 show, respectively, the current in a line of 6 sections for $k = 1$ and the current in a line of 3 sections for $k = {}^1/_2$ and ${}^4/_5$ as obtained by the series treatment. The corresponding oscillograms shown with the theoretically computed curves were obtained by the use of an artificial line especially designed and constructed to give a large time scale rendering it possible to employ a string type oscillograph with maximum film speed. The parameters of this line were: $L = 0.288$ henry per section (coil resistance = 30 ohms per section); $C = 1$ microfarad per section.

The conclusions reached in the longer paper (see footnote at beginning of this paper) are:

1. Unlike the indicial admittance of the corresponding nondissipative finite smooth line with the same termination, the transfer indicial admittance of the h section of the circuit shown in figure 1 for $k = 1$ differs from the indicial admittance of the h section of the corresponding line with an infinite number of sections, or the line assumed terminated into its characteristic impedance, by the presence of modulated oscillations caused by a series of complicated superimposed terms. (In accordance with their standardized definition, the words "modulated oscillations" are used here to denote the result produced by the superposition of oscillatory curves of different frequencies.) These superimposed terms have a virtual or apparent velocity of propagation of $1/\sqrt{LC}$ sections per second and for this reason may be called virtual or apparent reflections. The first and second apparent reflections, which produce the greatest disturbance relative to that of the succeeding reflections, become of maximum amplitudes $0.18\sqrt{C/L}/\sqrt{2n-h}$ and $0.18\sqrt{C/L}/\sqrt{2n+h}$ in the vicinity of the arguments $z = 2t/\sqrt{LC} = 7(2n-h)$ and $7(2n+h)$, respectively. All the apparent reflections can be considered physically as the response in the $2n-h$, $2n+h$, etc., sections of the corresponding line with an infinite number of sections to fictitious voltages suddenly applied at midseries position to the initial section. The fictitious voltage causing the first and second apparent reflections is shown in figure 3.

2. For values of R such that k takes on values other than 1, the transfer indicial admittance of the h section of the circuit shown in figure 1 can be considered as composed of the transfer indicial admittance of the h section of the corresponding line with an infinite number of sections plus a series of apparent reflections having a virtual or apparent velocity of propagation of $1/\sqrt{LC}$ sections per second. These reflections oscillate about and ultimately coincide with

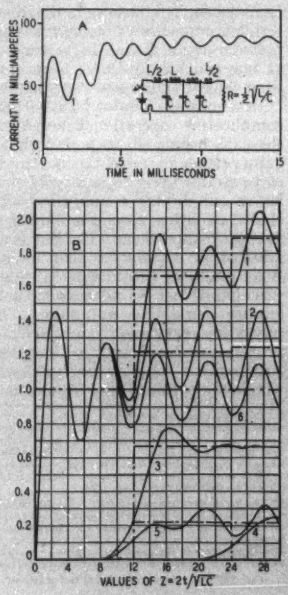


Fig. 4. Indicial admittance of initial mesh for a line of 3 sections terminated into the resistances $R = (1/2)\sqrt{L/C}$ (curve 1) and $R = (4/5)\sqrt{L/C}$ (curve 2) as computed by means of series treatment

Tracing of oscillogram (top)

—— Curves 3 and 4 are the first and second reflections for $k = 1/2$; curve 5 is the first reflection for $k = 4/5$; curve 6 is the current in initial mesh of infinite line

–·–·– Current in corresponding smooth line with same terminations

Note: Multiply ordinates by $\sqrt{C/L}$

the corresponding known reflections of the finite nondissipative smooth line with the same terminations.

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An Electronic Regulator for an Alternator

An automatic voltage regulator for an alternator consists essentially of a voltage sensitive element which controls, through suitable apparatus, the excitation of an alternator. In the voltage regulator described herein, the voltage sensitive element is a nonlinear bridge circuit. Its output controls, through a phase shifting circuit, a grid-controlled mercury-vapor tube, the output of which is fed into the field circuit of the alternator. The phase shifting circuit employs a fixed condenser and a variable resistance, the latter being obtained from 2 3-electrode vacuum tubes whose grids are controlled by the nonlinear bridge circuit. The regulator is rugged in construction and at constant frequency provides close regulation without apparent hunting or voltage distortion.

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THE increasing need for an automatic voltage regulator to meet the exacting requirements of industrial service has led to innumerable attempts to produce a device which will keep the terminal voltage of an alternator constant as the load is varied. If an alternator has its field current adjusted so as to supply rated voltage at no-load and rated frequency, the terminal voltage decreases as resistive or inductive load (the usual types of load) is applied to the machine. This condition is undesirable and the problem is to maintain automatically a constant terminal voltage regardless of the load on the machine. In order to accomplish this the generated voltage of the machine must be controlled to compensate the variable impedance drop and the variable demagnetization effects.

Many regulators have been built which will, in general, accomplish these results; but, considerable improvement in this field is still possible. The main faults encountered in the ordinary type of vibrating contact voltage regulator are: (*a*) its relatively slow pulsating action; and, (*b*) the wear and tear and the necessary readjustments of its moving parts.

The recent improvements which have been made in electronic tubes have provided the basis for many successful experiments on controlling and regulating mechanisms for various types of apparatus and circuits. The grid-controlled mercury-vapor tube, in particular, is being extensively applied to control circuits. The regulator described in this paper uses such a mercury vapor tube in conjunction with its control circuit and voltage sensitive circuit to vary the average field current of the alternator, as a means of controlling the effective field strength without the use of auxiliary windings or other devices on the alternator.

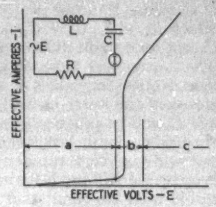

Fig. 1. Volt-ampere characteristic of the nonlinear bridge circuit of the alternator voltage regulator

This paper presents the explanation of the electronic voltage regulator in 4 parts:

1. The voltage sensitive element of the regulator: the nonlinear bridge circuit.
2. The control circuit of the mercury vapor tube.
3. The operation of the regulator.
4. Typical test data of the alternator with the regulator.

THE VOLTAGE SENSITIVE ELEMENT

In attempting to develop an electronic tube voltage regulator, a nonlinear bridge circuit[1] offered most interesting possibilities as the voltage sensitive element of the regulator circuit. A simple series circuit consisting of resistance, capacitance, and a saturable iron core reactor, forms the basic element of such a nonlinear bridge circuit. The effective voltampere

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1. For all numbered references, see list at end of paper.

characteristic of such a circuit is shown in figure 1. The region marked *a* on the figure is associated with the unsaturated condition of the iron core reactor; region *c* is associated with the saturated condition; and, in region *b* the circuit conditions become unstable and the current rises very rapidly. The value of the voltage at which this rise in current takes place is a characteristic of the circuit which is called the "critical voltage." (Detailed investigation of the phenomena in the unstable region is being carried on at The Polytechnic Institute of Brooklyn by Prof. E. Weber.)

Two series circuits each having characteristics of the type shown in figure 1 may be combined to produce a voltage sensitive, nonlinear bridge circuit as shown in figure 2. The output voltage E_0 is the difference in voltage drops across the 2 condensers. If the 2 capacitances are practically equal, the output voltage will be large when the current through one condenser is very much larger than the current through the other. This condition will exist when one arm of the bridge is operating in its unstable region. For the 2 cases when neither arm operates in its unstable region, or when both arms operate in their unstable regions, the output voltage will be very small. If both arms are identical, their characteristics are identical and the output voltage will be zero for all values of applied voltage.

Consider the case of a nonlinear bridge circuit in which $R_1 = R_2$, $C_1 = C_2$, and the reactors are similar except for a slight difference in their number of turns. The 2 arms will have slightly different critical voltages, so that for values of applied voltage E between zero and the lower critical voltage, the output voltage E_0 will be practically zero, but when one arm of the bridge circuit becomes unstable, the voltage output will rise very rapidly. As the applied voltage is increased still further, the second arm becomes unstable with the result that the output voltage again becomes small. It remains small for all higher values of applied voltage. The output voltage E_0

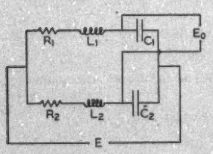


Fig. 2. Nonlinear bridge circuit of the regulator

E is the applied voltage of the bridge circuit

E_0 is the output voltage of the bridge circuit

will have slight irregularity for voltages above and below the critical values, since it is practically impossible to obtain identical magnetic characteristics for the 2 reactors. This condition is further influenced by the fact that the characteristic of the nonlinear bridge for increasing values of applied voltage may differ slightly from that for decreasing values of applied voltage, the difference depending upon the relative values of resistance R and capacitance C.

In addition to the critical voltage characteristic of the nonlinear circuit, there are phase angle changes which occur in between the regions *a* and *c* on figure 1; were it not for the changes in wave shape which also occur within this region it might be possible to make use of this phase shift to control the grid of the mercury vapor tube directly.

From the experimental work on nonlinear bridge circuits, it is found that the critical voltage depends predominantly upon the characteristics of the reactors in the circuits. The value of the output voltage after one arm of the bridge circuit comes into its unstable region is some function of the capacitance and resistance. As either the resistance or capacitance is decreased, the output voltage increases. A typical characteristic of one test on the nonlinear bridge circuit is shown in figure 3. It might appear at first glance that the output voltage could be increased to any desired value by decreasing the resistance of the circuit. This, however, is not true if the circuit characteristic is to be the same for increasing and decreasing values of applied voltage E. There is a particular combination of resistance and capacitance for which the output voltage E_0 is a maximum and for which the same characteristic results for both increasing and decreasing values of applied voltage. Any change of resistance or capacitance above these

E_0 is the output voltage
R_1 = 75 ohms
R_2 = 58 ohms
C_1 = 12 microfarads
C_2 = 10 microfarads
L_1 = No. 2,334, 110 volts
L_2 = Same, 10 volts, 8 volt Viking coil

Curve "a" is for increasing values of applied voltage

Curve "b" is for decreasing values of applied voltage

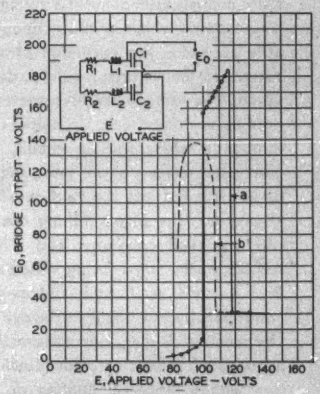


Fig. 3. Nonlinear bridge characteristics

values, while still producing a unique characteristic, renders a lower value of output voltage; and, any decrease in resistance or capacitance causes the characteristic to become double valued and the output voltage greater.

The characteristic of the nonlinear bridge circuit used in this regulator is shown in figure 4. From this it can be seen that if the bridge is connected directly across the alternator terminals, any attempt of the machine to increase its terminal voltage above its rated value of 118 volts results in a greatly magnified increase of output voltage from the bridge circuit. This condition is the foundation upon which the operation of the regulator circuit depends. The field current of the machine is initially adjusted so that at full load its terminal voltage is a little above

its rated value. Any decrease in load tends to increase the terminal voltage. The greatly increased output voltage from the bridge circuit, caused by this tendency, is made to operate a circuit which in turn regulates the average field current of the alternator and thus controls the terminal voltage. Having designed the voltage sensitive element of the regulator, a control circuit which would respond to these changes in the output voltage of the bridge was then developed.

Control Circuit of the Mercury Vapor Tube

As a relatively large and variable amount of direct current is required to produce the variation in the

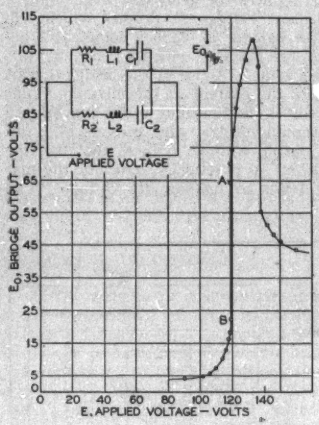


Fig. 4. Nonlinear bridge characteristic

E_0 is the output voltage
R_1 = 78 ohms
R_2 = 62 ohms
C_1 = 27.4 microfarads
C_2 = 20.0 microfarads
L_1 = No. 2,334, 110 volts
L_2 = Same, 10 volts, 8 volt Viking coil

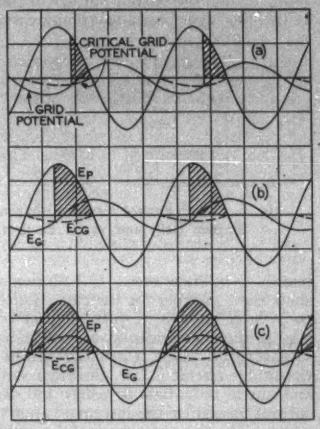
This curve is followed for increasing and decreasing values of applied voltage

average alternator field current needed to maintain constant terminal voltage over a wide range of load, a mercury vapor tube (General Electric Company type *FG*-27) was selected as the current carrying element.

Any one of several methods can be used to control the average current passed by the mercury vapor tube; but, in this particular case, since the grid and anode are supplied by a-c voltages, the phase shifting method[2] seemed best. By this method, the average value of current passed by the mercury vapor tube can be controlled from zero to full value by shifting the phase of the grid voltage with respect to the anode voltage. Whenever the grid potential becomes less negative than a certain value, known as the "critical grid voltage," the tube begins to pass current and continues to pass current until the anode potential becomes zero. The basic principle of the grid phase-shifting method of control is illustrated in figure 5. The shift of phase of the grid potential with respect to the anode potential can be secured by the use of a circuit having the principles of that shown in figure 6. From the vector diagram of this phase shifting circuit it can be seen that, as the value of R changes, the angle θ between the grid potential E_g and anode potential E_a changes. When $R = 0$, $\theta = 180$ degrees, and when $R = \infty$, $\theta = 0$.

In order to employ this circuit in an automatic voltage regulator, it is necessary to secure a resist-

Fig. 5. Phase shifting diagrams



ance for the variable arm R of the phase shifting circuit which will change from a relatively low value to an almost infinite value in response to the variable voltage E_0 from the nonlinear bridge circuit. Since this bridge circuit can supply no appreciable power output, the plate resistance of a 3 electrode, high vacuum type, electronic tube can be used as the variable resistance arm R. If this tube has its grid negatively charged during the time its plate is positive, the effective resistance of the tube can be increased from a relatively low value to an almost infinite value by further increasing the value of the negative charge on the grid. This principle is used in this regulator for utilizing the variable output voltage E_0 from the bridge circuit to provide the variable resistance for the phase shifting circuit of the mercury vapor tube. Two tubes, type 10, are arranged for 2-way rectification and are connected so that the grids are negatively charged from the output of the bridge circuit during the half cycles when the respective plates are positive. The values of anode potential and negative grid potential on these tubes are such that when one arm of the nonlinear bridge circuit operates in its unstable region (high output voltage), the negatively charged grid completely prevents the passage of current between anode and cathode; and, when the tubes pass their maximum current, their apparent or effective resistance is relatively low.

The maximum anode potential of these tubes is 470 volts. In order to secure cut-off at this voltage, a value of −62 volts is needed on the grids. The output voltage from the nonlinear bridge is capable of supplying up to −85 volts without an appreciable

change in applied (terminal) voltage. Thus, an almost infinite value of resistance is secured when the output voltage from the bridge circuit is high. This action serves to put the grid voltage practically in phase with the anode voltage and causes the mercury vapor tube to pass its maximum value of current. When the output voltage of the bridge circuit is low, the tubes pass a maximum current of approximately 5 milliamperes. Calculation and test both show that, in order for the capacitance voltage drop to be large enough to shift the grid voltage through a large angle, a condenser of 0.04 microfarad is most satisfactory. Thus, when the output voltage from the bridge circuit is low, the angle between the grid and anode potentials is nearly 180 degrees and the current passed by the mercury vapor tube is a minimum. The circuit diagram of the complete regulator is shown in figure 7.

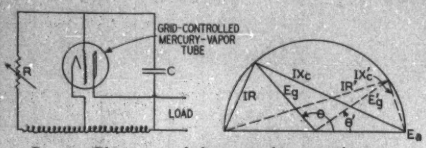


Fig. 6. Phase control diagrams, showing schematic diagram (left) and vector diagram (right)

Operation of the Regulator

The critical voltage of the nonlinear bridge is the rated terminal voltage of the alternator. Therefore, the output voltage of the bridge circuit is along the line AB of the nonlinear bridge characteristic, figure 4. This output voltage will be high when the terminal voltage is a very small amount greater than the critical voltage; and, it will be small when the terminal voltage is very slightly less than the same critical voltage. The total change in terminal voltage required to produce the full useful change in the bridge output voltage is so small as to be unobservable on an ordinary voltmeter. The field rheostat of the alternator is set so that at full load on the machine, and with the regulator disconnected, the terminal voltage is several volts above rated value. The output circuit of the mercury vapor tube is connected to the field circuit of the alternator in such a manner that, as the tube current increases, the field current is decreased. In order to protect the mercury vapor tube from an overload current which would be caused by the field rheostat being cut out too far, it might be desirable to connect the output of the mercury vapor tube across a fixed resistance in series with the field rheostat, instead of directly across the field rheostat. If this is not done a stop should be provided on the field rheostat to prevent it being cut out beyond a certain limit. Instead of connecting the mercury vapor tube so as to control the main field current of the alternator, its output may be fed into an auxiliary field winding to produce the same result. The regulator receives its power from any one phase of the alternator under regulation and this source constitutes the only power supply necessary.

While the cathode of the mercury vapor tube is being heated, the output voltage from the bridge circuit is high, since the terminal voltage of the machine is above the critical voltage of the bridge. This serves to shut off the 2 tubes constituting the variable resistance in the grid phase shifting circuit of the mercury vapor tube. The nearly infinite resistance of these 2 tubes (see vector diagram in figure 6) causes the grid voltage of the mercury vapor tube to be in phase with the anode potential as soon as the plate circuit is completed through the field rheostat and causes the mercury vapor tube to pass its maximum current instantaneously. This action reduces the average field current of the alternator and thus reduces the generated electromotive force and terminal voltage—a process which will continue until a balance is reached somewhere between A and B (see figure 4) with the terminal voltage at its rated value. A rise in the bridge output voltage increases the current in the mercury vapor tube and overcomes the tendency of the machine to increase its terminal voltage; and, conversely, a fall in the bridge output voltage reduces the mercury vapor tube current to practically zero and the machine thereby tends to increase its voltage. The slightest tendency of the alternator to change its terminal voltage disturbs the balance of the very sensitive nonlinear bridge circuit. The resultant change in the output voltage of the bridge circuit varies the effective resistance of the variable arm of the phase shifting circuit which changes the current in the mercury vapor tube in such a way as to main-

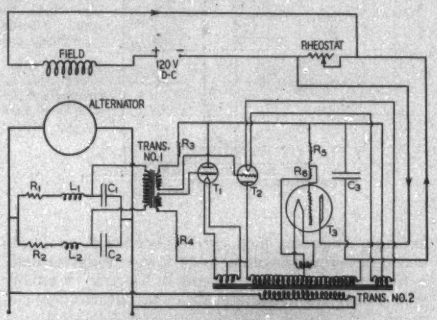


Fig. 7. Diagram of connections

R_1 = 78 ohms; R_2 = 62 ohms; R_3 = R_4 = 500,000 ohms; R_5 = 1 megohm; R_6 = 0.1 megohm
C_1 = 27.4 microfarads; C_2 = 20.0 microfarads; C_3 = 0.04 microfarad

T_1 and T_2 are 3 electrode vacuum tubes, type 10
T_3 is a grid-controlled mercury-vapor tube
Transformer number 1—70 volt primary coil (5,000 ohms impedance) 2 70 volt secondaries (5,000 ohms impedance)
Transformer number 2—120 volt primary coil, 330 volt secondary coil (center tapped); 2 7.5 volt secondaries (center tapped); 5 volt secondary coil (center tapped)

tain a practically constant terminal voltage at all loads.

Test Data of Alternator and Regulator

Tests made on a 12 kw alternator show conclusively the ability of the regulator to maintain constant terminal voltage while the load is varied from no-load to more than full load. The data of one of these tests are plotted and shown in figure 8.

Without the regulator in operation the voltage regulation of the alternator is $\frac{20}{118.5} \times 100$ per cent = 16.9 per cent. With the regulator in operation the total change in terminal voltage from no-load to full load is 0.2 volt. The voltage regulation is, therefore, 0.17 per cent. This regulation was obtained at 60 cycles, and although as yet no tests have been made at other constant frequencies, it is quite likely that with suitable circuit adjustments this sensitivity can be maintained at other frequencies somewhat above and below 60 cycles; the effect of varying frequency is to vary the voltage at which the circuit regulates.

The close regulation at constant frequency is due to the extreme sensitivity of the non-linear bridge circuit. To the knowledge of the authors this control system has never before been applied in this manner as a voltage regulator for alternators.

Summary of Advantages

With the regulator in operation on a 12 kw alternator, the terminal voltage is maintained with a regulation of 0.2 per cent as compared to the regulation of 17 per cent without the regulator. Closer regulation than 0.2 per cent is not maintained in present practice by ordinary voltage regulators for alternators. The commercial electronic tube voltage regulators, which have been developed for regulation of this order of magnitude, are relatively costly and complicated devices, generally requiring the use of some standard source of voltage as a datum for comparison. The electronic voltage regulator which has been explained in this paper is relatively inexpensive and it neither requires the use of any standard datum voltage nor the use of any power source other than that of the alternator under regulation.

The regulator has no parts requiring frequent adjustment or replacement; and it is adaptable to any alternator if the proper provision is made for current carrying capacities in the regulator parts. The action of the regulator is practically instantaneous and it is free from noticeable hunting or undesirable transient conditions. An oscillographic investigation of the conditions existing at the alternator terminals and of conditions existing in the field system reveals the following facts:

1. That the field current of the alternator is apparently as pure a d-c current with the regulator in operation as it is without the regulator.

2. That the regulating action of the regulator apparently does not appreciably distort the voltage wave form of the alternator.

The advantages of this electronic voltage regulator over many of those now in use are summarized as follows:

1. The regulator has no moving parts which require frequent adjustment or replacement.

2. The regulator is noiseless in operation.

3. It is readily applied to any alternator by the use of a single transformer to adapt the critical voltage of the bridge circuit to the rated voltage of the machine.

4. It provides close regulation without noticeable hunting, and its action is practically instantaneous and free from disturbing transient conditions.

5. The regulator does not require the use of any auxiliary windings or devices on the alternator, since its controlling action is obtained by varying the voltage drop across the field rheostat.

6. This regulator does not require any source of power other than that of the alternator under regulation and it does not need batteries or standard voltages for use as a datum for comparison.

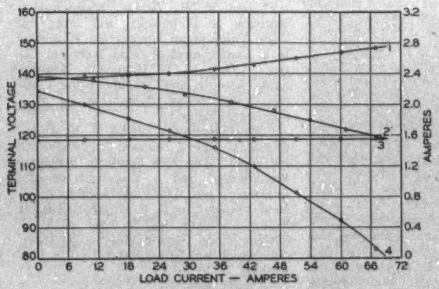


Fig. 8. Test with regulator in operation

1. The variation of field current (right-hand scale) caused by the regulator
2. The variation of terminal voltage (left-hand scale) without the regulator
3. The variation of terminal voltage (left-hand scale) with the regulator
4. The variation of plate current (right-hand scale) in the mercury vapor tube

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4. Electronic Regulators for A-C Generators, F. H. Gulliksen. *Elec. Engg.*, v. 53, June 1934, p. 877–81.

5. Voltage Regulators, M. de Querquis. *Elettrotecnica*, Oct. 25, 1932, p. 745–55.

6. Thyratron Voltage Regulator for an Alternator, C. E. Weinland. *Rev. Sci. Inst.*, v. 3, 1932, p. 9–19.

7. Corona Tube Voltage Regulator, H. W. Dodge and C. H. Willis. A.I.E.E. Trans., v. 50, 1932, p. 1466–8.

8. Carbon-Pile Voltage Regulators, E. H. Wolff. *Elec. Jl.*, v. 27, 1930, p. 101–3.

9. A-C Precision Regulator, H. M. Stoller and J. R. Power. A.I.E.E. Trans., v. 48, 1929, p. 110–3.

10. Automatic Regulators for Voltage Control Over Wide Range, W. H. Turner. *Power*, v. 65, 1927, p. 164–6.

11. Operation of Voltage Regulators for Alternating-Current Generators, W. H. Turner. *Power*, v. 64, 1926, p. 124–5.

News

Of Institute and Related Activities

The Summer Convention This Month at Cornell University

THE fifty-first annual summer convention of the Institute, which will be held on the campus of Cornell University, Ithaca, N. Y., June 24–28, 1935, promises to be an outstanding affair. The summer convention committee, under the chairmanship of R. F. Chamberlain, has arranged an excellent program combining sports, recreation, and social functions with an enlarged technical program consisting of 10 sessions and in addition a number of informal technical conferences. The splendid facilities which the university affords have made it possible to offer members and guests these features at a very reasonable cost, and a large attendance is anticipated. Headquarters will be in Willard Straight Hall.

Entertainment Features for Women

The entertainment features scheduled for the convention were outlined briefly in the announcement in the May 1935 issue of Electrical Engineering, page 563. In addition to the features mentioned therein, of interest particularly to women, several others are being arranged. The features for women's entertainment may be summarized as follows:

On Monday morning, June 24, following the annual business meeting, there will be a tour of Myron Taylor Hall and other campus buildings in the vicinity of Willard Straight Hall. In the afternoon there will be a tea in the reception room of Balch Hall. On Monday evening the president's reception and dance for all members and guests will be held.

On Tuesday morning a drive around the Cornell campus with an inspection of the Home Economics College and Laboratories has been arranged, and on Tuesday afternoon there will be the outing and picnic at Taughannock State Park, with a picnic supper served along the lake front. Details of this excursion were given in the preceding issue. Return from the outing will be in time for the lecture to be given at Bailey Hall in the evening.

Wednesday morning and afternoon will be the trip to Corning, N. Y., home of the Corning Glass Works. Luncheon for the women only will be held at the Corning Country Club, and there will be a bridge party for those who do not desire to go through Watkins Glen in the afternoon. There will be a buffet supper at Corning in the evening. There will also be a musicale on Wednesday evening.

On Thursday morning there will be a putting contest followed by a luncheon in the Memorial Hall at Willard Straight Hall. The annual convention banquet, with dancing and other entertainment, will be held Thursday evening for all members and guests.

On Friday morning there will be an automobile trip to Enfield Glen and Falls at Enfield State Park; and the final get-together luncheon will be held Friday noon.

It was stated in the last issue that it will be necessary to charge moderate fees for certain entertainment events but the total amount of the fees for all of them will not exceed $6 per person. This will include the annual dinner, picnic at Taughannock State Park, luncheon, dance, and all other entertainment features regularly scheduled as part of the convention.

Housing

Facilities for living accommodations were outlined in the preceding issue, page 564, and rates for different arrangements were given there. As mentioned, living accommodations will be confined largely to the university dormitories located on the campus, although other facilities are available. An additional note regarding housing arrangements is that at the university dormitories, members who are attending with wives or families will be housed together, that is, they will be given double rooms or adjoining rooms. Balch Hall is arranged with 2 rooms forming a suite, with a connecting hall and lavoratory for the use of occupants. Risley Hall has a number of double rooms. It is the intention to house those guests with families in Balch Hall and Risley Hall.

Technical Sessions

The technical program is of broad scope and timely interest. Papers on some of the most recent developments in various fields of technical committee activities will be presented in 10 sessions: instruments and measurements, power generation, electrical machinery (2 sessions), protective devices, education, applications to iron and steel production, selected subjects, electrochemistry and electrometallurgy, and power transmission. The technical program and the papers for these sessions with reference to the issues in which they are published were given in Electrical Engineering for May 1935, page 561. In addition, Dr. D. B. Steinman, consulting engineer, has been invited to give a special address on "Engineers' Registration and Related Problems of the Profession" at the session on education, Wednesday morning, June 26. A paper entitled "Automatic Control for a Sheet Bar Roughing Mill" by L. A. Watson, Clark Controller Co., has been added to the session on applications to iron and steel production, Thursday morning, June 27. This paper is published in this issue. Other papers on the program appear in this and preceding issues. Excellent discussions by many well-known engineers are sure to result and when the meeting is opened for general discussion anyone in attendance should feel free to take part in the discussion.

Technical Conferences

Besides the formal technical program, 14 technical conferences on various subjects will be held during the afternoons for the benefit of specialists and the younger members. The schedule and the objectives of several of these conferences were announced in Electrical Engineering, May 1935 issue, pages 561–2. Additional information is given on the following conferences.

Problems of the Student and Cadet Engineer

The chairman of this conference, M. G. Malti, announces the following program subject to some modifications. After opening remarks by L. A. Doggett, Pennsylvania State College, and chairman of the committee on education, Bancroft Gherardi, vice president of the American Telephone and Telegraph Company, will outline "The Future of Engineering and the Young Engineer," and Dexter S. Kimball, Cornell University, will talk on "The Cadet Engineer in This Changing World."

After a period for discussion, another group of subjects will be lead off by Alan Howard of the General Electric Co., who will discuss "The Young Engineer in Industry" and W. H. Timbie, Massachusetts Institute of Technology, will bring out "The Value of an Engineering Education in a Nontechnical or Semi-Technical Career." Then R. E. Hellmund, Westinghouse Electric and Manufacturing Company, will discuss "Qualifications of a Successful Engineer."

Following another period of discussion, Chester L. Dawes, Harvard University, will tell about "The New Graduate School of Engineering" and a statement on the Engineers' Council for Professional Development, prepared by C. F. Hirshfeld, Detroit Edison Company, will be read by A. C. Stevens of the General Electric Company, after which will be another period for discussion.

Research on Insulating Oils

This conference will be under the chairmanship of Kenneth S. Wyatt, research department, The Detroit Edison Company, and its purpose is to provide an opportunity for informal discussion by those interested in the subject of insulating oils, with particular reference to the much needed research in that field, indicated by the following questions:

Is it not possible, by breaking away from lubricating oil ideas, to produce oils for electrical insulating purposes, of greatly improved stability? By using new methods recently available, such as solvent refining, is it not now possible to select those constituents of crude petroleum which have maximum stability for use in transformers, high voltage cables, circuit breakers, capacitors, and other electrical equipment? What special characteristics should an electrical insulating oil have, for transformers, for cables?

What are the chief causes of deterioration of electrical insulating oils in service? What are the factors influencing this deterioration? How can they be controlled? Before improved oils are produced, will it not be necessary, first, to discard old-time motor-oil routine tests, and to develop precision and micro-methods for detecting deterioration and for evaluating electrical stability?

What is the economic importance of the electrical insulating oil problem? How much could be saved annually in replacements both of oil and equipment, by reduction of hazard, and by increase of factor of safety, if improved oils could be made available to the industry?

Dielectric Theories

This conference with H. H. Race, chairman, will consider the theories of dielectric capacitance and dielectric loss in: (*a*) crystals; for example, ice; (*b*) the system, cellulose plus water; and (*c*) synthetic resins.

The present plan is to open the discussion by having the following speakers, Dr. E. J. Murphy, Bell Telephone Laboratories, Dr. J. B. Whitehead, The Johns Hopkins University, Dr. S. O. Morgan, Bell Telephone Laboratories, and Dr. J. D. Clark, General Electric Company, each present a 10 minute summary of important data and underlying theory. The major portion of the available time will be reserved for free informal discussion during which additional data, theories, and physical concepts may be presented in accordance with the interests and wishes of those attending the discussion.

Research in Engineering Schools

The purpose of this conference, under the chairmanship of Vladimir Karapetoff, school of electrical engineering, Cornell University, is to discuss the proper function of the teaching staffs of our technical schools in connection with research. It is expected that topics such as the following will be discussed: what have American schools of engineering contributed to the advancement of the art and science of electrical engineering through research and how does this record compare with European countries; research by faculty members, by graduate students and by undergraduate students; and what kinds of research problems can be undertaken by faculty members which would be most helpful to the industry and to the profession?

The last 3-mentioned technical conferences, which deal with research, have each been scheduled on different afternoons, in order not to conflict with one another.

The complete program and important information relative to very reasonable accommodations and reduced railroad rates was given in Electrical Engineering for May 1935, pages 561–4. Members in the nearby Districts who have received the registration and dormitory reservation cards should fill them in and post them promptly.

Avail yourself of the opportunity now to attend this interesting convention in a splendid scenic setting.

The Pacific Coast Convention

The 1935 Pacific Coast convention committee is actively engaged in formulating plans for the coming convention which will be held in Seattle, Washington, August 27–30. The Olympic Hotel, one of the finest and one of the most modernly equipped in the northwest, will be convention headquarters.

The tentative program provides for 5 technical sessions: power transmission and distribution, electrical machinery, communication, electrophysics and instruments and measurements, and selected subjects. A number of the papers will deal with the latest engineering developments in the Pacific Coast region and it is also being planned to hold an informal discussion of the Grand Coulee and Bonneville power projects on the Columbia River. In addition there will be 2 Student sessions.

The evenings will be devoted to social functions with a reception on Tuesday evening and a banquet and dinner-dance on Thursday evening. Facilities for sports and golf also will be available to members and guests. Arrange your vacation plans now and attend the Pacific Coast convention at Seattle the latter part of August.

Great Lakes District Meeting

The Great Lakes District of the A.I.E.E. will hold a meeting on the campus of Purdue University, West Lafayette, Ind., October 24–25, 1935. Headquarters will be in the electrical engineering building. A Student convention will be held in conjunction with the District meeting.

The technical program is being arranged under the direction of C. Francis Harding, chairman of the program committee. Several of the papers already have been prepared while others are well along in the course of preparation. Some of the subject matter will have to do with the production of standard impulse voltages, sphere gap breakdown as affected by ultra-violet light, the Purdue cathode ray oscilloscope, and the control of potential distribution over insulator surfaces. Other papers which deal with interesting and valuable researches in several different fields of activity will be scheduled on the program.

The personnel of the District meeting committee in charge of arrangements for this meeting was announced in Electrical Engineering, April 1935 issue, page 451.

1935 Lamme Medal Nominations Due Nov. 1

Special attention is directed to the fact that the names of Institute members who are considered eligible for the Lamme Medal, to be awarded in the fall of 1935 may be submitted by any member in accordance with Section 1 of Article VI of the by-laws of the Lamme Medal committee, as quoted in the following:

The committee shall cause to be published in one or more issues of Electrical Engineering, or of its successors, each year, preferably including the June issue, a statement regarding the "Lamme Medal" and an invitation for any member to present to the national secretary of the Institute by November 1, the name of a member as a nominee for the medal, accompanied by a statement of his "meritorious achievement" and the names of at least 3 engineers of standing who are familiar with the achievement.

Each nomination should give concisely the specific grounds upon which the award is proposed, and also a complete detailed statement of the achievements of the nominee to enable the committee to determine

Aerial view of the north end of the campus of Cornell University, Ithaca, N. Y., showing the quadrangle, the engineering buildings, and to the right the Baker laboratory of chemistry. Many of the technical sessions during the Institute's forthcoming summer convention at Ithaca, June 24–28, will be held in the latter building. At the upper right-hand corner is Balch Hall, one of the dormitories which will be used for housing guests

its significance as compared with the achievements of other nominees. If the work of the nominee has been of a somewhat general character in co-operation with others, specified specific information should be given regarding his individual contributions. Names of endorsers should be given as specified above.

The Lamme Medal, founded as a result of a bequest of the late Benjamin Garver Lamme, chief engineer of the Westinghouse Electric and Manufacturing Company (deceased July 8, 1924), provides for the annual award by the Institute of a gold medal —together with bronze replica thereof— to a member of the A.I.E.E. "who has shown meritorious achievement in the development of electrical apparatus or machinery"; and for the award of 2 such medals in some years if the accumulation of funds warrants.

The seventh (1934) Lamme Medal has been awarded to Henry E. Warren (A'02) president of the Warren Telechron Company, Ashland, Mass., "for outstanding contributions to the development of electric clocks and means for controlling central station frequencies." Presentation will be made during the summer convention at Cornell University, Ithaca, N. Y., June 24–28, 1935. A brief biographical sketch of Mr. Warren appeared in ELECTRICAL ENGINEERING for March 1935, page 351.

Oklahoma City Section Is Host to Record Meeting of South West District

THE South West District's fifth District meeting, held in Oklahoma City, Okla., April 24–26, 1935, under the sponsorship of the Oklahoma City Section, established a new record for the District in total registration. The total registration of 571 not only topped the District's previous record of 541 set in 1929 at Dallas, Texas, but set a figure that in the history of the 30 Institute District meetings held since 1924 has been exceeded by only 3 other Districts, each of which has an Institute membership ranging from 230 to 490 per cent of the Institute membership in District 7. In point of average District meeting attendance as compared to District membership, District 7 now leads all Districts. Substantial delegations were present from each of the 6 Sections and 14 Student Branches in the District. Registration figures are given in an accompanying tabulation.

TECHNICAL SESSIONS

The popularity of the technical program was attested by the sustained heavy attendance at technical sessions and by the scope and character of the discussions. From the opening session Wednesday morning, with more than 250 present, to the closing session Friday afternoon, with more than 300 present, all sessions were punctual and heavily attended.

With but minor variations, the technical program presented was the same as that published in the March issue of ELECTRICAL ENGINEERING. Reflecting the useful flexibility of the Institute's present unified publication policy, 2 of the 7 formal technical papers were picked up for re-presentation from the 1935 winter convention papers previously published in ELECTRICAL ENGINEERING, 4 were published in the February, March, and April 1935 issues, and 1 will be published in a future issue. In addition to these 7 papers, 7 others of especial local interest were presented orally for discussion without publication or general circulation.

Presiding at the opening meeting Wednesday morning, F. J. Meyer, A.I.E.E. vice president from the South West District made some welcoming remarks, introduced the committee chairman in charge of key activities, and then called upon National Secretary H. H. Henline and Editor G. Ross Henninger, who respectively outlined briefly the history and trend of development of the Institute District meetings program and of its publication services. Presiding over the technical sessions were: R. F. Danner of Oklahoma City, Okla., and H. R. Fritz of St. Louis, Mo., for the opening general session; for the insulation and protection session Wednesday afternoon, O. S. Hockaday of Fort Worth, Texas, and L. C. Starbird of Dallas, Texas; for the second general session, Thursday morning, C. I. Hendricks of Fort Worth, Texas, and R. W. Linney of Oklahoma City; for the distribution and transmission session, Friday morning, D. D. Clarke of Kansas City, Mo.; and for the concluding general session, Friday afternoon, M. C. Hughes, College Station, Texas.

One of 2 special features was an informal "round-table" conference arranged informally for the evening of the first day in response to suggestions received by the program committee during the day. Embracing the general subject of rural electrification, and held on an entirely informal and spontaneous basis, this conference was expected to draw perhaps 25 interested persons. Instead it drew nearly 200 and lasted through the entire evening.

SYMPOSIUM ON ENGINEERING EDUCATION

The second special feature, and the concluding item of the meeting program, was a "symposium on engineering education," a general discussion session led by discussions prepared in advance by J. B. Thomas, Texas Electric Service Co., Fort Worth, Tex.; T. F. McMains, Western Union Telegraph Co., Wichita Falls, Tex.; F. C. Bolton, Texas A. and M. College, College Station, Tex.; B. D. Hull, Southwestern Bell Telephone Co., Dallas, Tex., and I. H. Lovett, Missouri School of Mines and Metallurgy, Rolla, Mo.

STUDENT SESSIONS

Student sessions were held Thursday and Friday mornings, in parallel with the general sessions. At these 2 sessions 14 excellent papers were presented:

WIDE RANGE REPRODUCTION IN SOUND ON FILM MOVING PICTURES, Ben H. Crowley, University of Oklahoma.

PROBLEMS IN TELEVISION, E. L. Kent, Kansas State College.

SEISMOLOGY IN PETROLEUM PROSPECTING, Philip W. Whitaker, Oklahoma A. & M. College.

THE CATHODE RAY OSCILLOGRAPH, James N. Walker, Southern Methodist University.

A PHOTOELECTRIC CELL SWEEP CIRCUIT FOR THE CATHODE RAY OSCILLOGRAPH, Erle Mayo and Marion Royalty, Texas Technological College.

Membership—

Mr. Institute Member:

The close of the fiscal year, April 30, 1935, showed the following number of applications received as compared with the year 1934:

	Year Ending April 30, 1934	Year Ending April 30, 1935
Number of applications received from enrolled Students	467	575
Number of applications received from all others	498	714
Total number of applications received	965	1289

Much of this increase came from your co-operation in sending in names.

Chairman National Membership Committee

Acoustical Measurements With the Cathode Ray Oscillograph, M. S. Burton, Texas A. & M. College.

Grid Controlled, Gaseous Discharge Tubes, E. D. Hoffman, Missouri School of Mines and Metallurgy.

Investigation of the Variation in the Velocity of Light, Guy C. Omer, Jr., University of Kansas.

An Alternator Voltage Regulator Utilizing a Non-Linear Circuit, W. H. Mayne, University of Texas.

Impulse Testing of Rubber, Hilton Remley, University of New Mexico.

Errors Inherent in and Corrections to Be Applied to the Electromagnetic Oscillograph, Walton J. Greer, Rice Institute.

Some Deductions From and Illumination Survey, Glenn O. Ladd, University of Missouri.

On Magnetic Side Pull, Jules R. Conrath, Washington University.

Principles and Operation of Selsyn Instruments, W. A. Fullwood, Jr., Southern Methodist University.

Although competing with the general sessions, the excellence of the student technical program kept the average attendance above 150 in addition to the 250 or more who attended the parallel general session.

In addition to the student technical sessions, the Enrolled Student delegation from each Branch in the District, together with their faculty counsellors, participated in the District's annual student conference which was held Friday morning. This session was presided over by Prof. J. A. Correll, counsellor of the Student Branch at the University of Texas, and chairman of the District committee on student activities. Each of the 14 Student Branches of the District was represented by its chairman, and 13 also by counsellors.

Branch counsellors present included: C. T. Almquist, University of Oklahoma, Norman; C. V. Bullen, Texas Technological College, Lubbock; J. A. Correll, University of Texas, Austin; E. H. Flath, Southern Methodist University, Dallas; R. G. Kloeffler, Kansas State College, Manhattan; A. C. Lanier, University of Missouri, Columbia; I. H. Lovett, Missouri School of Mines and Metallurgy, Rolla; E. W. Markle, Texas A. & M. College, College Station; Albrecht Naeter, Oklahoma A. & M. College, Stillwater; Chester Russell, Jr., University of New Mexico, Albuquerque; W. B. Stelzner, University of Arkansas, Fayetteville; R. W. Warner, University of Kansas, Lawrence; J. S. Waters, Rice Institute, Houston, Texas. Fifteen other faculty members from schools in the District were registered.

Student Branch chairmen present were: B. W. Crowley, University of Oklahoma; J. C. Evans, Washington University, St. Louis, Mo.; Glenn D. Farrar, Kansas State College; Walton Greer, Rice Institute; Frederic H. Holt, Missouri School of Mines and Metallurgy; T. B. Lewis, University of Arkansas; W. H. Mayne, University of Texas; Hiltom Remley, University of New Mexico; R. Roderick, Texas A. & M. College; Mark Townsend, Texas Technological College; Dan Weiser, University of Kansas; Philip R. Watson, University of Missouri; Philip W. Whitaker, Oklahoma A. & M. College; James N. Walker, Southern Methodist University.

Analysis of Registration at Oklahoma City District Meeting

Classification	Location: Oklahoma City Section	District No. 7*	Other Districts	Totals
Members	80	75	21	176
Students	59	96	1	156
Men Guests (paying)	120	32	3	155
Women Guests	65	17	2	84
Totals	324	220	27	571

* Exclusive of Oklahoma City Section territory.

Future AIEE Meetings

Summer Convention,
Ithaca, N. Y., June 24–28, 1935

Pacific Coast Convention,
Seattle, Wash., Aug. 27–30, 1935

Great Lakes District Meeting,
West Lafayette, Ind., Oct. 24–25, 1935

Winter Convention,
New York, N. Y., Jan. 28–31, 1936

North Eastern District Meeting,
New Haven, Conn., May 1936

Summer Convention,
Los Angeles, Calif., June 22–26, 1936

Middle Eastern District Meeting,
Akron, Ohio (date to be determined)

The discussion covered many phases of Student Branch operating problems, an exchange of ideas concerning which within the District was deemed by all present to be of definitely practical value. One of the principal topics discussed was the question of what constitutes a desirable and effective program for Branch meetings. The discussion brought out that some meetings were conducted on the basis of a seminar in connection with the school program, some emphasized social features, and some depended largely upon "outside" features. It was considered worthy of particular note that there is an increasing tendency in the constructive direction of developing a greater interest and wider participation by the students themselves in presenting papers and discussions, either of an original nature or based upon papers for discussion published in Electrical Engineering. There was unanimous agreement on the suggestion that some kind of refreshments served in connection with student branch meetings inevitably increased the attendance greatly.

At a group luncheon conference held by the counsellors Thursday noon, several routine matters of business of the District committee on student activities were brought up by District chairman J. A. Correll. Among the decisions arrived at were: an expression of satisfaction over the success of the student convention held jointly with the District meeting, and a recognition of the beneficial effect of having meeting room and facilities provided for the student sessions that were equally commodious and convenient to those provided for the general session; a 2-to-1 expression of opinion against the idea of offering local prizes for student papers. A discussion of the perennial question of traveling expenses brought from Secretary Henline an explanation that traveling expenses were authorized by the Institute for Branch chairmen and counsellors in a district to get together once a year for the purpose of discussing and perfecting branch activities from an operating viewpoint, and not for the purpose of promoting technical papers or a student technical program. It was suggested by one spokesman that it would be beneficial to all parties concerned for the counsellors' student activities committee to give branch officers more of a voice in determining District Student Branch policies.

Prof. R. G. Kloeffler, counsellor at Kansas State College, Manhattan, Kansas, was elected unanimously to serve as chairman of the South West District's student activities committee for the administrative year 1935–36.

Entertainment and Inspection Trips

A well balanced program of inspection trips and entertainment activities provided excellently for the large number of men, women, and enrolled students present. Of the 5 inspection trips offered, 3 were to properties of the Oklahoma Gas and Electric Company, including a demonstration of insulation power factor testing equipment, and an inspection of downtown underground installations, the new Belle Isle gas burning power plant, and the load dispatcher's office. Other trips included a thorough inspection of the Oklahoma City oil fields, and a visit to the University of Oklahoma at Norman. In addition to those who made these trips in private groups, the official registration showed 211 participating in the various trips.

A golf tournament held Thursday afternoon drew 60 entries for the play which was held on the Oklahoma City Golf and Country Club's championship course.

In this competition, a registered guest, E. L. Blass, won the trophy cup put up by the golf committee, 79–9, 70. A. C. Bookout, of Oklahoma City, captured the runner-up trophy cup, 88–15, 73.

Entertainment features designed especially for women guests included, in addition to some of the inspection trips that appealed to the women, a tea held at the Y. W. C. A. Club House attended by 83, and a luncheon party at the Oklahoma City Golf and Country Club attended by 96. The principal general entertainment feature comprising a banquet followed by a parallel dance and bridge tournament was held Thursday evening with 390 in attendance.

District Executive Committee Meeting

For the purpose of completing items of business in connection with the District meeting, and to discuss other items of District business including tentative plans for a meeting suggested for San Antonio in 1937, the South West District executive committee convened for a luncheon meeting April 24. Vice President F. J. Meyer presided, and District Secretary C. W. Mier officiated in that capacity. Section officials present included: from Dallas, Past Vice President B. D. Hull, Section Chairman E. T. Gunther, and Secretary L. C. Starbird; from Houston, Section Secretary L. B. Bricker; from Kansas City, Section Chairman R. L. Frisby, and Secretary

H. V. Rathbun; from Oklahoma City, Section Chairman Albrecht Naeter, and Secretary C. E. Bathe; from San Antonio, Section Chairman J. W. Farrelly; from St. Louis, Section Secretary C. O. Campbell. Others present by request included A. C. Bookout, chairman-nominee for the Oklahoma City Section, National Secretary H. H. Henline and Editor G. Ross Henninger.

Report of Institute Committee on Sponsoring Discussions of Social and Economic Subjects

A SPECIAL committee on the question of sponsoring discussions on social and economic subjects was created by the Institute's board of directors in 1934. This committee, under the chairmanship of A. W. Berresford, past-president of the Institute, recently completed its report, and this report was approved by the board of directors at its meeting of May 21, 1935. The full text of the report, dated May 10, 1935, follows:

To the Board of Directors A.I.E.E.:

Gentlemen:

The action which created the committee was taken by the board at its meeting on June 27, 1934, and is as follows:

"Mr. Juhnke, as a result of attitudes he has encountered in his contacts with Enrolled Students and members of the Institute, suggested the desirability of the Institute's displaying an interest in the economic conditions of its membership by sponsoring social and economic discussions."

"Voted that the President be authorized to appoint a committee to consider the matter."

The committee has felt that the term "sponsoring" (the assumption of responsibility for) is probably broader in its implications than was the actual intent, and has therefore devoted its consideration to the desirability of such discussions and to recommendation of method by which, if initiated, they might accomplish their maximum value.

The committee recommends that discussions of the character contemplated in the motion be authorized in the national conventions and District meetings of the Institute, the meetings of its Sections, and of its Student Branches.

This recommendation is based on the following:

(*a*). There is growing realization that no single activity in our complicated social and economic structure is sufficient unto itself and in position to disregard the influence of its operations upon others or of the operations of others upon it.

(*b*). That this realization is important in the degree in which the activity itself is important.

(*c*). That in view of the importance of the engineering profession in the present stage of economic and social development, thought must be given to the conditions which it affects and which in turn affect it.

(*d*). That within the profession there is growing appreciation of the fact that, properly to fulfill his professional obligations, the engineer must possess qualification beyond the purely technical and extending into the cultural, social, and economic fields. This has been clearly enunciated in the progress reports of E.C.P.D. and is held to be warrant for considering these subjects as properly within the field of irterest of an engineering body such as the Institute.

(*e*). That even under normal conditions these conclusions would have been reached, and that the effect of the existing confusion and uncertainty has been merely to accelerate realization.

(*f*). That in instinctive recognition of the need, and in increasing measure, such discussions have already become a factor in Institute procedure and the condition is less one of initiation than one of recognition and co-ordination.

In support of the above your committee cites that during the years 1933–34 there appeared in Electrical Engineering 23 articles dealing with social and economic subjects and aggregating 90 pages of material. Further, 37 items of similar character aggregating 83 fine print columns were printed; these consisting of "Letters to the Editor" and of news reports. While no actual comparison with earlier years has been attempted it is believed that review of the material indicated will demonstrate its value and pertinence.

Much of the matter contained in the papers is of exceptional character, and would form admirable text for discussions such as are proposed. The items and letters, save for material carried in A.E.C. and E.C.P.D. statements deal, as would be expected, with unit phases of the situation and would probably be of smaller value. There would seem to be a certain significance, however, in the fact that so many have yielded to a desire for expression and have expressed themselves sufficiently interestingly to attract editorial consideration. Undoubtedly, many were received which were not published.

Again, 274 papers presented before Section meetings during the period of September 11, 1933 to April 17, 1935 have been classified according to subject matter.

197 fell within the scope of the code of the meetings and papers (now technical program) committee of the A.I.E.E., edition of June 1929:

	No. Papers	
a to *m*. (Technical subjects) including 14 subjects on radio and television	194	
n. Co-operative activities of engineering professional organizations	0	
o. Ethical and social aspects of the profession and its members	3	
Total under code	197	72%

The remaining 77 papers were divided into the following 3 categories:

(*a*). History of A.I.E.E. and descriptions of meetings and conventions	10	
(*b*). Topics which depart from electrical engineering *per se* but which are of definite influence in the social and economic developments which directly affect electrical engineers or electrical engineering	39	
(*c*). Other branches of engineering, science, exploration, history, etc., not directly affecting electrical engineering or electrical engineers	28	
Total	77	28%

Note: This analysis does not include papers presented at 48 joint meetings of A.I.E.E. Sections with other professional societies such as A.S.M.E., I.R.E., I.E.S., etc.

Suggestions for Operation

It is evident that if such discussions are to become a recognized factor in Institute procedure, intelligent selection of subject matter is essential. This might be attempted by advance definition and limitation of the fields to be covered but your committee believes such procedure would prove not too satisfactory and perhaps not necessary. The desirable course would seem to be consideration specific to the individual instance rather than that of predetermination of general fields, and it would seem that existing Institute procedure would provide this.

Papers offered for presentation at general Institute meetings are subject to scrutiny and acceptance by committees organized to pass upon the value, desirability, and pertinence of the matter contained. Approval is essential to publication and presentation. When presented they become available for discussion by the Institute. Experience has proved the procedure to be necessary and adequate to technical presentation. It would seem equally applicable and adequate to subject matter of social and economic content.

To make the procedure effective it would be necessary only to broaden the definition of acceptable subject matter which is included in the code of the technical program committee. Your committee suggests that this might be done by adding a title as follows:

"Topics apart from electrical engineering *per se* but which are of definite influence in the social and economic developments which directly affect electrical engineering or electrical engineers."

If this were to be done your committee recommends that, to guard against misunderstanding, examples (*c*) and (*d*) of subjects *not suitable* for Institute presentation be retained in the code. These titles are as follows:

(*c*). Speculative and philosophical papers without electrical aspects.
(*d*). As abstract propositions not directly connected with electrical engineering—purely economic and allied studies such as rate making, project financing, obsolescence, depreciation, statistical methods, utility regulation, factory organization, etc.

Your committee further recommends that the Institute encourage discussion by Sections and Student Branches of subjects authorized by the above suggested procedure for publication or presentation. It feels that such encouragement might well include the direction of attention to the material available, co-operation by the staff in its preparation, in the securing of speakers, and the publication in Electrical Engineering of such transmitted reports of discussions as are deemed to be of general interest.

While making no recommendation for the inclusion of material other than that authorized for Institute presentation or publication, your committee notes that the publications of sister societies from time to time embody material of the nature contemplated. It would seem that, if authorized by the procedure above suggested, such material might be included in the lists of that available for discussion by Sections and Student Branches.

As instancing the character of material deemed suitable by your committee the

following titles appearing in ELECTRICAL ENGINEERING during 1933 and 1934 are cited:

April '33 —Private vs. Public Enterprise, Rautenstrauch
April '33 —Private Enterprise, Jordan
1933–34 —Reports and comments, E.C.P.D.
May '33 —Economic Forces (second report), A.E.C.
June '33 —Address to Student Branch Convention, R. E. Free
Aug. '33 —Communication (Engineer - Economists), Hirshfeld
Sept. '33 —Engineer and New Deal, Wickenden
March '34—Scientific Thought and Social Reconstruction, Mees
March '34—Social Aspects and Engineering Approach, H. A. Wallace
June, '34 —Engineering of Next Generation
June '34 —Making of a Profession, Wickenden
Nov. '34 —Engineering and the Economic Scene, Jordan and Chevalier

Respectfully submitted,
C. O. BICKELHAUPT
R. N. CONWELL
W. I. SLICHTER
A. W. BERRESFORD, *chairman*

A.I.E.E. Directors Meet at Institute Headquarters

The regular meeting of the board of directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, N. Y., on May 20, 1935.

There were present: *Past-Presidents*—H. P. Charlesworth, New York, N. Y.; and J. B. Whitehead, Baltimore, Md. *Vice Presidents*—F. O. McMillan, Corvallis, Ore.; and W. H. Timbie, Cambridge, Mass. *Directors*—L. W. Chubb, East Pittsburgh, Pa.; F. M. Farmer, New York, N. Y.; P. B. Juhnke, Chicago, Ill.; Everett S. Lee, Schenectady, N. Y.; A. H. Lovell, Ann Arbor, Mich.; and A. C. Stevens, Schenectady, N. Y. *National Treasurer*—W. I. Slichter, New York, N. Y. *National Secretary*—H. H. Henline, New York, N. Y.

In the absence of President J. Allen Johnson, on account of illness, Vice President Timbie presided.

Minutes were approved of meetings of the board of directors held January 21 and the executive committee on March 29, 1935.

Report of the executive committee of action, under date of April 12, 1935, admitting 361 applicants to the grade of Associate and enrolling 13 Students, was approved.

A report of a meeting of the board of examiners held April 24, 1935, was presented and approved. Upon recommendation of the board of examiners, the following actions were taken: 7 applicants were transferred to the grade of Fellow, 18 applicants were elected and 32 were transferred to the grade of Member, 236 applicants were elected to the grade of Associate, and 192 Students were enrolled.

The finance committee reported disbursements amounting to $17,345.86 in April and $18,427.78 in May. Report approved.

Section 14 of the by-laws was amended to read as follows:

"14. Any resignations received by the national secretary not later than June first of any year (September first in the case of members residing outside of the United States, Canada, and Mexico) may, at his discretion, be considered as having been received as of May first preceding. A resignation received after June first (or September first for non-resident members) shall involve payment of dues for that portion of the fiscal year ending with, and including, that quarter in which the resignation is received."

Upon request of the Indianapolis-Lafayette Section and recommendation of the Sections committee, an adjustment was made in the territory of that Section and its name was changed to Central Indiana Section.

The annual report of the board of directors to the membership, prepared by the national secretary, was approved for presentation at the annual meeting of the Institute in Ithaca, N. Y., on June 24, 1935. Contained therein were reports of general standing committees.

The annual report of the national treasurer was presented and accepted.

A report of the committee on award of Institute prizes covering the prizes awarded for papers presented in 1934 was received, and is published elsewhere in this issue.

In accordance with Section 37 of the constitution, the appointment of a national secretary for the administrative year beginning August 1, 1935, was made. National Secretary H. H. Henline was reappointed.

A report of the special committee appointed to consider the question of the Institute's sponsoring discussions on social and economic subjects was presented and adopted, and the committee was discharged, with an expression of the board's appreciation of its services. (The report is published elsewhere in this issue.)

The board approved A.I.E.E. representatives nominated by the committee on engineering schools of the Engineers' Council for Professional Development, for appointment as members of the delegatory committees in regions 1 and 2 (including the New England and Middle Atlantic States) in connection with the E.C.P.D. program for the accrediting of engineering schools.

An invitation was accepted to send delegates to the celebration, in Brussels, on June 13–15, 1935, of the fiftieth anniversary of the Societe Belge des Ingenieurs et des Industriels. A. S. Garfield, local honorary secretary of the Institute for France, and H. R. Summerhayes, of Schenectady, N. Y., were appointed as such representatives.

Other matters were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.

Guggenheim Aeronautic Medal Awarded. The 1935 Daniel Guggenheim medal for aeronautic achievement has been awarded to William Frederick Durand, professor emeritus of mechanical engineering at Stanford University, Calif. It was made "for notable achievement as pioneer in laboratory research and theory of aeronautics; distinguished contributions to the theory and development of aircraft propellers." The award was made by a board having 8 members in the United States, and 7 foreign members. Doctor Durand, a past president of the American Society of Mechanical Engineers, was a member of the Institute from 1912 to 1934. Previous recipients of the medal are Orville Wright (U.S.), Ludwig Prandtl (Germany), F. W. Lanchester (England), Juan de la Cierva (Spain), J. C. Hunsaker (U.S.), and W. E. Boeing (U.S.).

At Ithaca, 1935 Summer Convention Headquarters

A SCENE on the Ithaca (N. Y.) Golf Course, which, although obviously taken several years ago, will interest many of those attending the Institute's fifty-first annual summer convention on the campus of Cornell University at Ithaca, June 24–28, 1935. This golf course, just off the Cornell campus, overlooks Cayuga Lake, and is one of the best courses in the Finger Lakes region. In keeping with the policy of holding "a convention for the entire Institute," arrangements have been made so that the daily greens fee for this course for members and guests is $1. Other courses, too, are readily available in this region.

Section and Branch Activities

Summarized in Annual Report for 1934—35

FOLLOWING the plan established in 1933, of publishing the annual report on Section and Branch activities in ELECTRICAL ENGINEERING instead of in pamphlet form, the report for the fiscal year which ended April 30, 1935, is presented here. Similar information for the fiscal year which ended April 30, 1933, was published in ELECTRICAL ENGINEERING for June 1933, pages 726–8, and for the fiscal year ending April 30, 1934, in ELECTRICAL ENGINEERING for June 1934, pages 1027–9.

The accompanying comprehensive summary constitutes a report upon the large and important division of Institute activities coming under the supervision of the Sections committee and the committee on Student Branches, the 2 committees being composed of the following personnel: Sections—I. M. Stein, *chairman*, L. A. Doggett, Mark Eldredge, F. A. Hamilton, Jr., A. P. Hill, W. H. Timbie, and, *ex-officio*, the chairmen of all Sections of the Institute. Student Branches—L. A. Doggett, *chairman*, R. B. Bonney, F. O. McMillan, Charles F. Scott, W. H. Timbie, and, *ex-officio*, all Student Branch counselors.

SECTION ACTIVITIES

During the fiscal year which ended April 30, 1935, there was no increase in the number of Sections (61), but the total number of meetings held was about 50 greater than that for the preceding fiscal year and the total attendance was virtually the same.

The New York and Chicago Sections continued their technical group activities substantially as they have been operated for several years. The Pittsfield and Schenectady Sections continued their annual competition among their younger members at 2 joint meetings, and the Boston and Lynn Sections inaugurated a plan for competition among their members in both the writing and presentation of papers, having 3 selected papers from each Section presented at a joint meeting, and awarding 3 prizes.

Other important developments in Section activities include: the formation by the Portland Section of technical committees on communication, industrial power applications, and transmission and distribution, which held 6, 9, and 6 meetings, respectively, for the presentation of technical material, with an average attendance of about 16; the holding of special technical meetings of the San Francisco Section between regular meetings (see page 454, April 1935 ELECTRICAL ENGINEERING); the holding of forum meetings between regular meetings of the Toledo Section, and also the plan of having a brief talk on fundamental electrical theory by a member of that Section during the first part of each regular meeting (see page 566, May 1935 ELECTRICAL ENGINEERING).

The Sections were urged by the committee on student selection and guidance of the Engineers' Council for Professional Development to co-operate with other engineering groups in supplying advice to boys thinking of entering engineering.

Detailed information on Section meetings during the past year is given in table I, and table II contains a brief summary of these meetings held during the last 3 fiscal years.

Table I—Section Meetings Held During Year Ending April 30, 1935

Section	A.I.E.E. Members Aug. 1933	A.I.E.E. Members Aug. 1934	Meetings* During Year Number	Meetings* During Year Avg. Attendance	Meetings* During Year Avg. Attendance as Per Cent of Membership Aug. 1934
Akron	63	69	9	87	126
Alabama	19	39	4	21	54
Atlanta	65	76	4	—	—
Baltimore	157	157	9	204	130
Boston	377	370	6	238	64
Chicago	633	591	10	252	43
Power Group			3	101	
Cincinnati	146	140	11	92	66
Cleveland	193	200	8	147	74
Columbus	55	58	3	77	133
Connecticut	238	237	8	91	38
Dallas	78	78	9	67	86
Denver	130	130	9	96	74
Detroit-Ann Arbor	226	246	10	119	48
Erie	51	49	6	152	310
Florida	41	40	2	213	532
Fort Wayne	53	52	9	165	317
Houston	53	49	7	62	126
Indianapolis-Lafayette	73	85	5	138	162
Iowa	55	52	9	47	90
Ithaca	41	46	4	53	115
Kansas City	138	125	9	96	77
Lehigh Valley	176	176	9	166	94
Los Angeles	349	333	10	116	35
Louisville	48	46	7	77	167
Lynn	104	100	12	558	558
Madison	59	56	5	73	130
Memphis	30	29	12	58	200
Mexico	61	65	10	46	71
Milwaukee	161	153	18	138	90
Minnesota	79	76	6	60	79
Montana	31	29	6	19	66
Nebraska	45	46	1	49	107
New Orleans	32	42	5	66	157
New York	2,798	2,703	5	580	21
Communication Group			3	475	
Illumination Group			4	88	
Power Group			7	321	
Transportation Group			3	317	
Niagara Frontier	142	150	8	191	127
North Carolina	68	68	2	123	181
Oklahoma City	77	90	8	123	137
Philadelphia	529	512	7	170	33
Pittsburgh	409	383	8	242	63
Pittsfield	90	96	11	854	890
Portland	81	86	10	71	83
Communication			6	16	
Industrial Power Application			9	17	
Transmission & Distribution			6	15	
Providence	73	71	6	82	116
Rochester	64	59	10	119	202
St. Louis	195	173	7	124	72
San Antonio	40	30	9	43	143
San Francisco	379	359	8	119	33
Special technical meetings			6	39	
Saskatchewan	31	23	7	30	130
Schenectady	335	350	15	167	48
Seattle	133	124	9	63	51
Shasta	50	50	8	153	306
Spokane	33	32	7	37	116
Springfield, Mass.	72	60	9	72	104
Syracuse	62	62	4	234	377
Toledo	61	59	8	118	200
Toronto	302	287	14	116	40
Urbana	54	54	7	102	300
Utah	44	38	8	46	121
Vancouver	77	81	11	45	56
Virginia	72	81	4	113	139
Washington	155	173	8	140	81
Worcester	65	54	4	160	296
Total	61	10,531	10,337		

Total number of meetings	521
Total attendance	73,381

Table II—Section Meetings Held During Last 3 Fiscal Years

	Fiscal Year Ending April 30 1933	1934	1935
Number of Sections	60	61	61
Number of meetings held	498	472	521
Average number of meetings	8.3	7.7	8.5
Total attendance	73,806	73,271	73,381
Average attendance per meeting	148	156	141

Table III—Branch Meetings Held During Year Ending April 30, 1935

Branch	Meetings During Year Number	Meetings During Year Avg. Attendance	Approx. No. of Talks by Students
Akron, University of	1	9	
Alabama Polytechnic Institute	13	24	
Alabama, University of	11	39	14
Arizona, University of	23	7	20
Arkansas, University of	19	33	25
Armour Institute of Technology	9	52	
British Columbia, Univ. of	8	19	14
Brooklyn, Polytechnic Inst. of	7	57	7
Brown University[1]	4	32	
Bucknell University	4	15	1
California Institute of Tech.	9	31	1
California, University of	11	45	3
Carnegie Institute of Tech	8	48	3
Case School of Applied Science	16	44	35
Catholic University of America	4	20	3
Cincinnati, University of	9	47	7
Clarkson College of Technology	3	28	
Clemson Agricultural College	7	37	15
Colorado State Agri. College	8	12	3
Colorado, University of	9	58	1
Cooper Union	—	—	
Cornell University	7	77	5
Denver, University of	15	22	
Detroit, University of	5	21	
Drexel Institute	19	25	12
Duke University	9	21	9
Florida, University of	12	59	2
George Washington University	7	43	1
Georgia School of Technology	5	22	
Harvard University	4	46	
Idaho, University of	10	54	2
Illinois, University of	4	97	3
Iowa State College	9	71	6
Iowa, University of	21	38	10
Johns Hopkins University[1]	1	30	
Kansas State College	10	68	4
Kansas, University of	11	46	6
Kentucky, University of	5	76	
Lafayette College	5	29	5
Lehigh University	6	66	3
Lewis Institute	5	73	
Louisiana State University	6	22	5
Louisville, University of	5	18	6
Maine, University of	5	26	
Marquette University	10	42	
Massachusetts Inst. of Tech	9	51	5
Michigan College of Min. & Tech.	6	34	1
Michigan State College	1	18	
Michigan, University of	4	54	
Milwaukee School of Engineering	6	46	1
Minnesota, University of	8	33	4
Mississippi State College	7	15	11
Missouri School of Mines & Met.	9	44	3
Missouri, University of	4	36	

BRANCH ACTIVITIES

During the past year, new Branches were organized at Brown University, Johns Hop-

Montana State College	18	31	48
Nebraska, University of	11	27	1
Nevada, University of	10	40	
Newark College of Engineering	7	27	12
New Hampshire, University of	20	26	33
New Mexico, University of	10	22	2
New York, Col. of the City of			
(Day division)	13	33	1
(Evening division)	5	47	
New York University			
(Day division)	12	16	40
(Evening division)	2	45	10
North Carolina State College	9	30	3
North Carolina, University of	8	36	4
North Dakota State College	8	16	10
North Dakota, University of	12	15	14
Northeastern University	3	21	
Notre Dame, University of	12	141	6
Ohio Northern University	—	—	
Ohio State University	9	43	1
Ohio University	3	16	1
Oklahoma A. & M. College	14	50	10
Oklahoma, University of	8	46	8
Oregon State College	8	70	3
Pennsylvania State College	8	107	5
Pennsylvania, University of	5	11	
Pittsburgh, University of	11	78	5
Porto Rico, University of	8	36	2
Pratt Institute	8	76	7
Princeton University	3	24	
Purdue University	5	60	1
Rensselaer Polytechnic Institute	6	119	4
Rhode Island State College	12	22	12
Rice Institute	8	17	4
Rose Polytechnic Institute	1	17	
Rutgers University	4	20	
Santa Clara, University of	5	28	3
South Carolina, University of	27	25	12
South Dakota State College	4	49	1
So. Dakota State School of Mines	6	18	
South Dakota, University of	7	6	
Southern California, Univ. of	15	31	11
Southern Methodist University	13	27	11
Stanford University	18	25	
Stevens Institute of Technology	6	24	
Swarthmore College			
Syracuse University	19	14	28
Tennessee, University of	8	26	1
Texas A. & M. College	3	47	1
Texas Technological College	7	27	4
Texas, University of	—	—	
Tufts College[1]	1	51	
Union College[4]	5	40	2
Utah, University of	4	18	1
Vermont, University of	7	18	
Villanova College	11	25	6
Virginia Military Institute	—	—	
Virginia Polytechnic Institute	29	48	30
Virginia, University of	6	19	6
Washington, State College of	10	40	
Washington, University of	11	39	6
Washington University	21	23	
West Virginia University	13	38	80
Wisconsin, University of	1	18	
Worcester Polytechnic Institute	4	44	
Wyoming, University of	9	11	2
Yale University	2	40	
Total	117		708

Total number of meetings 986
Total attendance 36,629

Authorized by board of directors:
1. August 7, 1934 3. January 21, 1935
2. January 21, 1935 4. December 7, 1934

Table IV—Branch Meetings Held During Last 3 Fiscal Years

	Fiscal Year Ending April 30		
	1933	1934	1935
Number of Branches	111	113	117
Number of meetings held	1,026	1,015	986
Average number of meetings	9.3	9.0	8.4
Total attendance	59,439	41,772	36,629
Average attendance per meeting	58	41	37
Number of student talks	983	1,004	708

kins University, Tufts College, and Union College, bringing the total number to 117.

Nearly all Branches carried on a normal amount of activity, but, the total numbers of meetings, student papers presented and attendance were smaller than for the preceding year.

Section and Branch co-operation was continued in many cases in which it had previously been established, and the students have shown an increasing interest in forming contacts with Institute members. Unusually successful student sessions were held at the District meetings in Worcester, Mass., and Oklahoma City, Okla., and at the Pacific Coast convention in Salt Lake City. The 5 such sessions held at these 3 meetings included a total of 19 papers; the attendance and interest were excellent.

1983 students were enrolled during the past year, and about 50 per cent of those whose terms expired April 30, 1935, applied for admission as Associates. Comprehensive information on Branch activities during the year is given in tables III to VII.

Table V—Comparison of Branch Activities by Districts

District	No. of Branches Jan. 1	Avg. No. Meetings per Branch	Avg. Attendance per Meeting	Approx. Avg. No. Student Talks per Branch	No. Branches Reporting 8 or More Student Talks
1	15	7.3	36	5.9	3
2	19	7.1	42	8.8	3
3	9	8.0	37	8.8	2
4	17	9.9	34	6.9	6
5	16	6.7	58	2.4	2
6	10	8.9	23	3.2	2
7	15	9.6	36	5.3	4
8	7	12.7	26	5.4	2
9	6	10.2	42	10.0	1
10	1	8.0	19	14.0	1

Table VI—Conferences on Student Activities

District	Location	Date
1	Worcester, Mass. (North Eastern District Meeting)	5/18/34
8 & 9	Salt Lake City, Utah (Pacific Coast Convention)	9/7/34
2	Carnegie Institute of Technology Pittsburgh, Pa.	1/8/35
6	North Dakota State College Fargo, N. D.	4/12, 13/35
4	Virginia Polytechnic Institute Blacksburg, Va.	4/12/35
7	Oklahoma City, Okla. (South West District Meeting)	4/25/35

Table VII—Student Conventions

Sponsored by District	Location	Date	No. of Student Papers
1	Worcester, Mass. (No. Eastern District Mtg.)	5/18/34	7
8 & 9	Salt Lake City, Utah (Pacific Coast Convention)	9/4–5/34	12
1	Harvard University Cambridge, Mass.	12/15/34	5
4	Virginia Polytechnic Institute Blacksburg, Va.	4/12/35	6
6	North Dakota State College, Fargo, N. D.	4/12, 13/35	
7	Oklahoma City, Okla. (South West District Mtg.)	4/25–26/35	12
New York Section	New York	4/26/35	5
2	Lafayette College Easton, Pa.	4/29/35	5

Section and Branch Joint Meetings

As stated above, co-operation between Sections and Branches continued to receive much emphasis. Table VIII contains brief information on some outstanding examples.

Table VIII—Section or Joint Section and Branch Meetings With Active Student Participation

Sections	Schools	Date	Student Talks	Attendance
Oklahoma City	Oklahoma A. & M. College			
	Univ. of Oklahoma	5/10/34	4	121
St. Louis	Missouri Sch. of Mines and Metallurgy			
	Univ. of Missouri			
	Washington Univ.	5/12/34	4	90
Cincinnati	Univ. of Cincinnati	5/14/34	5	130
Portland	Oregon State College	5/19/34	3	112
Iowa	Univ. of Iowa	11/14/34	1	54
Kansas City	Univ. of Kansas	11/15/34	2	95
Vancouver	Univ. of British Columbia	2/1/35	4	40
Dallas	Southern Methodist Univ.	2/25/35	3	45
Spokane	Univ. of Idaho			
	State College of Washington	3/22/35	2	74
Houston	Rice Institute			
	A. & M. College of Texas	3/28/35	2	52
San Francisco	Univ. of California			
	Univ. of Santa Clara			
	Stanford Univ.	4/11/35	3	60
Urbana	Univ. of Illinois			
	Purdue Univ.			
	Rose Polytechnic Inst.			
	Washington Univ.	4/13/35	3	200
Los Angeles	Calif. Inst. of Tech.			
	Univ. of Southern Calif.	4/16/35	5	145
Seattle	Univ. of Washington	4/16/35	2	120
Cleveland	Case Sch. of Ap. Science	4/18/35	3	93
North Carolina	Duke Univ.			
	North Carolina State Col.			
	Univ. of No. Carolina	4/26/35	3	114
Minnesota	Univ. of Minnesota	4/29/35	4	43

Student Conference Held by Southern District

A conference of the student Branches in the Institute's southern district, number 4, was held on the campus of Virginia Polytechnic Institute at Blacksburg, Va., April 11–13, 1935. The registration at this conference was 162, of which 87 were counselors and members of Branches and 75 were A.I.E.E. members from the Virginia Section, near-by West Virginia points, and a few interested nonmember visitors. In addition, the meetings were attended by a number of Virginia Polytechnic Institute faculty members and students. Delegates from 15 of the 17 student Branches in the southern district were in attendance. Prof. Claudius Lee, counselor of the local Branch, acted as chairman of the conference, and S. B. West, secretary of the local Branch and chairman-elect, acted as secretary.

Registration began the afternoon of April 11, and that evening about 250 persons were in attendance for a series of talking motion pictures presented by the American Telephone and Telegraph Company. Following this an informal smoker was held, presided over by Mr. West.

On April 12, the morning session was called to order by Prof. Claudius Lee, and R. L. Humbert formally welcomed the visitors on behalf of the V.P.I. The engineering department and the department of electrical engineering were then represented by E. B. Norris and Dr. S. R. Pritchard, respectively. The technical session and presentation of student papers followed. The papers were:

Some Additional Litchenberg Figures, by R. B. Hutchins, University of Alabama.

The Photo-Voltaic Cell in Photometry, by O. D. Lyon, Georgia School of Technology.

The Tennessee Valley Authority—An Experiment, by H. P. Cotton, North Carolina State College.

A Vacuum Tube Voltage Regulator, by R. F. Hays, Jr., Mississippi State College.

An Experimental Vacuum Tube Voltmeter, by S. A. Black and C. C. Jones, University of South Carolina.

An Application of Operational Calculus to an A-C Circuit, by I. G. Foster, Virginia Military Institute.

A very encouraging sign was the high quality of the papers presented, and the fact that every one of them provoked some discussion. Prizes for these papers were awarded, the judges of the contest being: F. M. Craft, vice president A.I.E.E. Southern District; Dean S. B. Earle, Clemson College, South Carolina; and Dean W. S. Rodman, University of Virginia. The paper by Mr. Hutchins was awarded first prize of $15; that by Mr. Cotton, second prize of $10; and that of Mr. Foster, third prize of $5.

Following the technical session the conference went into a business session. It was voted that the next student Branch conference of the Southern District be held at Clemson College, South Carolina, and Prof. S. R. Rhodes was unanimously elected chairman of the student Branch conference for the ensuing year. Professor Rhodes also was unanimously elected to represent the conference at the A.I.E.E. summer convention at Ithaca, N. Y., June 24–28, 1935. A questionnaire is to be sent out to determine the most desirable date for holding the District's next conference.

Professor Lee delivered a report on the Institute's annual convention at Hot Springs, Va., June 1934, and on the plans discussed for betterment of student activities. Among other subjects considered, Vice President Craft suggested that the present method of Electrical Engineering in handling student activities appeared to be very good, and advised all students to read this publication religiously. The chairman then expressed his thanks to all committees, counselors, Students, and volunteers who had helped to make the conference so successful.

Following this afternoon business meeting, visitors inspected the various departments and near-by points of interest. At the dinner meeting that evening, A. J. Francis, vice chairman of the V.P.I. Branch, presided. Vice President Craft awarded the prizes for the Student papers, after which an informal social session was held.

The concluding day, April 13, was reserved for inspection trips to several nearby points of interest.

Engineering Boards Hold Joint Conclave

What are the professional engineering societies doing to advance the profession and practice of engineering in the interest of professional advancement and of effective service to American business and industry?

For the purpose of answering this and related questions through the medium of "verbal diorama," a large proportion of the officers and directors of the national societies of civil, mining and metallurgical, mechanical, and electrical engineers, together with members of the governing bodies of their several jointly sponsored functional organizations, met for dinner and a general conclave Monday evening, May 20, 1935, at the Engineers' Club in New York. Including a few special guests, a total of 89 persons were present. This was the first time in the history of the societies that a meeting of such ambitious scope had been undertaken, although in 1933 at Chicago, and perhaps once or twice in earlier years, joint meetings had been undertaken. The one claimed by A.I.E.E. Past-President Charles F. Scott as being the very first, was the "First Founders Feast" reported to have been held one evening in the spring of 1907 in the then new Engineering Societies' Building "shortly before its formal dedication and when there was some scaffolding in the large room on the fifth floor in which the table was set."

The prime purpose of the meeting of May 20, 1935, was to provide an effective opportunity for an increase in knowledge, understanding, and general interest in the various phases of the work of the several joint organizations created by the national societies to serve the engineering profession. Toward this end, carefully prepared concise statements covering the scope and significance of the work of each of the 8 jointly sponsored organizations were delivered at the meeting. The subjects of these statements, and the men who presented them, are as follows:

1. United Engineering Trustees, Inc., by Harold V. Coes, president of U. E. T.; past vice president of the American Society of Mechanical Engineers; manager, industrial department, Ford, Bacon and Davis, Inc., New York, N. Y.

2. Engineering Societies Library, by Walter I. Slichter, treasurer American Institute of Electrical Engineers; professor of electrical engineering, Columbia University, New York, N. Y.

3. Engineering Foundation, by H. P. Charlesworth, chairman Engineering Foundation Board, junior past-president American Institute of Electrical Engineers; assistant chief engineer, American Telephone and Telegraph Company, New York, N. Y.

4. American Standards Association, by Howard E. Coonley, president A. S. A.; president Walworth Company, New York. In Mr. Coonley's enforced absence, the statement was read by F. E. Moskovica, vice president A. S. A.; chairman of the board of the Marmom Harrington Company, Indianapolis, Ind.; vice president, Frederick H. Levey, Inc., 59 Beekman Street, New York, N. Y.

5. Division of engineering of the National Research Council, by Dr. D. S. Jacobus, vice chairman of the division; past-president American Society of Mechanical Engineers; advisory engineer, Babcock and Wilcox Company, New York, N. Y.

6. Engineering Societies Employment Service, by George T. Seabury, chairman of the National Advisory Board; secretary American Society of Civil Engineers, New York, N. Y.

7. American Engineering Council, by J. F. Coleman, president A. E. C.; past-president American Society of Civil Engineers; consulting engineer, New Orleans, La.

8. Engineers Council for Professional Development, by Dr. C. F. Hirshfeld, chairman E.C.P.D.; chief of research department, Detroit Edison Company, Detroit, Mich.

9. "Industrial Prospecting," a special address prepared by Dr. Charles F. Kettering, chairman of the division of engineering of the National Research Council; vice president General Motors Corporation; president General Motors Research Corporation; read in Doctor Kettering's absence by Maurice Holland, director of division of engineering and industrial research, National Research Council, New York, N. Y.

Presiding officer for the gathering was Arthur F. Tuttle, president American Society of Civil Engineers; New York state engineer, Federal Emergency Administration of Public Works. Toastmaster for the evening was Dr. Harvey N. Davis, president Stevens Institute of Technology, Hoboken, N. J.; past-president American Society of Mechanical Engineers. Honored guests were: Dr. Charles F. Scott of New Haven, Conn.; past-president A.I.E.E.; professor emeritus of electrical engineering Yale University; prime mover and cofounder of the project that nearly 30 years ago led to the realization of the dream of an Engineering Societies Building as the national home of the national professional societies; and Dr. Isaiah Bowman, president-designate of The Johns Hopkins University, Baltimore, Md., and chairman of the National Research Council.

Following the presentation of the several highly informative short addresses (the substance of which is scheduled to be reflected generously in a subsequent issue of Electrical Engineering) there was a discussion participated in by many who were interested in different phases of the varied

work described. At the close of this session, Toastmaster Davis capped a fitting climax upon a successful evening by calling, without warning, upon Dr. Alfred D. Flinn, for more than 17 years director of Engineering Foundation, and its devoted, inspiring leader. Doctor Davis aptly characterized Doctor Flinn of being responsible more than any other individual for the evolution of effective co-operation of the founder societies and their functional organizations. In his brief response Doctor Flinn paid tribute to Dr. Ambrose Swasey, founder of the Engineering Foundation "as an institution for the furtherance of research in science and engineering, or for the advancement in any other manner of the profession of engineering and the good of mankind." As tangible evidence of the work being done, Doctor Flinn urged critical consideration of the several reviews and reports presented.

Among the large delegation of Institute members present were many who, in addition to their Institute affiliation, were present as representative officers or board members of other societies or of one or more of the 8 joint functional organizations. Those present included the following (initials in parenthesis indicate representation of organization other than A.I.E.E.):

P. G. Agnew, New York, N. Y.; (ASA).
A. W. Berresford, past-president, New York, N. Y.; (AEC).
C. O. Bickelhaupt, past vice president, chairman publication committee, New York, N. Y.; (AEC, ECPD).
H. P. Charlesworth, junior past-president, New York, N. Y.; (EF; UET).
F. J. Chesterman, past director, Pittsburgh, Pa.; (AEC).
L. W. Chubb, director, East Pittsburgh, Pa.
F. H. Daggett, New Brunswick, N. J.; (ECPD).
F. M. Farmer, director, chairman research committee, New York, N. Y.
H. H. Henline, national secretary, New York, N. Y.; (ECPD, Library).
G. Ross Henninger, editor, New York, N. Y.
C. F. Hirshfeld, Detroit, Mich.; (ECPD).
Maurice Holland, New York, N. Y.; (NRC).
D. S. Jacobus, New York, N. Y.; (NRC).
F. B. Jewett, past-president, New York, N. Y.; (NRC).
P. B. Juhnke, director, Chicago, Ill.
G. L. Knight, past vice president, Brooklyn, N. Y.; (UET).
E. S. Lee, director, chairman membership committee, Schenectady, N. Y.
A. H. Lovell, director, Ann Arbor, Mich.
J. H. McGraw, Sr., New York, N. Y.
F. O. McMillan, vice president, Corvallis, Ore.
C. F. Scott, past-president, New Haven, Conn.; (ECPD).
W. I. Slichter, treasurer, New York, N. Y.; (EF, Library).
C. E. Stephens, past director, chairman committee on code of principles of professional conduct, New York, N. Y., (AEC).
A. C. Stevens, director, Schenectady, N. Y.
R. H. Tapscott, director, chairman finance committee, New York, N. Y.
W. E. Wickenden, Cleveland, Ohio; (ASME, ECPD).
H. R. Woodrow, director, Brooklyn, N. Y.; (UET).

Institute Prize Awards Announced for 1934 Papers

FOUR national prizes for papers presented during the calendar year 1934 have been announced by the committee on award of Institute prizes, which consists of R. N. Conwell (A'15, F'31) chairman, C. O. Bickelhaupt (M'22, F'28), and F. M. Farmer (A'02, F'13). These prizes in each case consist of a suitable certificate. Personal presentation of the prizes will take place at the opening session of the Institute's summer convention to be held on the campus of Cornell University, Ithaca, N. Y., June 24–29, 1935.

Authors presenting papers which are eligible for future prizes should bear in mind that to be considered for prizes, papers must be submitted specifically for this purpose to the proper committee. Prize consideration is not given automatically to all papers published or presented at conventions or meetings.

National Prizes

After due consideration of all highly recommended papers, the committee on award of Institute prizes made the following awards of national prizes for papers presented in 1934:

Best Papers

Prize for best paper in engineering practice was awarded to J. Allen Johnson (A'07, F'27 and president) and R. T. Henry (A'24, F'33) for their paper "Fundamentals of Design of Electrical Energy Delivery Systems," published in ELECTRICAL ENGINEERING for December 1933, pages 831–8, and discussed at the winter convention, New York, N. Y., January 23–26, 1934.

Honorable mention was made of "Auditory Perspective–Transmission Lines," by H. A. Affel (A'18, M'23), R. W. Chestnut (A'19) and R. H. Mills (A'33) published in ELECTRICAL ENGINEERING for January 1934, pages 28–32, and discussed at the winter convention, New York, N. Y., January 23–26, 1934.

Prize for best paper in theory and research awarded to H. S. Black (A'23, M'33), for his paper "Stabilized Feedback Amplifiers," published in ELECTRICAL ENGINEERING for January 1934, pages 114–20, and discussed at the winter convention, New York, N. Y., January 23–26, 1934.

Honorable mention was made of "High Frequency Induction Furnaces" by C. A. Adams (A'94, F'13, member for life and past-president), J. C. Hodge, and M. H. MacKusick, published in ELECTRICAL ENGINEERING for January 1934, pages 194–205, and discussed at the winter convention, New York, N. Y., January 23–26, 1934.

Prize for best paper in public relations and education was awarded to C. F. Hirshfeld (A'05) for his paper "Engineers of the Next Generation" published in ELECTRICAL ENGINEERING for June 1934, pages 857–9, and discussed at the summer convention, Hot Springs, Va., June 25–29, 1934.

Honorable mention was made of "Encouraging Initiative in the Engineering Student" by C. L. Dawes (A'13, M'15), published in ELECTRICAL ENGINEERING for June 1934, pages 910–14, and discussed at the summer convention, Hot Springs, Va., June 25–29, 1934.

Initial Paper

Prize for initial paper was awarded to J. R. Meador (A'34), for his paper "Calibration of the Sphere Gap," published in ELECTRICAL ENGINEERING for June 1934, pages 942–8, and discussed at the summer convention, Hot Springs, Va., June 25–29, 1934.

Honorable mention was made of the following papers: "Wide-Band Open-Wire Program System" by H. S. Hamilton (M'24), published in ELECTRICAL ENGINEERING for April 1934, pages 550–62, and discussed at the Pacific Coast convention, Salt Lake City, Utah, Sept. 3–7, 1934; and "Trolley Wire Lubrication Improved" by J. V. Lamson (A'29) published in ELECTRICAL ENGINEERING for November 1933, pages 771–6, and discussed at the winter convention, New York, N. Y., January 23–26, 1934.

In the class of the national prize for Branch papers only 2 papers were submitted. These papers received low gradings and were not recommended to be of sufficient value to warrant publication unless extensively revised. The committee recognizes the need to encourage the preparation and presentation of Branch papers, but, as only 2 papers were submitted and as neither of these was considered to be up to the standard of Branch papers, the committee did not award a national prize for Branch papers this year.

In each of the other classes of prizes the committee considered a number of papers which were of universally high caliber so that the task of choice between them was a difficult one. Commendation was extended to all authors for the high standard of papers and to the technical committee for their work in sponsoring a number of the papers and grading them at the same time they were initially reviewed, which has been of valuable assistance to the committee on award of Institute prizes in determining the most worthy papers for the awards.

District Prizes

District prizes as announced by 3 Districts to date include 2 awards of $25 each, together with appropriate certificates. Other District awards will be announced in subsequent issues, as the information becomes available.

District No. 1

Prize for Branch paper awarded to Albert E. French for his paper "The Place of Operational Calculus in Undergraduate Study of Electrical Engineering," presented at the North Eastern District Meeting, Worcester, Mass., May 16–18, 1934.

District No. 7

Prize for Branch paper awarded to Ralph A. Galbraith for his paper "Torque-Angle Characteristics of Synchronous Motors," presented at a joint meeting of the St. Louis Section, University of Missouri Branch, Missouri School of Mines and Metallurgy Branch, and Washington University Branch, May 12, 1934.

District No. 10

Prize for best paper awarded to H. Forbes-Roberts (A'25) for his paper "The British National Grid System," presented at meeting of the Saskatchewan Section, April 25, 1934.

Smoke Abatement Rules Published. "To insure construction of new plants and buildings and changes in existing plants being done in such a manner that smoke will not be made," the department of smoke regulation of the board of health and vital statistics of Hudson County, N. J., has issued a comprehensive pamphlet of rules and regulations governing details of fuel burning equipment required for the issuance of permits and certificates. This edition is revised as of March 1935. Copies of the pamphlet are reported as available to members of the Institute who will forward 3 cents postage to the department at the Court House, Jersey City, N. J.

E.C.P.D. Offers a Method of Self-Appraisal as a Basis for Post-College Training

WHEN does an engineer's education end? With his graduation from college? Or is further self-development necessary to enable the junior engineer to take responsible charge of engineering work, become a valuable member of society, and gain professional recognition?

In the opinion of the Engineers' Council for Professional Development, the years immediately after graduation from an engineering school are not only fruitful years for growth and development, but critical years in the young graduate's progress toward the goal of public recognition as a full-fledged engineer. It is the function of the E.C.P.D. committee on professional training to offer a program for further intellectual development that will bridge this gap between graduation, or its equivalent, and professional recognition.

The Engineers' Council for Professional Development is a conference of engineering bodies organized to enhance the professional status of the engineer by promoting higher standards of education and practice, and greater effectiveness in dealing with technical, social, and economic problems. It derives its existence and authority from 7 constituent bodies representing the technical, educational, legislative, and professional phases of an engineer's life—the American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, The American Society of Mechanical Engineers, American Institute of Electrical Engineers, American Institute of Chemical Engineers, Society for the Promotion of Engineering Education, and National Council of State Boards of Engineering Examiners.

The program of E.C.P.D. is embodied in the work of 4 major committees dealing with: (1) the selection and guidance of prospective engineering students; (2) the accrediting of engineering schools worthy of recognition; (3) the further professional and personal development of junior engineers; and (4) the formulation of minimum standards for professional recognition. Information regarding the E.C.P.D. and the activities of its committees can be obtained from the secretary of the E.C.P.D., 29 West 39th St., New York, N. Y.

Professional Training

Genl. Robert I. Rees, assistant vice president of the American Telephone and Telegraph Company, and chairman of the E.C.P.D. committee on professional training, recently outlined the program for junior engineers. "It is incumbent upon us," he said, "to prepare sound programs for the guidance of the intellectual development of the young engineer after he gets into practice. It is particularly important to stimulate his growth in cultural, social, and economic subjects, for the study of which his college course necessarily left little time."

For juniors and those who are about to enter the engineering profession, General Rees's committee has prepared a personal appraisal questionnaire that offers opportunity for a searching self-analysis of the individual's status. This questionnaire has been published to assist those who are looking forward to an engineering career, or in obtaining a broader appreciation of their own interests and ability and in planning a definite program of self-development. In this way, the committee hopes ultimately to bring about a higher level of professional attainment and consciousness. If the young graduate will thoughtfully and honestly answer the 65 questions in the appraisal regarding his present occupation, his professional status, his personal relations, and his general program of development, he should be able to outline an immediate plan of study based upon his individual strength and weakness, his background, and ambition. The committee has suggested that in using the list it be read over carefully first, and the questions raised and pondered upon for a few days, and perhaps discussed with intimate friends or an older man with sympathetic understanding whose judgment is trusted.

The questions contained in the list are as follows:

Occupation

1. What are the duties and responsibilities of my present job?

2. Have I the general education needed to do this job well? If not, what additional courses should I take, or what reading should I do?

3. Have I the knowledge of my duties, department, and company needed to enable me to do my job well? Can I gain additional knowledge through training courses, reading, or by better use of my experience, and by a broader range of contacts? If so, how?

4. Do I carry out assignments on time and in such a way that my work meets professional engineering standards and requires little, if any, revision? Is there additional work, beyond the routine assignments, which I might properly do? How can I improve my performance in these respects?

5(a). Does a condition of mutual respect and cordiality exist in the relations between my superiors and me? If not, is it because my work is not of the right quality; am I either too timid, or over aggressive; or do I lack understanding of my responsibilities? What steps should I take to strengthen the relations between my superiors and me?

5(b). Are my relations with my associates cordial and friendly? Am I doing my full share to promote such desirable friendly relations? Do I try to appropriate all the credit or shift the blame?

5(c). Is there friendliness and mutual respect between my subordinates and myself? Are my instructions to them always clear and complete? Do I supervise properly to make sure that those instructions are understood and at the same time do I avoid unnecessary interference in the execution of my orders? Do I insist upon good work from my subordinates, and do I give proper credit for work well done? Am I genuinely interested in the ambitions, problems, and well-being of my associates and subordinates?

5(d). Are my contacts with the customers or clients of my company and other members of the public friendly and effective?

6. Have I seen ways by which the accomplishment of my work and that of the group of which I am a member can be improved? Have I formulated any such ideas and examined them carefully? Have I taken the initiative in presenting for consideration

Grand Coulee Dam in the Columbia River Basin

LOOKING upstream at the site where Grand Coulee Dam is being constructed on the Columbia River in the eastern part of north central Washington, 80 miles west of Spokane. At the right, beyond the second bridge, may be seen one section of the cofferdam which is now under construction. The second coffer will be built on the opposite bank, and the third, to be completed in 1937, will consist of 2 rows of cellular sheet steel piling driven across the channel, 1 upstream and 1 downstream from the dam. At the right also may be seen the huge conveyer which carries excavated material from the dam site into a near-by canyon. The Government camp site may be seen at the right, and across the river, at the left, is Mason City, the contractor's town site. Inasmuch as the Grand Coulee project is (in a direct line) some 150 miles east of Seattle, it may be inspected by those attending the Institute's Pacific Coast convention in Seattle, August 27–30, 1935.

such ideas as, after serious consideration, still seemed sound? Has my presentation to my superiors and associates been clear, concise, and convincing?

7. Does my work suffer from the lack of physical vigor or from the wrong emotional attitude? How can I overcome any such handicaps?

8. For what general fields of activity am I best fitted by education, aptitude, and interest? Does my present work lead to development in such a field?

9(a). Does the company with which I am now connected have the right fields of activity to offer me and does it also offer the ideals, associations, and opportunities for advancement which I may reasonably expect?

9(b). If not, when and where should I seek a connection with genuinely greater promise in these respects?

10. What advanced positions, therefore, in my own company or elsewhere should I now prepare for? What are their duties and responsibilities? What further training, both along technical and economic or social lines, should I now begin; what added experience should I seek; and what personal qualities should I try to develop in preparation for such advancement?

PROFESSIONAL STATUS

1. What requirements for full membership in my professional society do I now fail to satisfy? What steps, beyond those already planned, should I take to correct my present deficiencies? When should I plan to attain full society membership?

2. Do I possess the qualifications which give eligibility for a professional degree in engineering? If not, what additional requirements must I satisfy to become eligible? Should I plan to secure such a degree? If so, how should I proceed?

3. Does my position and do my ambitions make it desirable for me to become a registered professional engineer? If I wish to do this, what steps should I take to meet the requirements? How soon should I plan to apply for registration?

PERSONAL STATUS

1. In terms of family relationships, what are my ambitions and what goals shall I set now? Are my education and cultural background adequate for the realization of my ambitions? If not, can I improve myself by taking courses or by reading beyond that already suggested?

2. What physical, personal, or emotional shortcomings may tend to prevent full realization of my ambitions? What steps should I take to overcome these handicaps?

3. Is my financial status adequate to enable me to reach my goal? If not, what program should I develop and put into practice?

4. As a neighbor and citizen, what place in my community and in government should I take? How can I prepare myself to carry out my community and political responsibilities more fully?

5. Am I developing my capacity for friendship and utilizing opportunities for broadening the circle of which I am a part? Do I contribute my share in the give and take of these relationships? Do I enjoy the social contacts which I have? How should I change my attitude or develop my personal qualities to deepen and extend my friendships?

6. What avocation, recreations, sports, or hobbies would be best suited to round out my life?

GENERAL PROGRAM OF DEVELOPMENT

1. On the basis of this appraisal, what educational courses and reading should I undertake during the next few years?

2. What experience should I seek, and how can I best utilize it?

3. What personal attitudes and qualities should I cultivate?

4. What health program should I follow?

5. What financial program should I lay out and try to carry through?

6. In what professional, civic, and social activities should I participate, and to what extent?

7. What program of sport, recreation, or avocation should I plan?

IMMEDIATE PROGRAM

What definite steps in each classification should I take now to reach, within a reasonable time, the various goals set for myself?

The questionnaire has been published in a 12-page $8^1/_2$ x $11^1/_2$-inchp amphlet which contains, following an introductory explanatory note, the 65 questions above, specially arranged with blank spaces for the answers to be written in. In addition, the pamphlet contains "Reading Lists for Junior Engineers" comprising over 100 titles of suggested books. This list has been published month by month in ELECTRICAL ENGINEERING as follows: December 1934, page 1667; January 1935, page 133; March 1935, page 345; April 1935, page 456; May 1935, page 509; and June 1935, page 681.

The pamphlet, containing both lists, and entitled "Suggestions for Junior Engineers," may be obtained from the secretary of the E.C.P.D., 29 West 39th Street, New York, N. Y. It is priced at 10 cents per copy, and 5 cents per copy in quantities of 50 or more.

S.P.E.E. Investigation of Engineering Education Reported Upon

SUFFICIENT interest has been exhibited in the investigation of engineering education that was carried on for several years by the Society for the Promotion of Engineering Education, to warrant calling attention of members of the Institute to the availability of the published report on this investigation. The investigation was "directed to a study of the objects of engineering education and of the fitness of the present day curriculum for preparing the student for his profession." The main investigation was carried on during the period from 1923 to 1929, with further investigation of particular phases extending to 1934.

Since its inception the investigation has been supervised by the board of investigation and co-ordination of the S.P.E.E., with Dr. Charles F. Scott (A'92, M'93, F'25, HM'29, past-president, and member for life) as its chairman. The work of the investigation was carried on by Dr. W. E. Wickenden (A'09, M'13) director of investigation, 1923–29, and H. P. Hammond, associate director, 1924–29, and director of summer schools, 1927–33. Doctor Scott is professor of electrical engineering, emeritus, Yale University, New Haven, Conn.; Doctor Wickenden is president of Case School of Applied Science, Cleveland, Ohio; and Professor Hammond is professor of civil engineering, Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

COMPLETE REPORT AND SUMMARY OF RESULTS ARE AVAILABLE

Various bulletins and reports on the investigation were presented from time to time in the S.P.E.E. monthly publication and in pamphlet reprints. These and other reports then were brought together in revised form in a complete report of 2 volumes. These volumes, entitled "Reports of the Investigation of Engineering Education 1923–1929" including the report on summer schools for engineering teachers (1927–1933), accompanied by a supplemental report on technical institutes (1928–1929), and with bibliographies and indexes, may be obtained from F. L. Bishop, secretary of the Society for the Promotion of Engineering Education, University of Pittsburgh, Pittsburgh, Pa., at $3 each, or $5 per set of the 2 volumes which total some 1,670 6 x 9-inch pages. Volume 1 is dated 1930, and volume 2, 1934.

The final report of Doctor Scott as chairman of the board of investigation and coordination is a summary of the results of the investigation, and appears as pages 1237–73 of volume 2 of the complete report. This "Summary of Results" also has been published as a pamphlet reprint $5^3/_4$ x $8^1/_2$ inches in size, copies of which may be obtained from F. L. Bishop, secretary of the S.P.E.E., University of Pittsburgh, Pa., at a cost of 10 cents each, or $7.50 per hundred. This summary is stated to be "frankly somewhat personal in that emphasis is laid on features appealing to the writer as most significant."

CONTENTS OF THE COMPLETE REPORT

Some conception of the scope of the investigation and the tremendous amount of data on many phases of engineering education contained in the complete report may be gained from the following foreword printed in volume 1:

"The . . . . . report marks the culmination of a comprehensive study directed to the improvement of engineering education proposed in 1922 and undertaken in 1923 by the Society for the Promotion of Engineering Education.

"The enterprise was inaugurated as a cooperative undertaking in which the schools should actively participate. The work was planned and conducted by a staff under the direction of a board of investigation and co-ordination. The schools supplied data in connection with the extended fact-finding features of the investigation and contributed through special and local committees in the study of particular problems and in other ways. Engineering societies, industry, governmental agencies and individuals cooperated.

"The assemblage of facts and data pertaining to the field of engineering education affords a definite idea of what is now being done. It presents to those who are familiar only with the particular institutions or fields of work in which they are engaged a general view; the present study integrates the whole field in a way to afford insight into needed developments as well as an appraisal of the present situation. It presents the conditions within the schools and much information regarding the entering student, the alumnus, the attitude of practicing engineers, teachers, and industrial managers. It presents a basis for consideration of problems within the engineering school, both undergraduate and graduate, and it shows in illuminating perspective its relations to other fields—the preparatory school, the training courses for gradu-

ates in industry, the technical institute (noncollegiate) the engineering profession, and the economic phases of modern life.

"Both the director of the investigation and the associate director visited most of the engineering schools in this country for information and counsel, thus gaining the intimate knowledge of conditions essential to an evaluation and interpretation of information gathered by other means.

"The director made 2 trips to European countries to visit the engineering schools. The result of these visits form the basis of a perspective comparison of engineering education at home and abroad.

"An important outcome of the general investigation has been the establishing by the Society in 1927 of summer schools for engineering teachers. These schools have brought together each year, for periods of several weeks, nearly a hundred engineering teachers for consideration of better methods of teaching as well as for discussion of the subject matter and the state of the art in their respective fields.

"The findings and preliminary reports of the investigation have been made available immediately through continuous publication in the Society's (S.P.E.E.) monthly *Journal of Engineering Education*, and in some 20 pamphlet reprints issued as bulletins and reports.

"These are now brought together, revised, and supplemented in the present complete report.

"The contributions by the board and by the staff present summaries, comments, conclusions, and recommendations. Director Wickenden presents in a general report the views of one whose prior career as teacher in engineering schools and as director of educational work in industry, qualifies him to appreciate the problems involved. Professor Hammond, associate director, has had charge of the immediate relations with the engineering schools during the fact-finding period. He has also organized and directed the conduct of the summer schools upon which he has prepared a special report.

"The initial funds for the investigation were provided by a grant from the Carnegie Corporation. These were supplemented by contributions from engineering societies, from industries, and from individuals.

"A supplemental study of technical institutes reveals the status of a neglected field closely related to the collegiate engineering schools and indicates the need of a comprehensive national scheme which will include all branches of technical education. The report of this study is published in this report for the first time in complete form."

Contents of the Summary of Results

In the previously mentioned "Summary of Results," the more important of the numerous bulletins and reports in the complete report are summarized briefly, giving some of the statistical information collected and the conclusions drawn from them. In the "Summary of Results," the following are stated to be among the conclusions reached. (In these excerpts, the superior numerals are references to pages in the complete report.)

"An undergraduate course should equip wholesome and qualified youth with a basic acquaintance with science, familiarity with engineering methods, and an appreciation of social relations.[84] These should be coordinated in time and in content and brought to a focus during the last year upon the student's major subject.[140]

"Three types of activity common to all engineering, for which the undergraduate program should provide a basis, are:[84,1037]

1. The control and utilization of the forces, materials, and energy of nature.
2. The organization of human effort for these purposes.
3. The estimation of costs and appraisal of values, both economic and social, involved in these activities.

An educational process appropriate to these purposes cannot be narrowly technical.

"Engineering education should be a unified process in which scientific, technological, and humanistic studies form an orderly whole; a self contained branch of higher education under unity of supervision.[132] This is in contrast to a divided program having a pre-engineering curriculum under separate administration and a subsequent purely technical curriculum—corresponding to practices in law, medicine, and dentistry.[112,105]

"Engineering education is good general education; it is characterized by a coherent and integral program, unifying an otherwise loose group of studies by professional orientation which becomes increasingly significant in the upper years and dominates the post-graduate period.[88,140]

"Four years, as at present, is the recommended norm for an undergraduate course leading to the bachelor degree. Following present high school graduation this implies a median age of 23 at graduation.[88,138] Students should be at liberty to extend the period to 5 years to include additional subjects or to overcome handicaps in preparation.[139]

"College training should be the foundation for the continued development of the graduate either as a professional engineer, or in other fields, by either of 2 principal methods.[140,1108]

1. By resident graduate study preliminary to his future work, technical and professional or administrative or other.
2. By entrance into practice where experience may be accompanied by continued post scholastic study.

"Engineering education can cope with enlarging responsibility to society and increasing exactions of professional practice by enhancing its own distinctive qualities rather than adding unrelated elements from without. Emphasis on humanistic subjects for enriching the conception of engineering and its place in the social economy, a more connected and better grounding in engineering principles, and greater capacity for self directed work may all be gained at the expense of unrelated studies and detailed training in technique. The latter should find place in postgraduate and post scholastic courses.[140,1048]

"For better engineering education we must look to better balanced curricula, better selection of students, better teachers, better methods, better subject matter, and better advanced training, rather than changes in educational organization.[141,1048]

"For developing teaching personnel each school should have a policy and a definite program covering selection, guidance, engineering experience, and teaching methods. Means may include summer schools for engineering teachers, conferences with engineers and with industry.[106] Engineering schools should provide adequate salaries, and encourage participation of teachers in engineering practice.[107] Teaching loads should not prevent personal development and contributions to engineering progress.[108,1090]

"The board states its views on various matters and offers suggestions. Some of these follow:

1. The credit hours in 4 years should not exceed 144. Simultaneously carried subjects should not exceed 6.[89]
2. The curriculum should be common for all engineering freshmen but for the last year may be widely differentiated; in intermediate years adjusted to local conditions.[90] Options in later years are desirable.
3. Concrete projects, lectures, and conferences should stimulate interest, orient to engineering activities, and serve as a try-out of aptitude.[90]
4. Social and economic studies should reveal the broad interplay of social forces and also the specific economic problems and social situations in the realm of engineering.[90,1068,1138] How to place proper emphasis on engineering economy is an open field for experiment by the engineering colleges. General economics should be taught with consideration for the engineering viewpoint.[91]
5. Specially gifted students should have special programs.[109] Particular programs depend upon sizes of classes and available facilities."

Some of the other conclusions and recommendations, taken from different sections of the "Summary of Results" follow:

"Assistance to high school students in gaining a perspective of engineering as a career may be rendered by conferences, addresses, literature, and moving pictures.[172] Greater discrimination in admission method is advised. Orientation courses in early college years are recommended.[130,183] The report of the board holds that it is a duty of engineering colleges to the profession to attract and admit qualified students, and to reject the undesirable and unfit.[94] . . . a joint agency for co-operation with secondary schools is recommended.[98] Selective admission procedure and subsequent tests[98] are advised."

"Placement examinations (educational tests designed to measure the training and aptitude of the student for subjects commonly included in the first year of engineering curricula) are ineffective in themselves. They furnish the data upon which remedial measures may be based, however, and when administered systematically and discriminatingly they may be of considerable importance in dealing with students."

"Numerous comparisons between graduates of co-operative plans (alternating attendance at school and at work in industry) and other engineering graduates as to positions, earnings, and general progress do not show marked differences. It is concluded that both methods produce equally meritorious results although not of identical character."

"The board advocates graduate work in a few institutions with notable teachers;[117,133,148] that this work be open only to proficient students, and that undergraduate study should not be considered as graduate work."

It is pointed out "that the research[839] in many institutions is routine testing rather than scientific investigation; that true research is limited to but few institutions; that the total expenditure is only 5 per cent of that for undergraduate instruction; that this amount is exceeded by each of 4 industrial concerns in their research activities; that the importance of research both for its

immediate results and for the training of men for research justifies increased development and expenditures."

"The need of guidance (of graduates) in the choice of first positions is given emphasis. The means suggested[888] are lectures to seniors outlining various fields; more effective presentation by representatives of industries; personal records of students by colleges."

"Continuation of education after leaving college[881-2] is essential to the graduate; it should be a responsibility of the colleges. Methods proposed are reading courses, correspondence courses, extension courses of various types, advisory services."

A study of the engineering graduate in industry shows that "conclusions[1029] based on statements of graduates and employers are that deficiencies in training are not limited to the engineering college, but involve secondary schools and the educational system as a whole; and that the endeavors of leaders should be: (a) in industry, to aid in industrial guidance and in shortening the time for fitting graduates for responsible positions; and (b) in the colleges, to develop personality, to give facility in expressing ideas in clear convincing English, and to aid students in choice of positions adapted to their personality and training."

Regarding the cost of education, it is concluded that "the cost per student[848] is much greater in engineering education than liberal arts."

The "situation regarding teaching staffs is quite satisfactory in so far as can be judged by the statistics. But intangibles enter the educational problem.[885] In the selection of teachers,[899-304] administrative officers feel that recruits are not secured from the highest levels of graduates. Adequate salaries, opportunities for engineering practice and for research and scrutiny of all around qualifications are remedial measures. The securing of the right type of teachers[885, 1181] is a major problem in engineering education."

Other subjects discussed in the "Summary of Results" are the need for a national system of technical education, as indicated by a comparative study of engineering education in the United States and Europe; the desirability of summer schools for engineering teachers; a study of technical institutes (noncollegiate); and the relationship between engineering education and the engineering societies.

A Reading List for Junior Engineers

A LIST of books recommended for reading by junior engineers has been prepared by a number of eminent men, many of them distinguished in the engineering profession. Previous sections of this list have been published in ELECTRICAL ENGINEERING for December 1934, page 1667, January 1935, page 133, March 1935, page 345, April 1935, page 456, and May 1935, page 569. The 2 concluding sections are published herewith. The complete list includes more than 100 titles.

Systematic reading of worth while books adds breadth and vision to the background of an engineer and should be considered a part of the intellectual development designed to fit the young engineer for full professional recognition. It is suggested that over a period of about 4 years a minimum of about 25 of these books might be selected and read, with the limiting recommendation that the selection made will include at least one book in each classification, preferably in accord with the individual engineer's most vital interests.

Literature, Including Poetry, Essays, and Fiction

Name and Nature of Poetry, A. E. Housman. Macmillan, 1933. A personal definition of the functions of poetry states that its aims must be to "transmit emotion—not to transmit thought." Nothing on modern poetry.

Oxford Book of English Verse, edited by Sir Arthur Quiller-Couch. Oxford University Press, 1910.

Plays and Sonnets, William Shakespeare.

American Poets, edited by Mark Van Doren. Little, Brown, 1932. Selections from 57 poets from 1630 to 1930.

English Literature, W. N. C. Carlton. American Library Association, 1925. Reading with a Purpose Series.

Enjoyment of Literature, Jay B. Hubbell. Macmillan, 1929.

Essays in Persuasion, J. M. Keynes. Harcourt, Brace, 1932.

Essays of Elia, Charles Lamb.

Marius the Epicurean, Walter Pater.

Emerson's Journals, edited by Bliss Perry. Houghton, Mifflin, 1926.

Thoreau's Journals, edited by Odell Shepard.

Wuthering Heights, Emily Bronte.

The Good Earth, Pearl Buck.

The Way of All Flesh, Samuel Butler.

Lord Jim, Joseph Conrad.

Tale of Two Cities, Charles Dickens.

Brothers Karamazov, Fyodor Dostoievski.

The History of Tom Jones, Henry Fielding.

Forsythe Saga, John Galsworthy.

Growth of the Soil, Knut Hamsun.

Tess of the d'Urbervilles, Thomas Hardy.

Morte d'Arthur, Sir Thomas Malory.

Giants in the Earth, O. E. Rolvaag.

Kidnapped, R. L. Stevenson.

Vanity Fair, William Makepeace Thackeray.

War and Peace, Count Leo Tolstoi.

Ethan Frome, Edith Wharton.

General

Good English, V. C. Bacon. American Library Association, 1928. Reading with a Purpose Series.

The Human Body and Its Care, Morris Fishbein. American Library Association, 1929. Reading with a Purpose Series.

Representative Government, H. J. Ford. Henry Holt, 1924. Three hundred pages of fundamentals by an able journalist who became professor of politics at Princeton through Woodrow Wilson's appreciation of his book on "Rise and Growth of American Politics."

Concise Oxford Dictionary of Current English, Henry W. Fowler. Oxford University Press, 1926. A large amount of information in very little space.

Handbook of English in Engineering Usage, A. C. Howell. Wiley, 1930. Clearly written book for practicing engineers. Promotes proficiency in making up reports, letters, and technical articles and is "a shining example of the principles enunciated."

The Educational Frontier, edited by W. H. Kilpatrick. Century, 1933. A description of a definite program for remedying the confusion existing today in purpose and curriculum of American education.

Education and the Social Crisis, W. H. Kilpatrick. Liveright, 1932. A plea for a study of our "tragically inadequate" system of adult education. Should be read along with Everett Dean Martin's "Civilizing Ourselves."

Public Opinion, Walter Lippmann. Macmillan, 1927. Psychological study and entertaining discussion of the weaknesses of public opinion and the means of influencing it.

Education, Intellectual, Moral, and Physical, Herbert Spencer. Appleton, 1914. Argument for rational scientific education of the body, natural and reasonable moral training, and self activity and interest in intellectual training.

International Congresses to Meet in Europe

Three congresses on engineering subjects are to be held in various parts of Europe during the next few weeks. Arrangements have been made for delegations of Americans to attend each of these congresses.

The first one to meet is the International Electrotechnical Commission, the plenary meetings of which will be held in The Hague and Brussels, Belgium, June 18–27, 1935. Dr. A. E. Kennelly (A'88, M'99, F'13, HM'33, Life Member and past-president) professor emeritus of electrical engineering, Harvard University, Cambridge, Mass., is president of the U.S. national committee of the I.E.C. This committee has made careful preparations for the plenary meetings, and it appears that American electrical industries will be represented by one of the largest and best technically qualified delegations which have been sent abroad in several years.

The second congress is the International Conference on Large High Tension Systems, which will be held in Paris, France, from June 27 to July 6, 1935. The object of this conference, which meets every 2 years, is to study all problems relating to the production, transmission, and distribution of electrical energy. Papers on these subjects are read and discussed, and at the forthcoming session 16 papers are scheduled to be presented by authors from the United States. As in previous sessions, the work will be divided into 3 sections: production and transformation of current; construction, maintenance, and insulation of lines; and operation and protection of systems. The secretary of the U.S. national committee of the International Conference on Large High Tension Systems is Frederic Attwood (M'27), vice president of the Ohio Brass Company, 50 Church St., New York, N. Y.

The third congress is that of the International Commission on Illumination, the

1935 session of which will be held at Berlin, Germany, July 2–5, and at Karlsruhe, July 7–10, 1935. The U.S. national committee, of which G. H. Stickeney (A'04, F'24), consulting engineer for the incandescent lamp department of the General Electric Company, Cleveland, Ohio, has recently been elected president (as announced in this issue, page 687) has been instrumental in insuring a large attendance of American experts in order to provide adequate expression of the viewpoints prevailing in this country.

Of interest also is the meeting of the Societe Belge des Ingenieurs et des Industriels in Brussels, Belgium, June 13–15, 1935, to celebrate the fiftieth anniversary of its foundation. Two Institute representatives have been appointed to attend the celebration.

A.S.T.M. to Revise Copper Wire Specifications

According to reports currently published by the American Society for Testing Materials covering its "committee week" series of meetings held in Philadelphia, Pa., March 4–8, 1935, important revisions were made in the standard specifications for bare concentric-lay copper cable, medium, hard, or soft (*B8-27*). These revisions, reported as providing new requirements for testing this type of copper cable, are scheduled to be referred to the membership of A.S.T.M. committee *B-1* in the form of a letter ballot. The proposed changes provide for the testing of the cable in its completed form whereas present specifications require tests of the individual wires comprising the cable before, but not after, stranding. Also scheduled for insertion in the new specifications is a new stranding table which seems to have met with the approval of the committee and also with the Insulated Power Cable Engineers Association and the Sectional Committee on Insulated Wires and Cables.

The A.S.T.M. committee also is reported as having received an interesting report of progress from its subcommittee on electrical transmission wire and cable specifications, which report included data resulting from tests made on transmission cable for the purpose of investigating the question of soft versus hard wire core in such cables.

Also, action is reported covering the proposal of tentative additions to the bronze trolley wire specifications to provide requirements covering a trolley wire of higher conductivity than the present 2 classifications. Tentative revisions providing for additional limitations of certain dimensions of grooved trolley wire, both bronze and copper, also were proposed.

Illuminating Engineers to Meet in Cincinnati. The 1935 convention of the Illuminating Engineering Society is to be held at the Hotel Netherland Plaza, Cincinnati, Ohio, September 3–6. A national illumination conference is scheduled for September 3, with the I.E.S. convention following immediately and ending on September 6. A lighting equipment exposition is also being planned.

Franklin Institute Medal Awarded. The Franklin Institute of Philadelphia, Pa., has announced the award for 1935 of a John Price Wetherill Medal, to Robert E. Naumburg, New York, N. Y., for his invention of the visagraph for enabling the blind to read any printed book without the aid of any other person. The award is for "an apparatus original in its accomplishments, and of unquestioned benefit to humanity."

A.S.T.M. Nominates Officers. Nominations for officers to serve the American Society for Testing Materials have been made. H. S. Vassar (A'06, M'18) laboratory engineer, Public Service Electric and Gas Co., Irvington, N. J., has been nominated for president. For vice president, A. E. White, professor of metallurgical engineering and director of the department of engineering research, University of Michigan, Ann Arbor, has been nominated. Members nominated for the executive committee are: W. H. Graves, chief metallurgist, Packard Motor Car Co., Detroit, Mich.; R. L. Hallett, chemist, National Lead Co., Brooklyn, N. Y.; N. L. Mochel, metallurgical engineer, Westinghouse Electric and Manufacturing Co., Lester Station, Philadelphia, Pa.; H. H. Morgan, manager, rail and fastenings department, Robert W. Hunt Co., Chicago, Ill.; and W. R. Webster, chairman of the board, Bridgeport Brass Co., Bridgeport, Conn. Officers elected assume office at the close of the business meeting which will be part of the opening session of the A.S.T.M. annual meeting, June 24–28. 1935, at the Book-Cadillac Hotel, Detroit, Mich.

American Engineering Council

The Federal Work-Relief Bill

American Engineering Council, the "Washington Embassy" of engineers, gives in its news letter of May 15, information on the status of the federal work-relief bill. Excerpts from this bulletin follow.

Progress under the work-relief has been delayed during the past month, as the set-up at top has gradually taken form. Actual starting of jobs and hiring of men still awaits the approval of individual projects by the new chain of federal boards which have been placed in control.

The set-up, briefly, starts with a division of application and information, headed by Frank C. Walker, director of the National Emergency Council. Applications for projects are passed from there to an allotment division under Harold L. Ickes. With the President's approval, projects go to a progress division under Harry L. Hopkins who thus is in a key position in the supervision of actual work. Admiral C. J. Peoples, director of treasury procurement, will handle purchase of materials under the Hopkins division. R. G. Tugwell is expected to take over subsistence homesteads and rural community projects. Rural electrification is tentatively under Morris L. Cooke, a member of the American Society of Mechanical Engineers.

Prominent engineers in the higher command include Maj. Gen. Edward M. Markham, chief of engineers; Dr. Elwood Mead, commissioner of reclamation; and Thomas H. MacDonald, chief, Bureau of Public Roads, all on the Works Allotment Division which takes its place in the alphabetical array as "WAD." Fred Schnepfe, director of projects, PWA, has been named secretary. These 4 men are members of the American Society of Civil Engineers.

Two billion dollars are to be released from the works fund, according to present plans, for allocation to projects. This represents half of the 4 billion dollars broken down in the April 15 "News Letter." (See ELECTRICAL ENGINEERING for May 1935, pages 571–2.) Each class of work (highways, rural electrification, etc.) gets, for the present, $^1/_3$ of the sum earmarked in the bill.

General policies stand essentially as stated last month. From recent Presidential statements, it is inferred that relatively small-scale projects, widely scattered, involving a high labor ratio, and possible of completion within a year, will be pushed forward rather than large undertakings, such as dams, where a huge sum would be spent in a restricted area on work which would take several years.

A related item is to the effect that a department of conservation and works is proposed in a bill sponsored by Ickes and introduced by Senator J. Hamilton Lewis of Illinois. This is designed to permit the President to institutionalize on a long-term basis some of the activities which have developed under the emergency units of the government.

Survey of the Engineering Profession

The survey of the engineering profession, by the U.S. Bureau of Labor Statistics in co-operation with Council and the engineering societies, at last goes forward. Heavy pressure of federal work at the Bureau has held up the mailing of the questionnaire forms over the large list of 170,000 names until now, but the final plan is to complete mailing by June 1. The closing date for blanks to be filled in and returned to the Bureau has been set for July 6.

It is essential that returns be complete so that there will be something approaching a census rather than a mere sample. If any professional engineer, or anyone who has qualified as an engineer in the past, fails to receive a questionnaire by about June 10, he is requested to write Andrew Fraser, U.S. Bureau of Labor Statistics, Department of Labor, Washington, D. C., for one of the blanks.

The questionnaires may look formidable but are mainly "yes" and "no" questions which can be checked off in a few minutes. Do it now!

Other A. E. C. Items

Grover C. Loening, a pioneer in aircraft invention and president of the Loening Aeronautical Engineering Corporation, has been appointed chairman of the A. E. C. committee on aeronautics. The purposes of the committee are to encourage civil aviation, promote research, and to sponsor specific improvement such as larger airports, better technical planning of airports, speeding of air services, and co-ordination of Federal and municipal activities. The development of metropolitan air ports was given special stress in a report of A. E. C. to the Federal Aviation Committee, December 1934, the recommendations of which are to be carried forward by Mr. Loening's committee. Mr. Loening has been a prominent figure in aircraft construction and design for more than 20 years. He has contributed many inventions and developments in the aeronautical field, and is the author of books and numerous articles on aviation. He built and flew the first flying boat in 1911, and he invented the first monoplane rigid bracing persuit machine in 1914. He also introduced steel construction.

A study of the civil service system in its relation to engineers will be made by Arthur W. Berresford, past president of A. E. C., who has consented to do this unofficially and to make an informal report as a basis for action by Council. The maintenance of the federal "merit system" is of interest to large numbers of engineers in its relation to salaries, tenure of office, and methods of appointment.

A digest of the Brookings Institution reports entitled "America's Capacity to Produce" and "America's Capacity to Consume" has been prepared by the Maurice and Laura Falk Foundation of Pittsburgh, Pa., through whose courtesy A. E. C. has copies for distribution to engineers who wish to study the results of these basic surveys. Requests will be filled as long as the supply lasts.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or to reject them entirely.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Control of Transients in Welding Generators

To the Editor:

The discussion of F. B. Hornby's paper ("Control of Transients in Welding Generators," ELECTRICAL ENGINEERING, volume 53, Dec. 1934, pages 1598–602) by T. M. Linville in the April 1935 issue of ELECTRICAL ENGINEERING, pages 441–4, must be very interesting to all students of arc welding generators. The Hornby machine presumably represents the abandonment by the General Electric Company of the imperfect and, in my opinion, dangerous "transformer reactor" as it has been called, in favor of apparatus which is correctly designed and proportioned according to principles which were made known by myself from 1926 onward as may be seen from my publications.

If we compare the interesting table published by Mr. Linville on page 444 of the April issue with that given by myself in my paper "Performance and Design of Electric Welders with Controlled Transients," A.I.E.E. TRANSACTIONS, volume 52, March 1933, page 274, they appear as in table I. I do not quite follow Mr. Linville's value of $M/\sqrt{L_f + L_w}$ which it seems to me should be 0.077 instead of 0.64.

It will be seen from this that the Hornby machine combines a high inductance in the welding circuit (even higher than I employ though I use an external reactor) with a low inductance in the field circuit (almost exactly the same as mine) which is, of course, correct design, as I have previously pointed out in the literature. For instance, claim 22 of my patent Reissue 19,446 (originally filed in Great Britain 1926) reads as follows:

Table I—Comparison of Generators

	Generator "A" Split Pole—Hornby	Creedy
Welding amperes (rated)	400	300
Welding volts (rated)	40	30
Open circuit volts	80	75
Poles	2	8
Rpm	1,785	1,785
Core diameter, inches	10	
Core length, inches	5	
Flux per pole, maxwells	2.6×10^6	
Excitation watts	500	
Self-inductance (henries) of		
Series field winding	0.0120	
Shunt field winding	1.24	
Armature winding	0.0024	
Commutating pole winding	0.0030	
Mutual inductance (henries) between		
Series and shunt field winding	0.084	
Armature and series field winding	0.0003	
Armature and shunt field winding	0.0015	
Armature and comm. pole winding	0.0017	
Total self-inductance of welding circuit (L_w) (very high)	0.0146	.003
Total self-inductance of field circuit (L_f) (very low)	1.24	1.26
Total coupling inductance of field and welding circuits (M)	0.086	0.03
Coefficient of magnetic coupling between the field and the welding circuit (0.077?) ($M/\sqrt{L_f + L_w}$)	0.64	0.027
Total transient inductance of welding circuit ($L_w - M^2/L_f$)	0.0087	0.0023

Claim 22: In combination, an arc welding circuit, and an arc welding generator with falling voltage characteristic connected to supply the welding circuit, said circuit including a high inductance in series with the arc, the generating circuits of said generator including a low inductance field circuit whereby transient effects are materially diminished as compared with those produced when said high inductance in the welding circuit is used with a generator having high inductance generating circuits.

Very truly yours,

F. CREEDY (M'30)
(Prof. of Elec. Engg., University of British Columbia, Vancouver, Can.)

Similarity Relations in Electrical Engineering

To the Editor:

The paper "Similarity Relations in Electrical Engineering" by J. G. Brainerd and Jacob Neufeld, in the March 1935 issue of ELECTRICAL ENGINEERING, page 268–72, calls attention to a field of mathematics which has not had the proper attention in theoretical investigations in electrical engineering. The first application of the Π-theorem, however, is not correct and leads, by mere chance only, to a correct result. As pointed out by P. W. Bridgeman in his book "Dimensional Analysis," Yale University Press, 1931, dimensional analysis can only be applied in the case of complete dimension systems. Bridgeman gives in his book a number of examples illustrating this point quite definitely. In electromagnetism, 4 fundamental dimensions are required in order to form a complete dimension system; the so-called absolute dimension systems are, therefore, not usable in dimensional analysis. (See "A Proposal to Abolish the Absolute Electrical Unit Systems," by E. Weber, A.I.E.E. TRANSACTIONS, Volume 51, 1932, pages 728–42.) The use of the complete dimension for resistance would have shown at once that an additional quantity is needed in order to establish a relation between the various quantities leading to a dimensional formula. This additional quantity is the permeability which has (even according to the newest decision of the International Electrotechnical Commission, see "Actions on Electric and Magnetic Units," by A. E. Kennelly, ELECTRICAL ENGINEERING 1934, pages 402–5) a dimension and is not a pure numeric. The tabulation of the complete dimensions is as follows:

Resistance	r	$[M][Q]^{-2}[L]^2[T]^{-1}$
Area of cross section	A	$[L]^2$
Frequency	f	$[T]^{-1}$
Permeability	Π	$[M][Q]^{-2}[L]$
Resistivity	ρ	$[M][Q]^{-2}[L]^3[T]^{-1}$

where $[M]$ is the dimension of mass, and $[Q]$ that of electrical charge. From this the dimensional equation results

$$r = A^p f^q \rho^s \Pi^v$$

where s, p, q, and v denote the arbitrary exponents. Inserting the dimensions from

the table above leads to the 4 equations for the 4 fundamental dimensions:

$$[M]: \quad +1 = +s + v$$
$$[Q]: \quad -2 = -2s - 2v$$
$$[L]: \quad +2 = +2p + 3s + v$$
$$[T]: \quad -1 = -q - s.$$

As in the case of the authors, the resistance appears finally in the form

$$r = A^{-1/2+q} \cdot f\mu \cdot \rho^{1-q} \cdot \Pi^q = \frac{\rho}{\sqrt{A}} \cdot \left(\frac{Af\Pi}{\rho}\right)^q$$

or

$$\frac{r_{a-c}}{r_{d-c}} = \varphi\left(\frac{Af\Pi}{\rho}\right)$$

which is identical with the form equation 4 of the original paper. With the additional permeability in the dimensional expression, the first of the equations 9 of the authors is obtained which they could not co-ordinate properly; though the authors promise to account for the factor μ used in this equation 9, they fail to do it.

In the paragraph on boundary conditions the authors again make use of the permeability quite arbitrarily. The boundary conditions for the case 2, the case of the "magnetic skin-effect," should be correctly written as follows:

$$H_{T(\text{conductor})} = H_{T(\text{air})}$$
$$(\mu H_N)_{(\text{conductor})} = (\mu H_N)_{\text{air}}$$

It is necessary to take μ into both sides of the equation. In the case of copper and air, for example,

$$\mu_{\text{copper}} = 0.999\ 9912, \text{ whereas}$$
$$\mu_{\text{air}} = 1.000\ 000\ 38,$$

which demonstrates the importance of being exact.

The value of the constant c in equation 6 of the paper is identical with the magnitude of the velocity of light and this is only approximately equal to 3×10^{10} centimeters per second. It does not, however, have the dimensions of velocity but is to be treated as a pure numeric.

Very truly yours,

ERNST WEBER (A'31, F'34)
(Research Professor, Dept. of Elec. Engg., Polytechnic Institute of Brooklyn, N. Y.)

Overcompounded Generators in Parallel

To the Editor:

The "compound generators in parallel" series of "Letters to the Editor" promises to rival the grand crescendo of the "square root of A squared plus B squared" series which so firmly held the public interest last year. (Previous "Letters to the Editor" on this subject have appeared in ELECTRICAL ENGINEERING as follows: by J. G. Brainerd, volume 51, October 1932, page 745; by O. W. Walter, volume 53, November 1934, pages 1553–4; by J. G. Brainerd, volume 54, January 1935, page 135; by E. H. Nelson and Sidney Rock, volume 54, March 1935, pages 347–8; and by J. O. Reid, volume 54, March 1935, pages 348–9.)

At the risk of boring your readers, I submit the following considerations for your attention:

It has been stated by some, and tacitly assumed by others, that the problem is of purely academic interest. This is hardly the case. The problem is not confined solely to d-c generators but finds application in other fields as well. In ventilation engineering, for example, it is occasionally the practice in large installations to employ 2 medium-sized fans instead of one prohibitively large one, supplying the same duct system (load) in parallel. It is common knowledge among engineers familiar with this field that if the fan characteristics are rising, the motors being ordinary commercial induction motors, there is a possibility of one fan's taking all the load, with a consequent danger of damage of its motor.

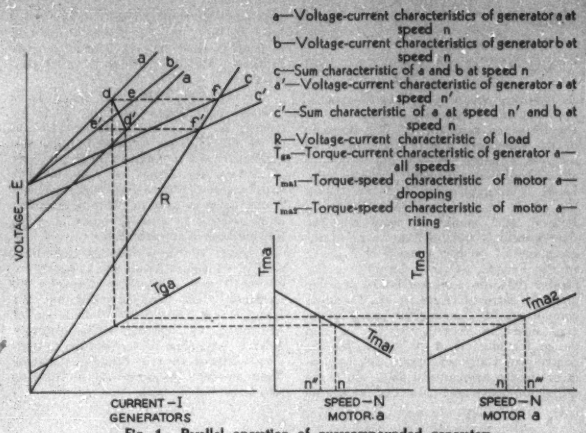

Fig. 1. Parallel operation of overcompounded generators

A somewhat more comprehensive graphical analysis than has hereto been given may be of interest. Several characteristics are shown on the accompanying diagram. For greater ease of construction and interpretation they are shown as straight lines. If desired these lines may be thought of as merely tangent lines to the true characteristics at the points of interest. a and b are the voltage-current characteristics of 2 overcompounded generators operating in parallel without equalizer at the speed n. c is the sum characteristic, and R the load characteristic. Evidently the division of load between the machines and the total load are given by the abscissas of the points d, e, f, respectively. Suppose that for some reason the speed of generator a drops to n', that of b remaining constant. c' is the new sum characteristic, and the division of load and total load are now given by d', e' and f', respectively. The operating point of machine b has passed from e to e'—a decrease of current, voltage, and power—while that of machine a has passed from d to d'—a decrease in voltage but an increase in current and possibly an increase in power, depending upon the slope of d-d' and the positions of these points. Thus, it is clear that the current change depends not alone upon the voltage change, but upon many other considerations.

Evidently the generator which slows down *may* take an increased load, if other conditions are consistent with such a result. To determine whether such a condition will exist in fact, the torque required by this generator and delivered by its motor must be considered. The torque of generator a has increased as shown. Projecting the generator torque-current curve over to the motor torque-speed curve it is seen that in the case of characteristic (1), which is drooping, the greater demand for torque produces a drop in speed, whereas in the second case it produces a speed increase. In the first case, if the slopes of all the characteristics are exactly right, the new motor speed n'' will be equal to n' the postulated new generator speed. (In nature, of course, the slopes of the characteristics determine the speed $n' = n''$ to which the motor-generator a will drop.) In the second case, the new motor speed is greater than the old, whereas a speed drop was postulated. The system, therefore, will not operate in this way and progressive instability is averted. Since in the first case n'' may be equal to n', the behavior depicted is possible. It requires only successive repetitions of the same process to produce a precipitation of the load to the slower machine. A similar construction in which the speed of generator a is assumed to increase shows that here, too, the action may be cumulative only if the torque-speed characteristic of motor a is drooping.

In the above analysis it is assumed that all changes take place so slowly that neither inductance nor inertia has any effect on them. It is felt that the analysis is entirely consistent with the experiments of Dr. Brainerd (ELECTRICAL ENGINEERING, volume 51, October 1932, page 745) which proved that this type of instability could occur. (He was careful to point out that he did no more than to show that the phenomenon could take place in at least one case); and of Messrs. Nelson and Rock (ELECTRICAL ENGINEERING, volume 54, March 1935, page 348) and in line with the assertions of Dr. Pender which were questioned by Dr. Walter (ELECTRICAL ENGINEERING, volume 53, November 1934, page 1553–4.)

A similar situation occurs when generators

with drooping voltage-current characteristics are driven by motors with rising torque-speed characteristics, such as the differentially compounded motor. In this situation the motor generator whose speed *increases* is the one which may take all of the load. The instability is of the same nature as the one under discussion, yet no one, to the writer's knowledge, has been puzzled by it.

Very truly yours,
HARRY C. HART (A'33)
(Penllyn, Pa.)

Operational Calculus

To the Editor:

In a letter, "Operational Calculus," appearing in the December 1934 issue of ELECTRICAL ENGINEERING, page 1681, I. H. Barkey has offered corrections to my paper, "Operational Calculus," in the October 1934 issue of ELECTRICAL ENGINEERING, pages 1339–47. Mr. Barkey gives evidence of having been a student of the historical aspect of operators in general. The field of operators in mathematics is immense. The operational processes which were under discussion in my paper are from only a portion of this field—a portion which can be particularly helpful to engineers interested in the analysis of transient vibrations, waves, and diffusion in linear systems. It is regrettable that the title of the paper did not adequately disclose this restriction, but the point was made in the subject matter that attention was directed primarily to operational methods such as employed so boldly and practically by Heaviside in connection with step functions. Because he has been unmindful of this restriction of field, Mr. Barkey has cited references which are not of moment to the engineer in this connection.

Operational processes which in *form* are the same as those Heaviside used do appear extensively in early mathematical literature, but their application is to functions which are analytic in the region of interest, i. e., functions which can be developed in a power series which is convergent in this region. One wishing to delve into the early history of operational or symbolic methods in general, which have been used in differential and integral calculus and in differential equations, should consult "Symbolic Calculus. Bibliography on General (or Fractional) Differentiation," by E. Stephens, Washington University Studies, volume 12, *Scientific Series*, number 2 (1925), pages 137–52.

Heaviside was interested in the application of operational processes to nonanalytic functions, such as his unit function. In this his work was heuristic, but it was subsequently substantiated and shown to be but a formal expression of the processes of the Laplacian transformation. Some helpful references, less widely known but bearing upon this, are given at the end of this letter. For the form of the Laplacian transformation—hereafter abbreviated L-transformation—see equation 21 of my paper. By means of it a set of dissociated rules of procedure has been replaced by a method highly systematic in its application and capable of being made as rigorous as desired. With the advantage of its philosophy, one not only understands why the Heaviside type of operational calculus proceeded as it did, but visualizes extensions along lines the seeds for development of which were hardly apparent in the Heaviside form.

This L-transform type of operational calculus facilitates the solution of linear differential, integro-differential, and difference equations. Certain restricted nonlinear applications have been made. See "Verallgemeinerte Laplacesche Integrale als Lösungen linearer und nichtlinearer Differentialgleichungen" by J. Horn, *Jahr. der Deut. Math. Ver.*, volume 25, 1917, pages 301–25, and earlier papers by the same author referred to there. While nonlinear problems can be formulated in terms of L-transforms, the process involves convolution in the complex domain, results in integral equations, and does not seem to simplify the solution. So in my paper the emphasis upon linearity was made advisedly.

The discussion was not upon mathematical operators in general, but upon the particular differential operators arising from linear differential equations. These operators *are* treated as ordinary algebraic elements, and the justification for this comes solely from the L-transform.

It is not stated that Boole was the first to use the operator D.

The question is not who was the first to use a partial fraction expansion in any way, but rather who used it first in solving differential equations. Mr. Barkey's comments here fall short of the mark. He has overlooked the important contributions of Cauchy, such as his "Mémoire sur le calcul intégral," *Oeuvres*, series 1, tome 2, pages 195–328, written in 1824, some 13 years before Lobatto's publication which is cited. Here Cauchy used partial fraction expansions, showed the relationship of the symbolic calculus to the Fourier integral, and solved the problem with general boundary conditions. His solution will be sketched briefly, as it discloses his thorough insight into the symbolic method of calculation years before Heaviside's time.

Starting with the linear differential equation with constant coefficients expressed in symbolic form (page 217, *loc. cit.*), and using the symbols as found there,

$$F(\alpha)u = f(t)$$

where α is the time differentiator $\frac{d}{dt}$ and enters only in positive integral powers, u is the unknown function of t, and $f(t)$ is the disturbing force function; the formal operational solution for u is made, giving

$$u = \frac{f(t)}{F(\alpha)}$$

By treating α as an algebraic element, $F(\alpha)$ is written as a product of linear factors

$$F(\alpha) = A_n(\alpha - \theta_0)(\alpha - \theta_1)\ldots(\alpha - \theta_{n-1})$$

where A_n is the coefficient of the highest derivative of u in the original differential equation. The partial fraction expansion of the operational solution gives

$$\frac{f(t)}{F(\alpha)} = \frac{1}{F'(\theta_0)}\frac{f(t)}{\alpha - \theta_0} + \frac{1}{F'(\theta_1)}\frac{f(t)}{\alpha - \theta_1} + \ldots + \frac{1}{F'(\theta_{n-1})}\frac{f(t)}{\alpha - \theta_{n-1}}$$

By means of the Fourier double integral, each term of this sum is shown to have a solution of the form

$$\frac{1}{F'(\theta_0)}\frac{f(t)}{\alpha - \theta_0} = \frac{1}{F'(\theta_0)}e^{\theta_0 t}\int_0^t e^{-\theta_0 T}f(T)dT$$

The indefinite integral is replaced, with equal generality, by the definite integral and a constant C_0.

$$\frac{1}{F'(\theta_0)}\frac{f(t)}{\alpha - \theta_0} = \frac{1}{F'(\theta_0)}e^{\theta_0 t} \times \left[C_0 + \int_0^t e^{-\theta_0 T}f(T)dT\right]$$

This C_0 with similar constants entering from each of the other terms in the partial fraction sum provide the necessary arbitrary constants, enabling one to make the solution fit the boundary conditions.

When Heaviside considered this problem, he recognized the practical importance of treating a simple boundary state of initial equilibrium, and a simple disturbing force function $1(t)$. It is well known that the stipulation of initial equilibrium is the same as saying the initial value of the dependent variable u and its first $n-1$ derivatives are to be zero at $t = 0$, and consequently that all arbitrary constants, such as C_0, must be zero. The result of each term in the partial fraction expansion under these conditions becomes

$$\frac{1}{F'(\theta_0)}\frac{1(t)}{\alpha - \theta_0} = \frac{1}{F'(\theta_0)}e^{\theta_0 t}\int_0^t e^{-\theta_0 T}1(T)dT$$

This integration, when carried out for each of the terms of the sum, gives the result which is known conventionally as the Heaviside partial-fraction expansion theorem. Heaviside, by interesting himself in a special case, arrived at a result which was latent in the literature at least 60 years prior to his writing.

In view of the treatment of this problem by means of L-transforms, wherein the initial conditions of the system may be entirely general, it is interesting to note that even this is anticipated by Cauchy. In his mémoire "Sur la détermination des constantes arbitraires renfermees dans les intégrales des équations différentielles linéaires," *Oeuvres*, series 2, tome 7, pages 40–54, he gives a process in which the arbitrary constants of the solution are written directly in terms of prescribed boundary values. The transform theory can do no more, although it makes the whole procedure more direct and easier to understand.

The above may be applied further to correct Mr. Barkey's remarks in regard to what the distinguishing features of the Heaviside type of operational calculus are. In addition to the use of the unit function, the important feature is the restriction of boundary conditions to those of equilibrium. It is as a *consequence* of this restriction that the inverse operator p^{-1} means integration between limits zero and t.

In Mr. Barkey's integral interpretation of p^{-1} he indicates that it is necessary to approach the lower limit from the positive side. The possibility of a discontinuity at the origin is apparently a matter of concern to him, whereas the possibility of a finite number of additional discontinuities thereafter is entirely overlooked, and such may well occur. Integration in a Riemann sense is involved; there is no need for the limit process which his notation suggests.

Contrary to Mr. Barkey's assertion, Heaviside did give on page 36, "Electromagnetic Theory," volume 2, an "explicit evaluation" of his unit function as

$$1(t) = \begin{cases} 0 & t < 0 \\ 1 & 0 < t \end{cases}$$

No doubt Mr. Barkey meant Heaviside gave no *other* representation. Furthermore, his statement regarding "the necessary and sufficient conditions under which" this function can have a certain representation is meaningless.

The D operational theorems

$$e^{hD}F(t) = F(t + h)$$

$$\phi_0(D)\{\phi_1(t)\phi_2(t)\} = \phi_1(t + D_0)\phi_0(D_2)\phi_2(t)$$

employed by Mr. Barkey need comment. Using the singly infinite L-transform, such as given in equation 21 of my paper, the first with h positive is invalid when used with nonanalytic functions, such as involved in his argument, unless $F(t) = 0$ for $0 < t < h$. It is a common mistake to bring over this old theorem, good for analytic functions, into the treatment of nonanalytic functions without any attention to its limitations. The transform theory is of greatest assistance in providing guidance here. The second theorem I neither recognize nor understand.

The solution for $i(t)$ which Mr. Barkey gives is far from recognizable as "the solution of the Heaviside problem as substantially given by Bromwich, and his disciple, H. Jeffreys." A study of the writings of these 2 would never disclose any substantial resemblance between the transform for $\phi(t)1(t)$ as they would have written it and the $\frac{\phi(t + D_p)}{p}$ which Mr. Barkey writes in the integrand.

Despite the eminent sources of the equation

$$\frac{1}{p} f(t) = \int_0^\infty e^{-px} f(x)\, dx = \int_0^t f(x) dx$$

presented by Mr. Barkey, it does not stand up under examination. It is an example of the confusion which vitiates the reasoning in this subject when the symbol p is used indiscriminately as an operator and as a complex variable. The middle member is the L-transformation. In it the symbol p is a complex variable. When this integral is evaluated, the result is the L-transform of $f(x)$, and is a function of the complex variable p. Violating the meaning of equality, the left member is an operational expression in which p is a symbol of operation, the right member is a definite integral which when evaluated gives a function of t. There is consistency between left and right members, but each is inconsistent with the middle member.

The final equation in his discussion is similarly confused. On the right is the L-transform of $i(t)$, which is a function of the complex variable p; on the left is an operational expression in p and 2 functions of the real variable t, resulting presumably in a function of t.

Mr. Barkey attempts to prove that Heaviside knew the direct L-transformation, and that this relationship was not due to Carson. It must be admitted that this transformation has been in the mathematical literature since 1785; see, for example, page 280 of Laplace's "Mémoire sur les approximations des formules qui sont fonctions de très grands nombres," *Oeuvres complètes*, volume 10, pages 209–338. Cauchy used it; see, for example, equation 13, page 148, of his "Sur la transformation des fonctions d'une seule variable en intégrales doubles," *Oeuvres*, series 2, tome 7. Of the many writers who have employed it as a means of substantiating Heaviside's methods, probably the first was Giorgi. See his "Sul Calcolo delle Soluzioni Funzionali," *Associazione Elettrotecnica Italiana Atti*, volume 9, 1905, pages 651–99, or his 1924 paper in English cited below.

In appraising the applicational success of the *L-integral* equation, Mr. Barkey does not seem to appreciate that the solution of this integral equation is given in all cases by the inverse L-transform. (See remarks relative to equations 24 and 25 in my paper.) This explicit solution in the form of a line integral in the complex plane of course may not be easy to evaluate in particular cases.

In conclusion, let me emphasize again that the trend of developments in this subject is distinctly away from formal symbolic methods toward the rigorous methods of transform theory—a situation which Mr. Barkey apparently does not appreciate; otherwise, it is unlikely that he would be approaching the subject in the manner in which he does. One will gain much insight into this development from papers such as the following:

On the Functional Dependence of Physical Variables, G. Giorgi. *Proc.*, International Math. Congress, Toronto, 1924, v. 2 p. 51–56.

Heaviside's Operational Method, D. P. Dalzell. *Proc.* Phy. Soc., London, v. 42, 1930–31, p. 41–2.

Operationskalkül von Heaviside und Laplacian Transformation, T. Von Szachó. R. Univ. Hung. Tech.-Fo., Szeged, Octa, 3, p. 107–20.

Überlich Über Gegenstand und Methods der Funktional Analysis, G. Doetsch. *Jahresber.* Deutsch. Math. Ver., v. 36, 1927, p. 1–30.

Die Anwendung von Funktionaltransformationen in der Theorie der Differentialgleichungen und die symbolische Methods (Operatorenkalkül), G. Doetsch. *Jahresber.* Deutsch. Math. Ver., v. 43, 1934, p. 238–51.

I am appreciative of the help given me by Dr. J. L. Barnes, of the department of electrical engineering, Massachusetts Institute of Technology.

Very truly yours,

M. F. Gardner (M'31)
(Assistant Professor, Massachusetts Institute of Technology)

Personal Items

V. J. F. Brain (A'22, M'32, and local honorary secretary) chief electrical engineer, Department of Public Works, Sydney, Australia, has been installed as chairman of the Sydney division of the Institution of Electrical Engineers, Australia. Mr. Brain graduated from Sydney University in 1922, after which he came to the United States, where he was connected with the General Electric Company at Schenectady, N. Y., and for a short time with the Alabama Power Company. In 1925 he entered the New York Edison Company, New York, N. Y., as assistant engineer in the electrical engineering department, where he remained until 1929, when he was appointed to his present position. Mr. Brain was a member of the Institute's committee on protective devices during 1928–29.

J. W. Cowles (A'02, M'03) since 1913 superintendent of the installation department, Edison Electric Illuminating Company of Boston, Mass., has retired from active service. Mr. Cowles was born at Norfolk, Conn., and was graduated from the electrical engineering course at Cornell University in 1890. Until 1893 he was with the Thomson-Houston Electric Company at Lynn, Mass., and after short periods of time as assistant city engineer at Malden, Mass., and with the Marks-Ayer Electric Company, New York, N. Y., joined the Boston Electric Light Company in 1895. Following the consolidation of this company with the Edison company in 1901 he became assistant head of the standardizing and testing laboratory, and the following year was appointed superintendent of distribution. Mr. Cowles served on the lighting and illumination committee (now committee on production and application of light) of the Institute during the period 1914–16.

Burkewood Welbourn (M'26) chief engineer, British Insulated Cables, Ltd., Prescot, England, has been awarded the honorary degree of master of engineering from the University of Liverpool. Presentation will be made in July 1935. Mr. Welbourn studied at King's College, London, and after a few years of employment entered British Insulated Cables, Ltd., in 1897 as an assistant engineer. In 1901 he became chief construction engineer, and since 1927 has been chief engineer. Mr. Welbourn is a past vice president and at present a member of the council of the Institution of Electrical Engineers (Great Britain) and a past chairman of its Liverpool Centre. He has been a member since its inception of the advisory committee of engineers to the electrical department at Liverpool University.

K. B. McEachron (A'14, M'20) research engineer of the General Electric Company at Pittsfield, Mass., has been awarded the Edward Longstreth medal of the Franklin Institute. Presentation was made on May 15, 1935. The award was established in 1890 for the "encouragement of invention, and in recognition of meritorious work in science and the industrial arts," and the official citation reads: "In consideration of

his careful conduct of a series of closely controlled investigations extending over a period of 6 years which resulted in the successful development of a process for the manufacture of thyrite." This material is used for a number of applications, principally lightning arresters. Mr. McEachron has been with the General Electric Company for 13 years, and since 1933 has been in charge of the high voltage laboratory at Pittsfield. He has been a member of the Institute's protective devices committee since 1933, serving previously on this committee 1926–28 and on the electrophysics committee 1926–32. Mr. McEachron has presented a number of papers before the Institute on the subject of lightning.

P. G. Burton (A'95, M'13, F'16, and member for life) general plant manager, Chesapeake and Potomac Telephone Company, Washington, D. C., has retired from active work after 41 years with the Bell System. Mr. Burton studied at Cornell University, but left because of illness. After 3 years in electrical contracting work he became connected with the Western Electric Company at New York, N. Y., becoming assistant superintendent of the installation department in 1900. In 1904 he accepted the position of superintendent of maintenance with the Chesapeake and Potomac Telephone Company, and the following year was appointed plant superintendent of the Washington division. He was appointed engineer of this and associated companies in 1912, and in 1920 was appointed general superintendent of plant, becoming general plant superintendent in 1927, the title being changed 2 years later to general plant manager. Mr. Burton was at one time chairman of the Washington, D. C., Section of the Institute, and presented several papers at Section meetings. He is a charter member of the Alexander Graham Bell chapter of the Telephone Pioneers.

Henry E. Warren (A'02) president of the Warren Telechron Clock Company, Ashland, Mass., has been presented with a John Price Wetherill medal of the Franklin Institute in recognition of his invention of the "telechron" clock motor. The John Price Wetherill medal, inaugurated in 1925, is of silver, and is awarded for discovery, invention, or development in physical sciences. Mr. Warren recently was awarded the Lamme medal of the A.I.E.E., presentation of which will be made at the summer convention at Ithaca, N. Y. A biographical sketch and photograph of Mr. Warren appear on page 351 of Electrical Engineering for March 1935.

L. F. Morehouse (M'16, F'20, and past vice president) who since 1933 has been assistant director of system development for the Bell Telephone Laboratories, Inc., New York, N. Y., is now in London, England, where he is technical representative in Europe for the American Telephone and Telegraph Company and the Bell Telephone Laboratories, Inc. He is succeeding H. E. Shreeve (A'07, F'30) who is planning to retire. Mr. Morehouse, a graduate of the University of Michigan, entered the Western Electric Company in London as transmission engineer in 1906 after several years of teaching electrical engineering. Three years later he became equipment engineer with the American Telephone and Telegraph Company at New York, and from 1919 to 1933 held the position of equipment development engineer. Mr. Morehouse was a manager of the Institute 1919–23 and a vice president 1924–26, and has been very active in committee work. He is the author of an Institute paper on machine switching for telephones.

G. H. Stickney (A'04, F'24) consulting engineer, incandescent lamp department, General Electric Company, Cleveland, Ohio, has been elected president of the U. S. National Committee of the International Commission on Illumination. He succeeds E. C. Crittenden (A'19, M'22) assistant director, National Bureau of Standards, Washington, D. C., who resigned after 7 years as president in order that the U. S. delegation to the forthcoming sessions of the commission in Germany might be headed by its president, Mr. Crittenden not being able to leave the country at this time. Mr. Stickney has been with the General Electric

G. H. STICKNEY

Company since 1896, when he entered the student course. In 1909 he became assistant director of the illuminating engineering laboratory at Schenectady, N. Y., and 2 years later went to Harrison, N. J., where he became head of the lighting service department. Mr. Stickney was president of the Illuminating Engineering Society 1917–18, and has served on several Institute committees. He has been a member of the standards committee since 1923, and served on the committee on the production and application of light 1919–33, being chairman 1921–25. He is a fellow of the American Association for the Advancement of Science.

M. K. Goldstein (A'33) formerly with the J. D. Radio Company, Baltimore, Md., and with the U.S. Navy aerodynamical laboratory, is now engineer in charge of the electronics department of the Molded Insulation Company, Philadelphia, Pa. Doctor Goldstein has been engaged in research on multiplex vacuum tubes and color music transmission and reproduction, and is now developing an automatic remote indicating system for anti-aircraft gun control apparatus. The 1933 A.I.E.E. Middle Eastern District prize for best paper was awarded to him for his paper "Telemetering in Large Power Stations." A biographical sketch and photograph of Doctor Goldstein appear on page 1683 of Electrical Engineering for December 1934.

F. M. Farmer (A'02, F'13) vice president, chief engineer, and director, Electrical Testing Laboratories, New York, N. Y., has been nominated as Institute representative on the Engineering Foundation board. Mr. Farmer is vice chairman of the standards council of the American Standards Association, and is chairman of the Institute's committee on research and a member of the committees on power transmission and distribution, co-ordination of Institute activities, technical program, executive, standards, award of Institute prizes, and Edison medal.

J. S. Murray (A'21, M'31) electrical engineer, Follansbee Brothers Company, Follansbee, W. Va., has recently been appointed manager of the electrical sheet department on sales and production. He will also continue to serve as electrical engineer, the position he has held since 1919. Mr. Murray is also a member of the American Society for Testing Materials and the Association of Iron and Steel Electrical Engineers, and served on the Institute's committee on applications to iron and steel production 1932–34.

T. H. Haines (A'23, M'31) superintendent of distribution, Edison Electrical Illuminating Company of Boston, Mass., has had his jurisdiction enlarged to include the installation department, the departments being merged following the retirement of J. W. Cowles (A'02, M'03) from active service. Mr. Haines has been with the company since 1913, and became superintendent of distribution in 1925. He is a member of the Institute's committee on power transmission and distribution, on which he has served since 1931.

J. B. MacNeill (A'18) general manager of distribution engineering, Westinghouse Electric and Manufacturing Company, who has been at East Pittsburgh, Pa., is now at Boston, Mass. Mr. MacNeill has been a member of the Institute's power transmission and distribution committee since 1933, and was a member of the protective devices committee 1920–22 and 1928–32. He has contributed several papers on circuit breakers to the Institute.

J. B. Whitehead (A'00, M'08, F'12, Life Member, and junior past-president) has been nominated as a representative of the Institute on the division of engineering and industrial research, National Research Council. Doctor Whitehead is now a member of the Institute's executive, electrophysics, Edison medal, and Institute policy committees, and is serving on the John Fritz medal board of award.

F. B. Jewett (A'03, M'10, F'12, and past-president) vice president of the American Telephone and Telegraph Company and president of the Bell Telephone Laboratories, New York, N. Y., has been appointed to a special service board of 8 scientists and engineering experts to investigate lighter-than-air craft, the future of which in the United States will be determined largely by the board's recommendations. The committee was appointed by K. T. Compton (F'31) president of Massachusetts Institute of Technology and chairman of the Navy's science advisory board.

W. M. Dann (A'04, F'26) assistant manager, Westinghouse Electric and Manufacturing Company, Sharon, Pa., has been appointed alternate representative of the Institute on the sectional committee on transformers. Mr. Dann is a member of the Institute's membership committee, and served on the electrical machinery committee 1924–31.

K. W. Jarvis (A'25, M'34) formerly assistant chief engineer, Zenith Radio Corporation, Chicago, Ill., is now eastern division general manager for the Meissner Manufacturing Company, New York, N. Y. Mr. Jarvis has been active on committees of the Institute of Radio Engineers, and is the author of a number of papers, published principally in the I.R.E. *Proceedings*.

Kennard Pinder (A'28) electrical engineer, E. I. du Pont de Nemours and Company, is now in the engineering department at Wilmington, Del. Since 1933 he had been at Waynesboro, Va., where he was in charge of all electrical design and electrical construction for the Du Pont Rayon Company during the building of a new plant.

J. E. Borland (A'22) who has been a general engineer with the Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa., is now with the Westinghouse Electric Company of South Africa, Ltd., at Johannesburg. Mr. Borland has been a member of the Institute's committee on applications to mining work since 1933.

G. M. Palo (A'32) formerly with the General Electric Company at Erie, Pa., is now assistant chief water heating inspector with the Puget Sound Power and L ght Company, Seattle, Washington. An article by him on water heating has appeared in technical publications.

R. E. Lyle (A'32) is now an electrical engineer at the engineering experiment station of Washington State College, Pullman. He recently conducted a survey of electric heating in the Columbia basin with the contractors camp at Mason City as a laboratory.

K. V. Condon (A'31) has resigned as superintendent of the Bolivian Power Company, La Paz, Bolivia, South America, and has entered business as a contractor for hydroelectric and allied construction, acting also in an advisory capacity for Fabulosa Mines Consolidated, La Paz.

William Webber (A'33) who has been connected with the Royal Dutch-Shell Oil Company at Mexico, Federal District, Mexico, is now in the engineering department of The Flintkote Company at Chicago Heights, Ill.

Jose Aguado (A'34) assistant to general manager, Armstrong Cork Products Company, who has been at Lancaster, Pa., is now at Cincinnati, Ohio. He has been engaged in organizing branches and in sales force training and has been traveling extensively.

Harold Egeberg (A'28) resigned as inspecting engineer with the Queensland Insurance Company, Ltd., Brisbane, Queensland, Australia, and is now assistant electrical engineer with the Department of Public Works, Queensland.

H. F. Bob (M'30) manager at Buffalo, N. Y., for the Westinghouse Electric and Manufacturing Company, has been promoted to the position of assistant manager of the eastern district, with headquarters at New York, N. Y.

E. F. Beck (M'35) chief engineer, Westinghouse X-Ray Company, Inc., Long Island City, N. Y., has been appointed one of the Institute's representatives on the sectional committee on safety code for lightning protection.

A. B. Lambert (A'31, M'32) who has been sales engineer with Bepco Canada Limited, Toronto, Ont., is now at Manchester, England, having rejoined the sales engineering staff of Crompton-Parkinson Limited.

S. W. Dana (A'33) formerly with the International Business Machines Corporation at Pittsburgh, Pa., is now in the distribution department of the Potomac Electric Light and Power Company, Washington, D. C.

W. F. Grauch (A'34) formerly with the Olean, N. Y., office of the Dresser Manufacturing Company of Bradford, Pa., is now with the Niagara, Lockport and Ontario Power Company and is at Batavia, N. Y.

A. J. Kohler (A'04) former appraisal engineer in the gas valuation bureau of the Public Utilities Commission of District of Columbia, Wash., is now engineer inspector, Public Works Administration, Elmira Reformatory, Elmira, N. Y.

A. E. Saldana (A'33) former engineer in the construction department, Cia. Colombiana de Electricidad, Barranquilla, Columbia, South America, is now with the Porto Rico Railway Light and Power Company, San Juan.

W. A. Barnes (A'24) who has been chief engineer of The Swartzbaugh Manufacturing Company at Toledo, Ohio, has accepted the position of chief engineer with The Dominion Electrical Manufacturing Company which is now located at Mansfield, Ohio.

F. S. Giller (A'13, M'25) former assistant general purchasing manager for the International Standard Electric Corporation, London, England, has engaged in private practice as an international business consultant at Hextable.

A. H. Brolly (A'27) engineer, Television Laboratories Ltd., who was at San Francisco, Calif., is now at Philadelphia, Pa. Mr. Brolly is the author of a paper on television published in Electrical Engineering in August 1934.

L. F. Griffith (M'33) former engineer in the distribution department of the Shanghai Power Company, Shanghai, China, is now employed as an engineer by the U.S. Government at Washington, D. C.

W. F. Laubscher (A'27) who has been at Florence, Ala., in connection with the Wilson Dam, is now at Chattanooga, Tenn., in the department of electricity of the Tennessee Valley Authority.

Robert McDonald (A'29) Cerro de Pasco Copper Corporation, who recently was with the hydroelectric department at La Oroya, Peru, South America, is now at Malpaso, Peru, as chief electrician.

P. O. Bobo (A'33) formerly a draftsman with the Oklahoma State Highway Department, Oklahoma City, is now in the relay department of the Oklahoma Gas and Electric Company, Oklahoma City.

J. A. Fizzell (A'34) formerly with the Standard Electrical Instrument Laboratories, Kansas City, Mo., is now in the research department of the Illinois Testing Laboratories, Chicago.

W. W. Brooks (A'34) who has been field engineer for the Illinois Water Survey at Mason City is now research assistant in electrical engineering at the University of Illinois, Urbana.

J. M. Srock (A'31) formerly with the Cia de Electricidad del Sud Argentino, Buenos Aires, is now employed by the Yorkshire Electric Power Company, Southampton, England.

C. H. Kenny (M'25) former chief engineer of Bart Laboratories, Belleville, N. J., is now an electrical engineer with the Public Service Commission of the State of New York, and is located at New York City.

H. H. Ehrenburg (A'28) former city electrical engineer, Rotterdam, Holland, has taken the position of manager of the Twentsch centraal station for the Electrische Stroomievering at Hengelo.

H. F. Kingdon (A'26) former design engineer, Canadian Crocker-Wheeler Company, Ltd., St. Catherines, Ont., Can., is now with the Commonwealth Electric Corporation, Ltd., at Welland, Ont.

C. C. Campbell (A'24) former assistant engineer, Pacific Gas and Electric Company, San Francisco, Calif., has engaged in the automobile service and accessory business at Truckee, Calif.

R. J. Philipps (A'34) former designing engineer with Kenyon Transformer Company, New York, N. Y., is at Bristol, Pa., as electrical engineer and plant superintendent for Fleetwings, Inc.

G. C. Sharma (A'24) former principal of the Victoria Diamond Jubilee Hindu Technical Institute, Lahore, India, is now technical representative for the Tide Water Oil Company (India) Ltd., Lahore.

P. K. Moffatt (A'25) who has been with the Cia. Cubana d' Electricidad, Havana, Cuba, is now with the Potomac Electric Power Company, Washington, D. C., as cable engineer.

T. J. Burrin (A'34) formerly in the engineering department of the Public Service Commission of Indiana, Indianapolis, has been appointed superintendent of the utilities department of Lebanon, Ind.

M. K. Toeppen (A'21, M'21) Lansing, Mich., has resigned as chief consulting engineer of the Michigan Public Utilities Commission. Mr. Toeppen has been with the commission since 1920.

R. J. Wensley (A'28) formerly a division engineer with the Westinghouse Electric and Manufacturing Company at Newark, N. J., is now with the I-T-E Circuit Breaker Company at Philadelphia, Pa.

E. W. Thorncroft (A'31) former resident electrical engineer, Sutherland Shire Council, Sutherland, New South Wales, Australia, is now with Essantee Switchgear Limited, Sydney, Australia.

G. A. Booth (A'13) former local manager at Mukden, Manchuria, for Andersen, Meyer and Company, Ltd., is now manager at Tientsin, China.

Oney Evans (A'34) of Uvalde, Tex., is now with the Lago Oil and Transport Company, Ltd., at Aruba, Dutch West Indies.

D. J. Corrigan (A'34) of Sunrise, Wyo., is now electrical power survey engineer for the State of Wyoming, Cheyenne.

R. C. Carlson (A'34) of Ludlow, Pa., is now a student engineer with International Business Machines Corporation, Endicott, N. Y.

Webster Richardson (A'34) Cleveland, Ohio, is now an engineer in the house heating department of the East Ohio Gas Company, Cleveland.

G. J. Schottler (A'25) former patent lawyer with Emery, Booth, Varney, and Whittemore, New York, N. Y., is now with the General Cable Corporation, New York.

Fortunato Bazzechin (A'22) former electrical draftsman with Thomas E. Murray, Inc., New York, N. Y., is now with the American Brake Shoe and Foundry Company, Mahwah, N. J.

J. D. Harper (A'34) junior electrical engineer with the Aluminum Company of America, who has been at Tapoco, N. C., is now at Alcoa Tenn.

A. J. Hughes, Jr. (A'33) of Fountain Inn., S. C., is now with the emergency crop loan office of the U.S. Farm Credit Administration at Memphis, Tenn.

B. E. Yusim (A'30) Amtorg Trading Corporation, New York, N. Y., has returned to New York from Moscow, U.S.S.R., after 3 years in Russia.

R. L. Daeley (A'34) of Streamstown, Alberta, Can., is now Canadian representative of the Helwig Company at Vancouver, B. C.

K. M. Joehnk (A'34) General Electric Company, who has been in the testing department at Schenectady, N. Y., is now at Bridgeport, Conn.

A. B. Nomann (A'32) of South Pasadena, Calif., is now employed as a foreman in the instrument shop of the U.S. Coast and Geodetic Survey at Pasadena.

J. L. Tonge (A'31) former consulting architect at Cranston, R. I., is now a valuation engineer with M. E. Scharff, New York, N. Y.

E. S. Steinbach (A'09, M'22) industrial engineer, Stone and Webster Engineering Corporation, who has been at Boston, Mass., is now at St. Louis, Mo.

J. A. Pollak (A'33) who has been in the U.S. Engineer's Office at Cape Girardeau, Mo., is now at St. Louis as a student engineer.

W. S. Finlay, Jr. (A'18, F'21) president, The West Penn Electric Company, who has been at Pittsburgh, Pa., now has his offices at New York, N. Y.

C. F. Myers (A'31) Puget Sound Power and Light Company, who has been at Wenatchee, Wash., is now distribution engineer at Everett, Wash.

G. W. Kemper (A'31) of Wapello, Iowa, is now in the test department of the Westinghouse Electric and Manufacturing Company at Sharon, Pa.

J. M. Morgan (A'22, M'30) former rural electrification engineer, State of South Carolina, Columbia, is now with the Federal Power Commission, Washington, D. C.

I. M. Dow (A'27) Washington, D. C., is now an assistant engineer in the ordnance design division of the U.S. Navy Department.

R. E. Reid (A'12) engineer formerly with the La Grange Gold Dredging Company, La Grange, Calif., is now with the Capital Dredging Company at Folsom City, Calif.

E. F. Adams (A'33) Elizabeth, N. J., is now an electrical engineer with the Weston Electrical Instrument Company, Newark, N. J.

C. A. Rosencrans (A'33) of Warwick, N. Y., is now a student engineer with R.C.A. Victor Company, Camden, N. J.

R. B. Zane (A'34) The Okonite Company, who has been at Passaic, N. J., as a research engineer, is now in Chicago, Ill.

J. B. Fountain (A'35) division engineer Mississippi Power and Light Company, has been transferred from Greenville to Jackson.

Tetsujiro Yokota (A'19) formerly at Kobe, Japan, is now with the Mitsubishi Electric Company at Nagoya.

A. W. Bechlem (A'25) of Syracuse, N. Y., is now an engineer with The Solvay Process Company at Baton Rouge, La.

J. T. Mullen (A'29) plant chief, Indiana Bell Telephone Company, who has been at Marion is now at Evansville.

A. B. Cohen (A'34) of Dorchester, Mass., is now at Philadelphia, Pa., with station WCAU.

Obituary

Franklin Washington Wood (A'05, M'20) marine electrical engineer, Great Neck, N. Y., died April 18, 1935. He was born at London, England, January 2, 1870. In 1887, 2 years after coming to America, he became associated with Chas. Cory and Son, Inc., manufacturers of marine signaling and intercommunicating equipment in New York, N. Y. During the period 1893 to 1907 Mr. Wood was engineer in charge of construction and installation work for them at Newport News, Va., after which he was appointed chief engineer with offices at New York. In 1914 he became vice president of the company, and in 1920 went to England as European representative, but because of ill health retired in 1926, although he maintained his interest in the industry. He returned to the United States in 1933, and accepted a position as consulting engineer for Chas. J. Henschel and Company, Inc., Amesbury, Mass. Mr. Wood is credited with holding over 100 patents, among which are engine direction and revolution indicator systems, d-c self-synchronizing motors, for many years standard in all U.S. Navy telegraphs for communication and fire control purposes, various types of electrical and mechanical signaling appara-

tus for submarines, and various marine lighting fixtures and wiring appliances. Numerous technical descriptions and treatises on the care and operation of these different equipments were prepared by him for the instruction of Navy and merchant marine personnel. Mr. Wood was a member of the Institute's marine (now applications to marine work) committee from 1913 to 1922.

Hassan Camil Ali Sabbah (M'29, F'33) electrical engineer, General Electric Company, Schenectady, N. Y., died March 31, 1935. He was born at Nabatiah, Beirut, Arabia, August 16, 1895, and studied at the American University of Beirut. During 1918 he commanded a military wireless station in Thrace, then taught mathematics at the Imperial College of Damascus, Syria, and the American University of Beirut. In 1921 he came to the United States, and for a short time studied at Massachusetts Institute of Technology. He entered the vacuum tube section of the engineering laboratory of the General Electric Company at Schenectady in 1923, where he was engaged in mathematical and experimental research, principally on rectifiers and inverters, receiving a number of United States and foreign patents covering his work. Mr. Sabbah was engaged in work on television and motors as well, and originated circuits for use with rectifiers. He prepared a series of articles on polyphase polycyclic static converters which were published in the *General Electric Review*, and his paper on the effect of circuits on arc backs in mercury arc rectifiers was read before the International Electric Congress at Paris in 1932.

Natalis Mazen (F'22) sous-directeur, Chemins de Fer de L'Etat Francais, La Roche, France, died in August 1934 according to word received at Institute headquarters. He was born at Clermont-Ferrand, France, May 2, 1863, and early became interested in railway work. As a pioneer of electric traction in France, during 1899–1900 he had charge of the installation and inauguration of the first electric traction on a large scale in France on a branch line between Paris and Versailles. For a time he was chief engineer of materials and operation and assistant director for the State railroads, and was for 18 years professor of a course of applied mechanics and of electric traction at the School Superior of Electricity at Paris. At the time of his election to the Institute he was honorary director of the railways of the State of France. Mr. Mazen also served as consulting engineer for railroads in southern France, railways in the province of Rhone and in Paris, and for a metallurgical company. He was a former president of the French Society of Electriciens, and a member and officer of a number of other societies.

Frank Bailey Steele (M'18) consulting engineer and deputy city engineer, Utica, N. Y., died April 17, 1935. He was born at Stewartson Furnace, Pa., May 25, 1885, graduating from Virginia Military Institute and entering the engineering apprentice course of the Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa., in 1905. Two years later, as assistant engineer in charge of construction for the company, he was engaged in work on government buildings in Washington, D. C., where he entered George Washington University, receiving the degree of electrical engineer in 1909. Later in that year he became electrical engineer for the Keystone Coal and Coke Company, Keystone, W. Va., and in 1913 accepted the position of power engineer with the Dayton Light and Power Company, Dayton, Ohio. Mr. Steele went to Utica in 1918 as vice president and general manager of the Utica Gas and Electric Company, resigning from this position in 1929. He then engaged in consulting engineering, and at the time of his death was on leave from his duties as deputy city engineer to serve as assistant to the Temporary Emergency Relief Administration commissioner.

Anthony Saunders Morris (A'04) Haverford, Pa., died recently. He was born April 13, 1862, and attended schools at Philadelphia, Pa., after which he entered Stevens Institute of Technology, from which he received the degree of mechanical engineer in 1884. He became connected with the Westinghouse Electric and Manufacturing Company in 1887 and remained there a number of years. Since 1915 he had been vice president of the Cresson-Morris Company, Philadelphia. Mr. Morris was about to be enrolled as a member for life of the Institute.

R. Seshasayee (A'31) consulting engineer, Messrs. Seshasayee Brothers, Ltd., Trichinopoly, India, died February 11, 1934, according to word just received at Institute headquarters. He first became an Associate in 1910. Mr. Seshasayee had been engaged in the construction of power plants of various sizes since 1913, installing diesel and small engine plants in a number of buildings and several towns.

Membership

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before June 30, 1935, or Aug. 31, 1935, if the applicant resides outside of the United States or Canada.

Allen, E. W., Southwestern Bell Tel. Co., Dallas, Texas.
Alspaugh, R. M., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Bacon, E. Jr., Washington Water Pwr. Co., Spokane.
Becker, L. S., Harvard Graduate School of Business, Boston, Mass.
Belshe, R. L., Petroleum Rectifying Co. of Calif., Long Beach.
Bennett, R. D. (Fellow), Mass. Inst. of Tech., Cambridge.
Black, D. S., Ohio Brass Co., Mansfield, Ohio.
Blascak, S. J. (Member), American Tel. & Tel. Co., New York City.
Braun, E. C., General Meter Service Corp., Brooklyn, N. Y.
Brown, R. D., Jr., Philadelphia Storage Battery Co., Philadelphia, Pa.
Carney, E. M., Brooklyn Edison Co., Brooklyn, N. Y.
Carral, C. S., General Elec. S. A., Mexico D. F., Mexico.
Cisler, W. L. (Member), Public Service Elec. & Gas Co., Newark, N. J.
Daykin, H. R., Bostwick-Braun Co., Toledo, Ohio.
DeKinder, J. M., Bureau of Reclamation, Lovelock, Nev.
Dogan, A. E., University of New Hampshire, Durham.
Doolittle, H. S. (Member), Six Companies, Boulder City, Nev.
Farmer, A. C., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Frisby, E. F., Virginia Elec. & Pwr. Co., Richmond, Va.
Funk, J. T. S., 2100 Monterey Blvd., San Francisco, Calif.
Gentsch, E. J., Picker X-Ray Co., New York City.
Gore, C. W., Clark & Wilson Lumber Co., Linnton, Ore.
Hafely, C. H., Ford Instrument Co., Inc., Long Island City, N. Y.
Hewett, J. L., Jensen Bowen & Farrell, Ann Arbor, Mich.
Irwin, E. M. (Member), Calif. Inst. of Tech., Pasadena.
Lazo, R. L., N. Y. State Public Service Comm., New York.
Lee, M., Burndy Engg. Co., Inc., New York, N. Y.
Linklater, T. B., Ontario Forestry Branch Radio, Toronto, Can.
Loewel, M. E., Western Elec. Co., Inc., New York City.
McDunnough, P. N., Shawinigan Water & Pwr. Co. Montreal, Que., Can.
McEntee, A. L., Consolidated Elec. Lamp Co., Lynn, Mass.
Morgan, C. F., Oklahoma Gas & Elec. Co., Drumright.
Mouat, T. W. Jr., Canadian Elec. Mfg. Co., Ltd, Vancouver, Can.
Pendleton, O. A. (Member), The Empire Dist. Elec. Co., Joplin, Mo.
Peterson, H. A., General Elec. Co., Pittsfield, Mass.
Schwartz, A., 161 Jackson Ave., Jersey City, N. J.
Tolman, S. C., 32 High St., New Haven, Conn.
Walmsley, C. A., N. Y. & Queens Elec. Lt. & Pwr. Co., Long Island City, N. Y.
Watson, L. A. (Member), Clark Contracting Co., Cleveland, Ohio.
Whitney, H. V., General Elec. Co., Richmond, Va.
Wikstrom, A. (Member), Cornell Univ., Ithaca, N. Y.
Young, D. A., Westinghouse Elec. & Mfg. Co., Newark, N. J.

42 Domestic

Foreign

Harvey, A. Q. (Member), Springs Municipality, Transvaal, South Africa.
Iyer, S. N., Hubli Elec. Co. Ltd., Hubli, Dharwar Dist., Bombay, India.
Mathews, J. T., Westinghouse Elec. & Mfg. Co., Berlin, Siemensstadt, Germany.
Thorburn, R. W., Allmanna Svenska Elektriska Aktiebolaget, Herrgarden, Ludvika, Sweden.
Trivedi, T. N., The Katni Cement & Industrial Co. Ltd., Katni, India.

5 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the address as it now appears on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

French, Benedict, V. K., c/o United American Bosch Corp., Springfield, Mass.
Germenshausen, K. J., M.I.T. Dorm., Cambridge, Mass.
Golikoff, A., Main P. O. Gen. Del., Moscow, U.S.S.R.
Greene, F. M., 656—50th St., Brooklyn, N. Y.
Haddad, Raphael A., 500 Riverside Drive, N. Y. City.
Hansen, A. Fred, 206$^{1}/_{2}$ W. 30th St., Los Angeles, Calif.
Houston, Chas. E., 400—10th Ave., S. E., Minneapolis, Minn.
Rasmussen, David, 423 Hickory St., Ridgway, Pa.
Roselle, P. M., 2018 Chestnut St., Harrisburg, Pa.
Smedley, A. B., 82 Warner Ave., Hempstead, N. Y.
Thomson, W. L., 3630 Spruce St., Philadelphia, Pa.
Verrier, E. J., Anglo Newfoundland Dev. Co., Grand Falls, Newfoundland.
Watson, J. Connell, 69 Cambridge Terrace, London, W. 2, Eng.

13 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

SCHWEIZ. VERBAND für die MATERIALPRÜFUNGEN der TECHNIK (Association Suisse pour l'Essai des Materiaux). Diskussionsbericht No. 27, Bericht No. 69 der Eidg. Materialprüfungsanstalt. Zürich, Jan. 1933. 57 p., illus., 12x8 in., paper, apply. These papers, read before sections of the Swiss Society for Testing Materials, discuss the determination of the tensile strength of paper, pasteboard, and cloth used for electrical insulation, the determination of humidity, the testing of cotton, and the testing of the permanency of colors.

SCIENCE MUSEUM (South Kensington). HANDBOOK of the COLLECTIONS illustrating ELECTRICAL ENGINEERING. RADIO COMMUNICATION, Pt. 1, History and Development. By W. T. O'Dea. London, His Majesty's Stationery Office, 1934. 95 p., illus., 10x8 in., paper, 2s 6d. Starting with the history of our knowledge of electromagnetic waves and of detectors, this work proceeds to describe early experiments in wireless telegraphy and the development to commercial practice. The history of thermionic valve and of the development of methods of speech transmission and television is given.

SERVICE CHARACTERISTICS of the LIGHT METALS and THEIR ALLOYS, prepared by Subcommittee VII of Committee B-7 on Light Metals and Alloys, Cast and Wrought. Phila., American Society for Testing Materials, 1934. Vol. 34, Pt. 1, 33 p., tables, 9x6 in., paper, $.50. This pamphlet is intended to present the essential data about aluminum and magnesium and their more important alloys in a concise form. The metallurgical characteristics of the metals are discussed, their usefulness in certain industrial fields is explained, surface protection by painting, anodising, or electroplating is described, and tables are given of the trade designations, compositions, physical constants, mechanical properties and foundry characteristics of various alloys.

SIGNIFICANCE of TESTS of PETROLEUM PRODUCTS, a Report Prepared by A.S.T.M. Committee D-2 on Petroleum Products and Lubricants. Phila., Pa., American Society for Testing Materials, 1934. 76 p., illus., 9x6 in., paper, $1.00. This report is intended to give the general public authoritative information about the applicability of the tests in common use for petroleum products and lubricants, and the significance of the results. It aims to assist in the proper choice of tests and their correct interpretation.

APPLICATIONS de l'ÉLECTRICITÉ. (Memento d'Électrotechnique—IV). By A. Curchod. Paris, Dunod, 1935. 831 p., illus., 9x5 in., paper, 136 frs.; bound, 146 frs. The final volume of a reference work covering the whole field of electrical engineering, and discussing the applications of electricity.

Care and Repair of FRACTIONAL-HORSEPOWER MOTORS. By A. G. Smith. Scranton, Pa., International Textbook Co., 1933. 126 p., illus., 8x5 in., lea., $1.10. A manual of practical information for the electrician, describing each main type and design, and windings.

GASENTLADUNGSTABELLEN. Tabellen, Formeln und Kurven zur Physik und Technik der Elektronen und Ionen. By M. Knoll, F. Ollendorff and R. Rompe. Berlin, Julius Springer, 1935. 171 p., illus., 10x7 in., cloth, 29 rm. Formulas, tables, and charts upon the physical behavior of atoms, electrons, and photons; the kinetic theory of gases; the kinetics of charge carriers and their ionisation phenomena; the properties of vacuum tubes; high vacuum technique, etc.

Great Britain. Dept. of Scientific and Industrial Research. Report of the FOREST PRODUCTS RESEARCH BOARD, 1933. Lond., His Majesty's Stationery Office; (obtainable from British Library of Information, N. Y.) 1934. 67 p., illus., 10x6 in., paper, is 3d.; $.45. A summary of investigations of methods of seasoning timber, timber preservatives, the chemistry of decay, insect damage, etc.

LIGHTING CALCULATIONS. By H. H. Higbie. N. Y., John Wiley & Sons, 1934. 503 p., illus., 9x6 in., cloth, $5.00. The problem method of teaching applied to illumination engineering, together with the lighting data needed by the student

NEON, a Handbook for Electrical Engineers, Neon Manufacturers, Sign Salesmen and Advertisers. By S. Gold. Lond., Crosby Lockwood & Son, 1934. 178 p., illus., 9x6 in., cloth, 7s 6d. The design, manufacture, and installation of neon signs in non-technical terms.

Les RÉSEAUX de TRANSMISSION d'ÉNERGIE, Réglage et Stabilité, Surintensités, Surtensions, Protection Sélective. By J. Falou. Paris, Gauthier-Villars, 1935. 558 p., illus., 10x7 in., paper, 125 frs. A discussion of the chief problems encountered in the construction and operation of transmission systems, covering theory, regulation, overloads, and protection.

MACHINE DESIGN, 3 vols. By M. E. Steczynski. Scranton, Pa., International Textbook Co., 1933, illus., 8x5 in., lea., vol. 1, 130 p., $1.25; vol. 2, 154 p., $1.50; vol. 3, 160 p., $1.75. An elementary course in practical machine design, intended primarily for home study; only elementary mathematics is used, and theoretical discussions omitted.

Science Museum, Lond. Board of Education. Technical Pamphlet No. 2. The AUTOMATIC TELEPHONE, by W. T. O'Dea. London, His Majesty's Stationery Office; (obtainable from British Library of Information, N. Y.) 1934. 13 p., illus., 10x6 in., 6d.; $.20. Non-technical description of the Strowger automatic telephone systems.

SCIENCE of WORK. By M. S. Viteles. N. Y., W. W. Norton & Co., 1934. 442 p., diagrs., 9x6 in., cloth, $4.00. A non-technical discussion of the applications of psychology to industry. Personnel selection, methods of training, the effect of various influences upon output, etc., are considered.

V D E—FACHBERICHTE 1934. Berlin-Charlottenburg 4, Verband Deutscher Elektrotechniker, 1934. 152 p., illus., 12x8 in., paper, 10.20 rm; bound, 13.50 rm. The technical proceedings of the Stuttgart, 1934, meeting of the Verband deutscher Elektrotechniker, containing 44 papers.

AMERICAN SOCIETY for TESTING MATERIALS, PROCEEDINGS of the 37th Annual Meeting, v. 34, 2 v., 1934. Phila., American Society for Testing Materials, illus., 9x6 in., cloth, v. 1, 1325 p.; v. 2, 943 p., cloth, $6.00; half leather, $7.00 each. Part 1 contains the reports of committees, the "tentative standards," and the tentative revisions of standard specifications and tests. Part 2 includes the papers and discussions upon metals, cements, ceramics, masonry, paints, rubber, and other topics.

The CHALLENGE to LIBERTY. By H. Hoover, N. Y. and Lond., Charles Scribner's Sons, 1934. 212 p., 8x6 in., cloth, $1.75. A discussion of the pressing political and economic questions of the day, and a criticism of current tendencies in the treatment of national problems.

DIESEL HAND BOOK, a Practical Book of Instruction for Engineers and Students on Modern Diesel Engineering, Land, Marine, Locomotive, Aero, Automotive and Portable Installations. 2nd ed. By J. Rosbloom. Jersey City, Diesel Engineering Publications, 1935. 549 p., illus., 7x5 in., lea., $5.00. A practical text and reference book for the operating engineer, presented largely in questions and answers.

MacRae's BLUE BOOK consolidated with Hendricks' Commercial Register. 42nd annual edition. Chicago, MacRae's Blue Book Co., 1934. 3340 p., illus., 11x8 in., cloth, $15.00. A directory of manufacturers and distributors of materials of all kinds, a classified list of materials, a directory of towns and cities, with their facilities for trade, and a list of trade names.

MISSISSIPPI VALLEY COMMITTEE of the PUBLIC WORKS ADMINISTRATION. Report Submitted October 1, 1934 to Harold L. Ickes, Administrator of Federal Emergency Administration of Public Works. U.S. Government Printing Office, Washington, D. C., 1934. 234 p., illus., 12 x 9 in., cloth, $1.50. The complete text of the report upon the use and control of water within the Mississippi drainage basin.

ELECTRONS (+ and −), PROTONS, PHOTONS, NEUTRONS, and COSMIC RAYS. By R. A. Millikan. Chicago, Univ. of Chicago Press, 1935. 403 p., illus., 8x5 in., cloth, $2.50. A nonmathematical review of recent discoveries and developments in physics, replacing the author's former book, "The Electron."

HIGH VOLTAGE PHYSICS. By L. Jacob. Lond. Methuen & Co., 1934. 107 p., illus., 7 x 4 in., cloth, 3s. A survey in outline of the physics of high voltage phenomena.

PRINCIPLES of ALTERNATING CURRENTS. By R. R. Lawrence. 2 ed. N. Y. and Lond., McGraw-Hill Book Co., 1935. 475 p., illus., 8x6 in., cloth, $4.00. A text for college students and a presentation of alternating current theory for reference use in practice.

X-RAYS in THEORY and EXPERIMENT. By A. A. Compton and S. K. Allison. N. Y., D. Van Nostrand Co., 1935. 828 p., illus., 9x6 in., cloth, $7.50. A comprehensive view of the whole field of X-rays, and discussion of the theory of the phenomena.

ATOMIC STRUCTURE and SPECTRAL LINES. I. By A. Sommerfeld, translated from the 5th German ed. by H. L. Brose. N. Y., E. P. Dutton & Co., 1934. 675 p., illus., 9x6 in., cloth, $10.80. The new edition will appear in 2 volumes, the present one containing the older quantum theory.

AUTOMATIC PROTECTION of A-C CIRCUITS. By G. W. Stubbings. Pittsburgh, Instruments Pub. Co., 1935. 295 p., illus., 9x6 in., cloth, $5.00. A discussion of the theory of protective transformers and their interconnection, the theory of protective relays, the protection of electrical machinery and cable networks, and the testing and maintenance of protective gear.

DESIGN of A-C MACHINES, TRANSFORMERS. By C. D. Sanders and D. D. Coffin. $2.40. DESIGN of DIRECT CURRENT MACHINES. By S. Hancock. $2.15. Scranton, Pa., International Textbook Co., 1934. Ills., 8x5 in., lea. A practical course in the design of electrical machines, using only simple mathematics and a minimum of theoretical discussion.

Deutsches Museum. Abhandlungen und Berichte, Jg. 6, Heft 3. NEUZEITLICHE LICHTERZEUGUNG MITTELS GASENTLADUNGSLAMPEN. By E. Lax. Berlin, VDI-Verlag, 1934. 81 p., illus., 8x6 in., paper, 90 rm. A popular account of modern methods of illumination, covering light, gaseous discharges, and modern gas filled lamps.

ELEKTROINSTALLATION in der SIEDLUNG, Vorbilder und Richtlinien. By M. Mengeringhausen, ed. by F. Hoppe. Berlin, VDI-Verlag, 1935. 51 p., illus., 12x8 in., paper, 1.90 rm. A pamphlet giving plans and standards for economical distribution in small villages.

ELEMENTARY MECHANICS. By J. B. Reynolds. rev. ed. N. Y., Prentice-Hall, 1934. 336 p., diagrs., 9x6 in., cloth, $2.75. A text for a first course in mechanics in technical schools, calling for only an elementary knowledge of algebra and geometry, and confined to the easier applications.

ELEMENTS of LOUD SPEAKER PRACTICE. By N. W. McLachlan. Lond. and N. Y., Oxford Univ. Press, 1935. 160 p., illus., 8x5 in., cloth, $1.75. Nontechnical explanation of the purpose, working, design, and effect of placement of loud speakers.

Engineering Societies Library

29 West 39th Street, New York, N. Y.

MAINTAINED as a public reference library of engineering and the allied sciences, this library is a cooperative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

Industrial Notes

Large Steel Mill Order to Westinghouse.—Contracts have been awarded to the Westinghouse Electric & Mfg. Co., amounting to approximately $1,250,000 by the Bethlehem Steel Co. for motors, control and power equipment to be installed in new hot and cold strip mills of the Lackawanna Plant of the steel company, at Buffalo. The electrical units include: four 3000-hp and one 1000-hp alternating-current motors, nine 1250-hp direct-current motors, and one 2500-kilowatt and one 1300-kilowatt motor-generator sets. Westinghouse is also supplying nearly 800 motors and variable frequency units for the roll tables of the mills and motors, motor-generator sets and control for a flying shear which catches and cuts to accurate lengths strip steel as it passes through the final rolling process. Westinghouse equipment will be installed to provide a cool air circulating system to ventilate the larger motors and motor-generator sets. Nearly all of the apparatus will be made in East Pittsburgh, work to start immediately.

Sherwin-Williams Appointment.—Announcement is made by The Sherwin-Williams Co., Cleveland, that H. J. L. Cotton has been appointed head of the insulating varnish and compound division of that company. Mr. Cotton was formerly assistant to Dr. Ware in the Varnish Research Department of the company.

New Brass-Bushed Insulators.—The Hemingray Division of the Owens-Illinois Glass Co., Muncie, Ind., has introduced a new line of brass-bushed glass insulators. The bushing is locked into position without cement or alloy to hold it in place, assuring smooth, perfect pin threads, eliminating breakage due to pin expansion and causing no radio interference. The most important advantage, however, is the greatly increased mechanical strength. Higher dielectric properties are also characteristic of the new insulator. All styles of the new insulators are made in clear and brown color glass with ratings up to 15,000 volts.

New Farm-Line Transformer.—The Wagner Electric Corporation of St. Louis has developed a new line of farm-line distribution transformers designed to reduce installation and maintenance costs and to provide maximum protection against lightning. They are manufactured in 1- and 3-kva sizes, 60 cycles, 2400 to 7620 voltage classes, for operation on a three-phase, four-wire service with solidly-grounded neutral. Standard 1-kva ratings are provided with two low-voltage leads for single-wire, low-voltage service (i. e., 120 volts). Standard 3-kva ratings are provided with three low-voltage leads for three-wire, low-voltage service (i. e., 120/240-volts).

New Graphic Kilovolt-Ampere Meter.—The Esterline-Angus Co., Indianapolis, Ind., announces a new kilovolt-ampere recording instrument, designed for use in making a continuous record of electrical energy. The new instrument embodies the standard model A.W. wattmeter in conjunction with a phase shifting net work which supplies the wattmeter with a lagging potential corresponding to the average power factor of the circuit. By means of three sets of taps, the instrument is made to cover a range of power factor from .54 to .94, with an error not to exceed $1^1/_2$ per cent. A tap is provided on the phasing net work, to permit measurement of reactive volt-amperes with the same instrument. By omitting the network, the instrument can be used as a graphic wattmeter. The instrument is furnished either as a complete unit including graphic wattmeter and phasing network, or the network can be furnished separately for use with existing meters. It is supplied in a combination 100–200 volt range, potential transformers being employed for higher voltages. These instruments are made in flush, front of board, wall, and portable types.

Improved Paper-Insulated Cable.—Five major improvements in the construction of paper-insulated cable which result in cable of smaller diameter over-all, higher dielectric strength, increased reliability, and longer life have been announced by the General Electric Co. The first of these improvements is a new compact-strand conductor which reduces the diameter of the cable, gives it higher dielectric strength, lowers the a-c resistance, and results in longer life. In addition, the change from annular to segmented construction in large single-conductor cable increases the current-carrying capacity for a given diameter. Second, the layers of insulation are graduated, with super-dense paper next to the conductor, improving the mechanical and dielectric strength. Third, the insulation is washed in carbon-dioxide gas, providing a more thorough impregnation and eliminating oxygen and moisture. Fourth, the lead sheath is applied by the General Electric hydrogen process which eliminates oxidized areas and provides a sheath free from weak and inferior spots. Fifth, on all classes of G-E Type H cable, the metal shields are interlocked with paper tapes, which results in more satisfactory shielding.

Trade Literature

Direct Current Generators.—Bulletin 1171, 12 pp. Describes generators for industrial, railway and power station service. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Circuit Breakers.—Bulletin GEA-1972, 4 pp. Describes type FK-144A, high-speed, oil-tight, circuit breakers for 50,000-kva service; 600 amperes, 15,000 volts; 1200 amperes, 7500 volts. General Electric Co., Schenectady, N. Y.

Air-Conditioning System Regulation.—Bulletin 4001, 24 pp. Describes and illustrates the application of electrical thermometers in and the efficient regulation of air-conditioning systems. Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia.

Potentiometers.—Bulletin 270, 8 pp. Describes potentiometers for laboratory and industrial use, including slide wire, simplified laboratory, precision laboratory, portable precision and high precision instruments. Rubicon Co., 29 No. Sixth St., Philadelphia.

Mercury Arc Power Rectifiers.—Bulletin 1169, 12 pp. Describes mercury arc power rectifiers (Brown Boveri design) for converting alternating to direct current. Installations are pictured. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Portable Electric Tools.—Silver Anniversary Catalog, 50 pp. Includes a comprehensive description, with prices, of a wide variety of portable tools, including drills, saws, hammers, grinders, sanders and polishers, bench grinders, valve refacers, etc. Black & Decker Mfg. Co., Towson, Md.

Polyphase Motors.—Bulletin, 8 pp. Describes Century squirrel-cage, induction polyphase motors, $^1/_6$ to 600 hp; open, enclosed, explosion proof, totally-enclosed fan-cooled, gear splash-proof, multispeed, general purpose and special characteristics. Century Electric Co., 1806 Pine St., St. Louis, Mo.

Electric Heating Systems.—Bulletin, 12 pp. Describes the Hynes electric heating systems, with automatic control, for rooms, buildings, power plants, hydro stations, substations, dam gates, water tanks, etc. Typical installations together with names of many industrial and public utility users are included. Hynes Electric Heating Co., 240 Cherry St., Philadelphia.

Instruments.—Catalog 48. Describes a-c and d-c, panel and switchboard type, $3^1/_2$, $4^1/_2$ and 9 inch round pattern and rectangular, horizontal edgewise and illuminated dial ammeters, milliammeters, voltmeters, milli-voltmeters, pyrometers, single and polyphase wattmeters, frequency and power factor meters and accessories. Roller-Smith Co., 233 Broadway, New York.

Welding Electrodes.—Bulletin 2, 16 pp. Describes Murex all-mineral coated welding electrodes. Considerable technical data, covering principles of design and operation, as well as physical properties and chemical analysis of deposited metals, are included. Illustrated, showing applications of various types of electrodes. Metal & Thermit Corp., 120 Broadway, New York.

Electrical Application of Plastics.—Bulletin 4 pp. Discusses insulation characteristics and describes a service to electrical manufacturers for the selection and proper design of insulating materials for use in electrical apparatus. This company assists in the design of apparatus and devices for any operating potential up to 220,000 volts and test potentials of 2 million volts. Examples of work accomplished are illustrated. Another bulletin on moisture proofing, from an insulating standpoint, is also available. Joseph C. Rah & Co., 5745 West Ohio St., Chicago.

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This Month—

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The turbine-electric liner "Normandie" at night after it docked in New York harbor at the completion of its record-breaking maiden trip from France on June 3. Its own lights were augmented by a half dozen 1,000 watt floodlights installed along the pier. The 4 40,000 horsepower propelling motors are reported to be the largest motors ever built for any purpose.

Photo courtesy General Electric Company

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INCREASING application of the synchronous machine necessitates a critical investigation of the principles underlying its operation. The increasing importance of exact knowledge of machine performance when saturated requires that the designer be able to calculate accurately the leakage reactances of the machine. In one paper in this issue a method is proposed that makes possible a direct determination of the leakage reactance drop (*pages 700–05*). In many analyses of machine performance it is important also to take armature resistance into consideration. In a companion paper to the foregoing, the results of a series of tests of armature resistance under various conditions of operation are reported (*pages 705–09*).

GREATER dissemination to engineers of information regarding their professional societies and the joint organizations which carry on different phases of the work, was the purpose of a meeting of the officers and directors of these bodies held in New York, N. Y., May 20, 1935. At this meeting, each of the 8 functional organizations sponsored jointly by the 4 national engineering societies was made the subject of an address. Believing that all engineers are interested in the purposes and activities of their engineering societies, these addresses are published essentially in full text in this issue (*pages 788–94*).

DEFINITE plans whereby the engineering profession may obtain more adequate recognition as a profession have been announced by the Engineers' Council for Professional Development, joint organization of 7 national engineering societies. The E.C.P.D. has undertaken to define minimum qualification of education and experience, the fulfillment of which will enable an engineer to be "certified into the profession." The certification program developed is now under consideration before the governing boards of the societies sponsoring the E.C.P.D. (*pages 786–7*).

VACATION plans of many members will include attendance at the Institute's 1935 Pacific Coast Convention, to be held at Seattle, Wash., August 27–30. The country surrounding Seattle is well known for its scenery, including mountain ranges and national parks. The technical program, entertainment features, and inspection trips have been arranged. Two Student sessions have been scheduled and the titles of the Student papers are given in the "tentative technical program" (*pages 783–4*).

PRODUCTION of steam from electric energy has proved to be a highly satisfactory method of utilizing surplus and off-peak power where hydroelectric power is abundant. Large electric steam generators use the water itself as the resistance element. Equipment of this type now installed totals more than 1,500,000 kw in Canada and about 200,000 kw in the United States; the individual units range in size up to 42,000 kw (*pages 712–19*).

PRESIDENT J. Allen Johnson's opening address at the Institute's summer convention being held on the campus of Cornell University, Ithaca, N. Y., just as this issue goes to press, is published in the "news" section of this issue (*page 785*). A complete report of the 1935 summer convention activities is scheduled for inclusion in the August issue.

SEVERAL steep transmission line spans were found to be necessary to transmit power from the Boulder Dam plant to the switching station on the rim of the canyon above the plant. A simple and accurate method of compiling stringing charts was developed for these spans; it is applicable also to spans of any degree of inclination (*pages 719–28*).

IN AN EFFORT to classify the various species of the genus Electrical Engineer, a prominent engineering educator has made an analysis of the membership of the A.I.E.E. On the basis of his findings he makes several recommendations for improving the nomenclature of electrical engineers (*pages 695–9*).

THE Institute's board of directors presents in this issue its annual report to the membership for the year ending April 30, 1935. The report contains the usual financial statements and a brief review of the principal activities of the Institute for the year (*pages 735–47*).

TWO methods of obtaining steady state solutions for circuits containing magnetically saturated synchronous machines are given in this issue: One involves the use of equivalent reactances or impedances; the other, the superposition of current diagrams (*pages 728–34*).

AMERICAN Engineering Council, the "Washington Embassy" of engineers, continues to supply news of affairs in Washington, prepared from the engineer's point of view. Increased participation in national affairs is urged upon engineers (*pages 795–6*).

PRIZES presented by the Institute and several of its Districts for papers presented during 1934 were announced in ELECTRICAL ENGINEERING for June 1935, page 677. Awards made by 2 additional Districts have recently been announced (*pages 785*).

ADDITIONAL plans for the A.I.E.E. Great Lakes District meeting, which will be held at Purdue University, West Lafayette, Ind., October 24–25, 1935, have been made, and the subjects of several of the technical papers announced (*page 785*).

ELLIPTIC integrals often are used in calculating mutual and self-inductances of cylindrical coils. Tables of complete integrals of the first kind for large moduli are published in this issue (*pages 709–11*).

Structure of the Electrical Engineering Profession

By THEODORE J. HOOVER
Stanford University, Calif.

What is the structure of the electrical engineering profession? What are the chief branches of the profession recognized today, and relatively how many engineers are engaged primarily in each branch? What are the relationships of each branch to the other special branches? In an effort to clarify these questions, a quantitative study has been made of the membership of the A.I.E.E. and is reported herewith. On the basis of his findings, Dean Hoover makes several recommendations for improving the nomenclature of electrical engineers. Discussion is invited.

DEVELOPMENT of many new fields of engineering in recent years and the rapid growth of the tendency for engineers to specialize in certain fields have made acute the necessity for attempting to classify, for practical purposes, the main branches of the various traditional fields of engineering—civil, mechanical, electrical, mining, and chemical. This is not a matter of mere academic interest, but is of high practical concern to engineering educators, to officers of national societies whose memberships have widely varying professional fields of practice, to those dealing with state licensing and registration of engineers, and to every active engineer who desires to understand the place he occupies among the members of his profession and to define his relationships to other parts of our complicated social structure.

What are the main branches of electrical engineering? At first thought, it would seem to be an easy task to name those branches in which large numbers of electrical engineers are engaged. Anyone who has attempted to make such a list, however, soon is brought to a standstill because of the lack of any uniform nomenclature or reliable statistics on this point.

Although electrical engineering is comparatively a latecomer among the major fields, it has by far the greatest profusion of titles. No less than 3,753 different titles were discovered among those given in the 1931 Year Book of the A.I.E.E. More than 500 different kinds of engineers were found, ranging from "accounting engineer" and "acting engineer" to "X-ray engineer" and "yard engineer." Moreover, at least 8 different types of professional titles were distinguished. Of these types, the more important are those designating *general field* (electrical, civil, mechanical, mining, and chemical), *rank* (assistant, chief, etc.), *zone of interest* (acoustical, automotive, battery, etc.), and *engineering function* (design, production, research, sales, valuation, etc.). Of all the various titles found, only a few designated general field; only 9 per cent of the group described themselves merely as "electrical engineer," and it would seem that this historical scheme of classification has been broken down considerably into its elements. Although some titles given were descriptive of the special zone of interest and function of the engineer, the largest group of titles was that designating rank.

An attempt to present a cross section of the electrical engineering field at the present time through a study of professional titles is admittedly difficult. Yet, since it seems that neither census records nor the divisions and technical committees of the national society give a complete picture, anyone wishing to make a quantitative fact-analysis of these special branches can approach the question only by using as his data the titles by which the engineers themselves designate their specialties. Such a preliminary analysis is reported in this article, in the belief that it will be of no little interest to all men in the electrical engineering group.

A Study of Engineering Titles

The Year Book of the A.I.E.E. for 1931 was chosen as most representative of recent years for this particular purpose. An alphabetical frequency list of every variation of title given after the names of all the members in that year was prepared and was classified in several different ways in an effort to reveal the true structure of the electrical engineering field.

In making these classifications, it became clear that the effort to obtain an unclouded picture of the electrical engineering field was complicated by several kinds of misleading usages in title nomenclature. The most confusion was created by the fact that many of the words used have no well defined and widely accepted meanings. How should all these various labels be interpreted? Many anomalous titles would disappear at once if definitions were drawn properly and consulted at the time an engineer chooses the professional title he wishes to use in all his relations. The need for definitions is especially apparent in the use of words describing the proper functions of engineering; such words as "research," "development," "organization," "valuation," "distribution," and "management," although frequently used, seldom mean quite the same things to different persons.

Further difficulty is caused when titles are chosen that are not primarily *descriptive*. What is the value of a professional title that does not inform others of the functions the engineer performs and the place he occupies in the vast domain of engineering activities?

Written especially for Electrical Engineering, this article is one of a series of similar studies on the structures of the main fields of engineering, others of which are being published elsewhere. Those interested in the general program of the studies, and the results of a study of the engineering profession as a whole, are referred to "The Structure of the Engineering Profession," by Theodore J. Hoover, *Journal of Engineering Education*, January 1935, pages 356–72. Manuscript submitted April 8, 1935; released for publication April 19, 1935.

The need for this criterion becomes at once apparent to anyone who has examined the exotic and chaotic collection of titles given by electrical engineers at the present time. Unless a title is informative to those who hear it, the engineer is open to suspicion that vanity or even less agreeable motives have impelled his selection.

Confusion also arises from the widespread lack of discrimination between a man's *professional title* and the designation of his current *position;* in the directory, these 2 are used indiscriminately. A man, for example, may have devoted his career to "illumination engineering," and for the purpose of this study the fact that he is at present "assistant superintendent, street lighting department" is of no great concern. A great many titles in the list evidently are titles of rank in a large corporation, which, although they might signify much to the corporation's executives, convey no meaning at all to the general public or even to other engineers. The designation of his rank and place in some organization is usually a transitory thing, and a matter over which the engineer has no control; but he certainly should take great care, when choosing his professional title, to select those words that most appropriately describe his special interest throughout a considerable period of practice.

Again, the unmodified term "engineer," frequently found, is exact if the possessor is competent to practice in almost any segment of the broad realm of engineering; but if the man's career has been associated closely with any special branch, it is more informative and more accurate to have him designate this special interest by calling himself an "electrical engineer," a "telephone engineer," an "acoustical engineer," a "research engineer," or the like. In contrast to giving the unmodified title is the practice of putting down a too-specialized title. More than 17 per cent of the members of the Institute bear titles unique to them alone among all the thousands of their fellows; and a division of engineering that has only one representative in the whole American group cannot be a very important subdivision of that field. These 2 extremes of nomenclature are seldom justifiable and have added to the difficulty of properly interpreting the frequency lists presented next.

The basic list of all variations in titles of the 17,327 A.I.E.E. members in 1931 revealed a total of 3,753 different titles (without any attempt at grouping and considering, for example, the title "electrical and mechanical engineer" to be distinct from "mechanical and electrical engineer"). Out of these 17,327 men, 1,212, or 7 per cent, gave no title. Of the remaining 16,115 who gave titles, 907, or 6 per cent, gave simply "engineer," and 1,414, or 9 per cent, gave simply "electrical engineer." The length of the titles given varied from 1 to 15 words. There were 2,794 *unique* titles in the group, or *74 per cent* of the various different titles found. This high degree of originality is cause for wonder concerning the motives for selecting and using engineering titles.

Some titles might be considered synonymous (*e. g.*, "teacher" and "instructor") or are found in slightly differing or inverted forms (*e. g.*, "consulting electrical engineer" and "electrical engineer, consulting engineer"); but any attempt to condense the list by arbitrarily throwing together even these fairly simple variations leads to impossible confusion.

Numerical Frequency List

A first attempt was made to reduce the list on the basis of numerical frequency. The 101 most frequent titles in the list, all of which appeared 20 times or more, are as follows:

electrical engineer	1414	industrial engineer	43
engineer	907	equipment engineer	43
sales engineer	415	partner	42
president	406	assistant manager	41
assistant engineer	392	commerical engineer	41
manager	312	district engineer	40
chief engineer	306	member of firm	39
consulting engineer	241	president and general manager	39
vice president	234	junior electrical engineer	38
professor	209	designer	37
telephone engineer	176	switchboard engineer	37
assistant electrical engineer	174	district sales manager	36
superintendent	170	testing engineer	36
research engineer	161	construction engineer	34
instructor	150	mechanical engineer	34
district manager	132	supervisor	34
assistant professor	129	operating engineer	33
draftsman	116	secretary	33
design engineer	113	assistant vice president	32
chief electrician	106	plant engineer	31
engineering assistant	104	inspector	30
general manager	95	patent attorney	30
electrician	93	secretary and treasurer	30
salesman	93	power engineer	28
member of technical staff	86	meter engineer	27
vice president and general manager	86	student engineer	27
chief electrical engineer	85	electrical foreman	26
engineering department	80	electrical inspector	25
electrical designer	76	electrical tester	25
junior engineer	75	retired	25
associate professor	74	superintendent of power	25
field engineer	71	works manager	25
radio engineer	71	service engineer	24
electrical draftsman	69	substation operator	24
development engineer	62	treasurer	24
distribution engineer	61	electrical engineering department	23
electrical superintendent	61	local manager	23
proprietor	60	superintendent of distribution	23
general engineer	59	technical assistant	23
general superintendent	59	test engineer	23
transmission engineer	58	assistant to president	22
managing director	55	general foreman	22
designing engineer	53	laboratory assistant	22
director	53	special representative	22
sales manager	52	supervising engineer	22
assistant superintendent	50	tester	22
consulting electrical engineer	49	transformer engineer	22
foreman	46	technical employee	21
assistant chief engineer	44	chief draftsman	20
division engineer	43	president and treasurer	20
		vice president and chief engineer	20

Although this list, based upon a count of the commonest titles used by the men in the group, takes care of 9,773 names, or 61 per cent of all who gave titles, it is still far from revealing very much in regard to many of the important branches of electrical engineering. By far the greater number of titles listed indicate *rank*, such as "president," "chief engineer," and "superintendent," rather than special technical interest. Moreover, even if only those who specifically designate themselves as engineers are considered, they may classify themselves from several different points of view. For example, it is clear that modifying words like "sales" and "research" are of a sort different from words like "telephone" and "radio," and that words like "chief" or "consulting" are of sorts different from any others.

Adjectives Modifying "Engineer"

A second attempt was made to achieve some sort of order by selecting from the alphabetical list all

adjectival terms anywhere to be found modifying the word "engineer," thus boldly ruling out all who did not classify themselves primarily as engineers. These modifying adjectives, which indicated a total of 520 branches of engineering represented by A.I.E.E. members, then were sorted into 9 groups of different categories as follows:

1. Words *"engineer"* or *"general engineer."*
2. Words designating *general field*. These comprise the major traditional engineering fields, as follows:

chemical (engineer)
civil
electric
electrical
mechanical
mining

3. Words designating *zone of interest*. Such words indicate the specific structures, materials, or products to which the specialist devotes himself, or the special technology he uses in his particular work. The list as a whole furnishes a good general description of the varied kinds of problems that may be encountered in the domain of electrical engineering:

accountant
accounting (engineer)
acoustical
acoustics
aeronautic-radio
alternating-current
apparatus
appliance
automatic substation
automatics
automotive
battery
bearings
brush
building
buildings
cable
capacitor
car-equipment
catenary
central-station
charge
circuit
circuit-breaker
circuit-breaker insulation
city
coil
combustion
commercial
commercial cable
commercial power
commercial survey
communication
communications
compass
condenser
conduit
cost
cost control
data
dial
dial equipment
direct-current
distribution-station
drafting
draftsman
electric-railway
electrical drafting
electrical hammer
electrical heating
electrical instrument
electrical railway
electrical recording
electrochemical
electrolysis
electromechanical
electron-tube
electrostatic condenser
elevator
elevator-control
equipment
exchange
exchange fundamental plan
exchange plant
exchange rate
exchange transmission
facilities
facility
factory
fire-alarm
fire control
fire prevention
fire protection
fixed-capital
foreign wire relations
fundamental plan
gas
gas-works
gear
gem
generating
gyro-compass
high-frequency
high-tension
high-tension switchgear
high-voltage
hydraulic
hydroelectric
illuminating
illumination
induction co-ordination
induction motor
inductive co-ordination
inductive heating
inductive relations
industrial
industrial control
industrial gas
industrial heating
industrial power
inside plant
inspection methods
installation
installing
instrument transformer
insulating
insulator
insurance
interconnection
interference
inventory
laboratory
lamp
liaison
lighting
lightning-arrester
line
line-extension
load
long-lines
mains
manual equipment
manual switchboard
manual system equipment
marine
material
materials
mercury-arc rectifier
meter
methods
municipal
network
noise prevention
ocean cable equipment
office layout
oil circuit-breaker
outside plant
outside plant telephone
overhead
overhead system
paper mill
patent
photometric measurement
photophone
plant
plant equipment
plant extension
plant inventory
police signal
power
power apparatus
power cable
power plant
power station
power supply
power transformer
preliminary plans
process
product
projector
propeller
property
proposal
protection
protective gear
public utilities
public service
pyrometer
radio
radio interference
radio protection
radio transmitter
radio tube
railway
railway control
railway equipment
railway motor
rate
receiving
record
recording
rectifier
refrigerating
regulation
relay
relay protection
results
road
rubber mill
rural electrification
shop
signal
signal control
small motor
sound
sound projection
sound transmission
starting
station
stationary
statistical
steam
steam plant
steel mill
street
street lighting
structural
studio
substation
subway
super-tension cable
supply
survey
switchboard
switchgear
switching
switching-equipment
synchronous
system
system relay
systems studies
telegraph
telegraph equipment
telephone
telephone apparatus
telephone equipment
telephone plant
telephone practice
test methods
test plant
textile
timber products
toll
toll cable
toll equipment
toll facilities
toll fundamental plan
toll lines
toll plant
toll plant extension
toll system
toll transmission
town
traction
traffic
traffic results
traffic routing
traffic signal
traffic toll line
tramway
transformer
transformer accessories
transmission
transmission instruments
transmission line
transmission system
transportation
trunk
trunk traffic
turbine
underground
underground cable
underground system
utility
vacuum tube
voltage regulation
welding
winding
wire
wiring
works
X-ray
yard

4. Words designating *engineering functions*. The word "function" is used herein in its common meaning as "any special kind of action, activity, office, or service properly belonging to a person or thing." The engineering process, carried on from the time a particular human need is recognized until the time when that need is satisfied through organized engineering effort, may be divided into several steps, each one of which calls for the exercise of a certain function. The functional adjectives used to modify "engineer" are much fewer than those describing zones of interest, but are used in the titles of a great many more men. Since functional words are not so self-explanatory as those describing zones of interest, they should be used only when their meanings are defined clearly. The adjectives which seem to the writer to be clearly functional are as follows:

application (engineer)
appraisal
constructing
construction
contract
contracting
design
designing
development
developmental
distribution
efficiency
erecting
erection
estimate
estimating
examining
executive
experimental
inspecting
inspection
inspector
investigating
investigation
investigations
investment
maintenance
managing
manufacturing
operating
operation
plan
planning
production
purchasing
quality
research
safety
sales
service
specification
standardization
standards
superintending
supervising
supervisory
test
testing
valuation

5. Words in combinations designating (a) *field and function* or (b) *zone of interest and function*. From the point of view of descriptiveness, these combinations are excellent. They give a clear picture not only of the field or zone of interest of the specialist, but also of the particular function he performs. It should be pointed out that, in addition to those found and listed here, a great many other appropriate titles like these may be made easily by combining almost any adjective under list 2 or list 3 with almost any adjective under list 4.

alternating-current design (engineer)
apparatus development
battery service
bridge designing
broadcast receiver development
brush sales
cable development
circuit design
circuit standardization
cost control
direct-current motor design
electrical conductor sales
electrical construction
electrical design
electrical designing
electrical development
electrical distribution
electrical erecting
electrical estimating
electrical operating
electrical planning
electrical research
electrical sales
electrical service
electrical testing
electrical valuation
electrochemical research
electron-tube application
equipment development
equipment maintenance
equipment sales
exchange sales
factory planning
industrial sales
industrial service
installation service
installation supervising
lighting sales
load supervising
load supervision
motor design
outside plant development
outside plant distribution
overhead distribution
plant design
power-apparatus development
power-cable testing
power development
power sales
power station design
protection development
public utility investment
radio design
radio development
radio installation
radio research
railway sales
refinery construction
relay maintenance
service sales
station design
station equipment development
structural design
substation design

substation maintenance
switchboard specification
system control
sytem planning
system test
telephone-circuit design
telephone-circuit development
telephone design
telephone installation
telephone systems design
telephone systems development
tramway distribution
transformer design
transformer designing
transformer sales
transmission construction
transmission design
transmission development
transmission instruments development
transmission system research
transmitter development
turbine test
underground distribution
vacuum tube development

6. Words denoting *capacity* in which the engineer utilizes his knowledge and skill:

advisory (engineer)
consulting
staff

7. Words denoting *rank*. These words indicate present position held by the engineer, but are of little value in classifying the branches of electrical engineering:

acting (engineer)
assistant
auxiliary
chief
deputy
director
first
principal
second

8. Words describing *geographical location* of the engineer. These also are of little value for classification purposes. It is likely that in reality most of them are indications of position held by the engineer rather than his special professional field:

borough (engineer)
branch
county district
district
division
eastern
European
foreign
local
northwestern
Pacific coast
resident
state
traveling

9. Words describing *professional status*. Such words are least useful of any for the purpose in view:

cadet (engineer)
chartered
junior
professional
senior
student

A few titles were found that did not fit clearly into any one of the 9 foregoing categories. Several of these, most of which appear only once in the list, impress one as being merely weird inventions which are meaningless and unnecessary.

Significant Words in Engineering Titles

For many reasons, the foregoing study of adjectives used to modify "engineer" could not yield to numerical treatment. A plan was devised which, it was hoped, would combine a numerical frequency listing with a word study such as that just described. Accordingly, the laborious task was performed of making an alphabetical frequency list of all significant words (omitting "and," "of," "in," etc.) found in the titles given. Certain variant words from a single root were listed together, *e. g.*, "generat(ing)(ion)(or)," or "manag(er)(ement)(ing)," since all these variants were taken to represent virtually the same idea.

A total vocabulary of 718 significant words (plus their variants) was found in the titles given. These words appeared 34,256 times, making 2 significant words the average number for each title. These significant words then were classified according to groups of categories similar to those used in the study of adjectives modifying "engineer," as already defined, and a frequency count was made of the total times each was used in the titles. Only a summary of this revealing word list can be given here (table I).

This summary seems to show that words indicating general field (2), zone of interest (3), engineering functions (4), and rank (6) are preponderant among all the types used in the engineering titles found. The fairly low frequency of words designating general field (chemical, civil, electrical, mechanical, and mining) reveals that the traditional classification has been broken down largely among electrical engineers; this is further evidenced by the fact that of all those giving titles, only 9 per cent gave simply "electrical engineer."

Table I—Summary of Results of Numerical Frequency Study of Significant Words in Engineering Titles

	Category	Number of Significant Words + Variants	Number of Times Such Words Appeared	Per Cent of Total Times
1	Words "*engineer*" or "*engineering*"	2	3,751	26
2	Words designating *general field* (chemical, civil, electrical, mechanical, mining)	5	3,023	9
3	Words designating *zone of interest* (acoustical, battery, cable, etc.)	322	5,162	15
4	Words designating *engineering functions* (appraisal, construction, design, etc.)	52	6,590	19
5	Words designating *capacity* (advisory, consulting, expert, etc.)	29	1,603	5
6	Words designating *rank* (acting, assistant, chief, etc.)	50	5,235	15
7	Words designating *geographical location* (American, borough, branch, etc.)	70	1,124	3
8	Words designating *professional status* (apprentice, cadet, junior, professional, etc.)	25	370	1
9	Words designating occupations *not primarily engineering* (accountant, attorney, banker, etc.)	50	419	1
10	*Miscellaneous* words (mainly auxiliary, or not clearly belonging to a previous group)	113	1,889	6
	Totals	718	34,256	100

Rank is independent of function or zone of interest; it is something that comes by promotion whereas function or zone represents the man's particular type of education and his chosen sphere of activity. The high frequency of use of words designating rank would support the belief that this type of title should be given separately from professional title. If this be done, it then appears that 3 types of descriptive words—those here termed as designating *general field*, *zone of interest*, and *function*—are used predominatly, and it seems clear that all these types should be included in any scheme proposed for classification of engineers. The remaining types of words—those here termed as designating *capacity*, *geographical location*, *professional status*, and *not primarily engineering*—are not used greatly at present, although they may be needed, in combination with titles of rank, to indicate a man's present position in an organization; such words might well be left out of consideration in planning a standard system of classification of engineers by professional title.

Recommendations

Rapid increase in specialization among electrical engineers has brought with it an urgent necessity to attempt to establish some standard scheme by which

the recognized branches of the profession and the titles of engineers devoting themselves to special branches might be designated. The adoption of a good standard scheme would be of great practical value to engineering educators, to officers of national engineering societies, to those concerned with the licensing of engineers, and to all active engineers who themselves desire to understand the place they occupy in the structure of their profession and to inform the general public of their position in modern industry.

For this reason, the following proposals are offered for discussion as possible steps toward the establishment of an improved nomenclature for electrical engineers:

1. That all men primarily engaged in work of an engineering nature—applied scientists as distinguished from pure scientists on the one hand and from nonprofessional technicians on the other—use the word "engineer" as a part of their professional titles. Titles such as "draftsman," "mechanic," "electrician," "machinist," and "designer" should be reserved for the nonprofessional artisan. If the man is actually an engineer, it seems clear that he should use that word in his title.

2. That all engineers be asked to make a distinction between *professional title* (indicating the branch of engineering to which their careers have been devoted) and *present position* (indicating the place and rank they occupy in an organization). At present these 2 kinds of titles are used indiscriminately.

3. That all professional titles be composed of 2 types of adjectives: first, adjectives indicating special *field* or *zone of interest*, and second, adjectives indicating special *function* performed. These combination titles would be of such a sort as "electrical research engineer" or "transformer sales engineer." In certain instances, words indicating special *capacity* might need to be prefixed (*e. g.*, "consulting electrical research engineer").

4. That in choosing an appropriate professional title, the engineer might best describe his activities by using one of the 4 following combinations:

(*a*) If the engineer is competent to practice in all branches of engineering, he should designate himself as "general engineer."

(*b*) If the engineer considers himself to be a specialist in all functions in a particular *field* or *zone of interest*, he should designate himself as "general electrical engineer," etc., or as "general telephone engineer," "general power engineer," etc.

(*c*) If the engineer considers himself to be a specialist in all fields or zones of interest in a particular *function*, he should designate himself as "general research engineer," "general design engineer," "general sales engineer," etc.

(*d*) If the engineer considers himself to be a specialist in a certain *field* or *zone of interest*, and likewise in a certain *function* in that field, he should designate himself by a combination of these 3 types of titles, such as "electrical research engineer," "telephone design engineer," "power sales engineer," etc.

Using only the words to be found in the lists of adjectives previously given, each of which may be defined rigidly in small space, it is possible according to this recommended scheme to make up several thousand different combination titles of this sort that are highly descriptive and the meanings of which may be at once clear. This plan of building titles from interchangeable words would be flexible enough, it is believed, to permit a good classification of engineers indefinitely, since new words may be admitted to the lists when demanded to describe new functions and new zones of interest taken over by the profession. The practical working of the foregoing proposals is exemplified in a classification form here suggested for consideration as part of the blank sent to A.I.E.E. members to obtain directory information (see figure 1).

5. That, since most of the words descriptive of electrical engineering functions are not self-explanatory, a list of definitions be composed and agreed upon to delimit the indiscriminate use of these terms.

It is considered important for scientists and engineers to classify with great care the natural objects, products, and materials they study and handle. How much more important, then, should it be to give attention to the classification of the various species of the genus Electrical Engineer, the members of which have had such a hand in the making of the modern world! The writer feels strongly that any attempts at this time to promote among the engineering fraternity a more logical scheme of classification of the branches of engineering cannot but lead to valuable results in greater understanding of the logical divisions of the profession, to clarification of the differences that distinguish one branch from another, and to better comprehension of the qualities requisite for success in each branch.

1. **Profession or occupation:** _____

NOTE: If you are an *engineer*, please give above your professional title, by prefixing to the word "engineer" one of the adjectives in either list *A* or list *B* below, or a combination of an adjective in list *A* and one in list *B*. For example:

Electrical engineer (from list *A*)
Acoustical engineer (from list *A*)
Research engineer (from list *B*)
Acoustical research engineer (combined from list *A* and list *B*)

The word "consulting" may be added before any title if required. A double title may be given (*e. g.*, "electrical and mechanical engineer," "design and construction engineer," "professor and electrical engineer"). Adjectives in titles need not be restricted to those in the lists below

List A (Fields and Zones of Interest)		List B (Engineering Functions)	
Acoustical	Power	Application	Managing
Apparatus	Power-plant	Appraisal	Manufacturing
Cable	Protection	Construction	Operating
Central-station	Public-utility	Contracting	Planning
Chemical	Radio	Design	Production
Circuit	Railway	Development	Research
Circuit-breaker	Railway-equipment	Distribution	Safety
Civil	Rate	Efficiency	Sales
Combustion	Recording	Erection	Service
Commercial	Relay	Estimating	Standardization
Communications	Signal	Executive	Supervising
Condenser	Sound	Experimental	Test
Control	Specifications	Inspection	Valuation
Cost	Station	Investigation	Other function:
Electrical	Steel-mill	Maintenance	
Electrical heating	Street-lighting		
Electrochemical	Structural		
Electrolysis	Substation		
Equipment	Switchboard		
Exchange	Switchgear		
Hydraulic	Telegraph		
Hydroelectric	Telephone		
Illuminating	Telephone-equipment		
Industrial	Traffic		
Installation	Transformer		
Laboratory	Transmission		
Mechanical	Underground		
Meter	Vacuum-tube		
Patent	Works		
Plant	Other zone of interest:		

2. **Present position and rank** (*e. g.*, "superintendent, power division, _____ Electric Company," "assistant professor of radio engineering, _____ University"):

_____

Fig. 1. Model form for classifying electrical engineers suggested by author as part of a blank to be submitted to A.I.E.E. members when soliciting information for A.I.E.E. Year Book

Test Values of Armature Leakage Reactance

Armature leakage reactance of synchronous machines has recently received considerable attention because of the important part which it plays in the accurate calculation of the performance of the saturated machine. (See, for example, reference 15 at end of this paper.) Test methods for determining the proper values of armature leakage reactance, and the results of these tests, are presented in this paper and should be of interest as an indication of the reliability of the formulas for the unsaturated value of this reactance and also as an indication of the variations in the reactance due to machine saturation. This paper is a companion paper to "Tests on Armature Resistance of Synchronous Machines" appearing on pages 705–9 of this issue.

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THE ever increasing application of the synchronous machine, and its growing importance in the problem of power system stability, have quite recently necessitated a more critical investigation into the physical principles underlying the machine operation. Rapid advances made in the last 8 years have subjected to review the implications of the 2-reaction theory, and have brought forward many additional problems, one of these being the performance of the machine under conditions of saturation.

The increasing importance of exact knowledge on machine performance under conditions of saturation requires that the designer be able to calculate accurately the leakage reactances of the machine so that values of excitation may be determined for the various important load conditions. Present methods of calculation take saturation into account somewhat empirically, giving results sufficiently close for many problems. However, in other cases the results are not satisfactory, and greater accuracy is desired. It is, therefore, important that the physical concepts of armature leakage reactance and its relation to machine performance be critically reviewed and design formulas be compared with test data.

A paper recommended for publication by the A.I.E.E. committee on electrical machinery, and scheduled for discussion at the A.I.E.E. Pacific Coast convention, Seattle, Wash., August 27–30, 1935. Manuscript submitted May 6, 1935; released for publication May 27, 1935.

Developments of Concepts and Methods of Calculation

Calculations on leakage reactance were unorganized until C. A. Adams[1] correlated in one paper the ideas of previous authors and redeveloped the expressions in a more logical manner. Adams' work was confined entirely to the induction motor, stress being placed on its design and operating characteristics. Practically no work was done in the synchronous machine until Fechheimer[2] investigated the relationship of leakage reactance upon motor starting characteristics. His was the first extensive study of this quantity and its effect upon the characteristics of the synchronous machine and it led to a better understanding of the phenomena taking place within the motor.

The term transient reactance was introduced by Durgin and Whitehead[3] in the same year as Fechheimer's study, 1912, to explain the action of the armature current under short circuit. This reactance included the effect of both field leakage and armature leakage fluxes. A further and more complete study was made by Doherty and Shirley[4] in 1918 on the armature leakage reactance and its bearing upon the subject of alternator short circuits. The paper by Doherty and Shirley was the first attempt to develop a single expression that could be used in the calculation of armature leakage reactance for all lines of synchronous machines.

Little more was done on the development of theoretical expressions for leakage reactance until the entire theory of synchronous machine operation was reviewed to consider the variation of armature reaction with pole position. The papers by Doherty and Nickle[5] have thrown an entirely new light upon the subject of synchronous machine operation, and, as a consequence, the ideas underlying the definitions of armature leakage reactance had to be modified in correspondence with the new theories. The task of developing new expressions for this reactance, in conformance with the newer concepts, was accomplished by Alger[6] in 1928. The derivation of Alger's expressions is based upon a better physical knowledge of the factors involved and upon a more rigorous mathematical treatment than that of any previous writer. The more recent study by Kilgore[7] presents the subject from a somewhat different viewpoint, in that flux plotting methods are employed to determine expressions for several of the reactance components. Numerical calculations for a given machine indicate that there is little difference in the results obtained by the methods of either Alger or Kilgore.

The concept of what is meant by armature leakage reactance has not changed too greatly from the first ideas on it until the present definitions. It is interesting to note that the expression for slot leakage flux used in the present day calculations is not much different from that developed by Dick[8] and Fischer-Hinner[9] in 1898 for the d-c machine. The

1. For all numbered references see list at end of paper.

expressions for the end connection, zig-zag, tooth-tip, and belt leakage fluxes have varied greatly, and until the work of Alger and Kilgore little correlation of ideas existed. In view of the recent development of the 2-reaction theory of synchronous machines, there arose the necessity of redefining certain components of the armature leakage reactance so as to maintain conformance with the general theories. These later definitions will be adhered to throughout this discussion.

Definition of Armature Leakage Reactance

In the very early studies on synchronous machines, there was only one reactance, armature leakage reactance, this value being used to determine the inherent regulation of a loaded alternator. Later it was found necessary to combine with this term a second quantity which included the effects of armature reaction, the sum of these 2 effects to be called synchronous reactance. However, just where the exact line of demarcation between armature reaction flux and armature leakage flux can be drawn never has been answered fully. Armature reaction flux can be thought to exist only under conditions of no saturation.

Initially, it was considered that armature reaction was merely equivalent to the action of a coil moving along the armature surface, combining vectorially its ampere-turns with those of the main field winding. Because armature reaction exists only at the armature surface, hence not having quite the same effect as though due to the field winding, and because the principle component of magnetomotive force which is stationary with respect to the poles is sinusoidally distributed, the original concept of armature reaction has been modified slightly. Armature reaction, therefore, is understood to refer to the fundamental or stationary component of armature magnetomotive force. There has been the question, however, whether it should include the synchronous magnetomotive force in the end windings or should relate only to the stacked length of the armature.

Theoretically, it seems desirable to treat armature reaction as due to the fundamental components of magnetomotive force in both the end windings and the stacking length. For practical computations however, it appears better to limit the term only to the magnetomotive force in the stacked length of the machine. In normal salient pole machines, the errors introduced by this manner of definition are negligible. From this viewpoint, armature leakage reactance is an arbitrary component of the synchronous reactance and is due to the difference between the space fundamental of flux in the air gap and the flux produced by the armature current acting alone for the case of no field magnetomotive force.

Doherty and Nickle[8] define armature leakage reactance as the difference between the total synchronous reactance and the reactance of armature reaction. Specifically, they state: "The voltages induced by the space fundamental magnetomotive forces existing within the limits of the armature core are taken as the reactance voltages of armature reaction, and the voltages produced by space harmonic magnetomotive forces within these boundaries are classed as leakage reactance voltages, ordinarily referred to as due to tooth-tip and belt leakage. . . . . In addition, there are also leakage reactance voltages due to slot and end turn fluxes which are independent of rotor position."

Application of Armature Leakage Reactance

Consideration of armature leakage reactance as above defined leads to a greater practical application in synchronous machine studies. The total armature leakage reactance, while purely fictitious with no existence as a separate quantity, is open to practical application in the design of machines, being one of the components determining the air gap voltage. Recent studies on the saturated machine[10] employ both the effective armature resistance and the armature leakage reactance in calculating the air gap voltage under load in order to determine the actual flux existing within the machine and the additional field ampere turns necessary to overcome the saturation in the iron paths.

Within the last 2 years, the development of circuit breakers and relay circuits has brought the transient stability limit of the transmission system closer and closer to the steady-state stability limit. It became necessary therefore, to calculate as accurately as possible both stability limits to insure continuous operation where firm power has been guaranteed. To this end, the theory of synchronous machines has been reviewed to include the effects of saturation upon the operating characteristics of the machine in connection with the entire system, and, as a consequence, armature leakage reactance must be known definitely.

The more exact theory suggested by Crary, March, and Shildneck,[10] on the influence of saturation in machines, is based upon a knowledge of the air gap flux and the air gap voltage generated by this flux, as this is a measure of the saturation. It was the aim of that paper to develop a series of expressions that could be used in representing the actual saturated machine by an equivalent unsaturated machine having similar angle, excitation, and stability characteristics to those which the actual machine would have under the assumed conditions. From these expressions the synchronizing power could be predicted with much greater accuracy than that obtained from the unsaturated theory.

In the discussion of Crary, March, and Shildneck, the assumption is made that the leakage reactance

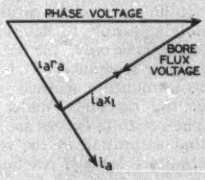

Fig. 1. Vector diagram for the air-core test

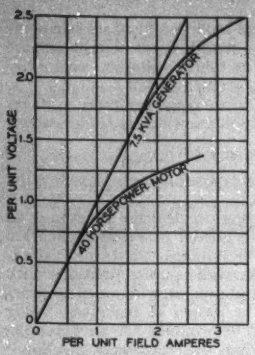

Fig. 2. Comparative saturation curves of the 2 machines

Rated values taken as unity

does not vary from the calculated unsaturated value when the machine is operating well up on the saturation curve. Under these conditions the stator teeth and the stator iron may be highly saturated and hence reduce the leakage flux per ampere for the slot, tooth-tip, and belt components. The calculated value of air gap voltage, obtained from the terminal voltage, resistance drop, and the calculated value of armature leakage reactance drop, will be higher than the actual value existing within the machine for the over-excited condition of operation. As a consequence, the additional field ampere turns or the equivalent values of the synchronous reactances determined from this air gap voltage will give, when used in the performance calculations, results which indicate that the machine may have greater stability than it actually has. The stability limit calculated for the machine in this manner may be too high, and would lead to optimistic conditions of system operation.

Because of the complications introduced by the non-linearity of the saturation curve, it is difficult if not impossible to determine, from theoretical considerations only, the saturated values of armature leakage reactance. It is the purpose of this paper to introduce a method of testing for the variation of the reactance under conditions of saturation. The resulting curves are an indication of the extent that saturation in the stator iron affects the total armature leakage reactance.

Experimental Methods

Many methods have been suggested for testing either an induction motor or a synchronous machine for armature leakage reactance. Few of these have been consistent with the definitions existent at the time, and only one corresponds to the present definitions. Rushmore[11] suggested, in 1904, that the leakage reactance of an alternator could be measured easily if the rotor of the machine could be removed and the terminal quantities used. This procedure is not exact, for the reactance thus determined includes not only the armature leakage reactance but the reactance of armature reaction produced by the magnetic flux in the air core of the machine. The air core flux, although it is much smaller than that existing when the rotor is in place, may not be neglected, because it may generate a reactive voltage equal to or greater than that produced by the leakage flux.

Modifications of Rushmore's method, suggested by Schenkel,[12] 1910, and by Roth,[13] 1925, have led to a procedure that is in agreement with the present definition. Briefly, the modifications consist of placing a rectangular test coil in the machine bore, one side equal to the stacking length and the other side equal to the machine diameter less the 2 air gaps. A 3-phase voltage, of sufficient magnitude to cause rated current to flow in the windings, is applied to the armature. The current, voltage, and power input to the armature are measured, as well as the voltage generated in the test coil. From these data the effective resistance drop and the voltage due to the bore flux are calculated and subtracted vectorially (figure 1) from the terminal voltage, leaving the armature leakage reactance drop. This method subtracts from the total reactive voltage only that due to the space fundamental component of flux crossing the air gap, and the results, therefore, correspond to the definition above.

If instead of measuring or calculating the armature reaction flux in the bore of the machine, a thick copper cylinder equal in length to the stacking length of the armature is placed in the machine, the eddy currents induced in it due to the 3-phase magnetomotive force of the armature will oppose the bore flux, leaving only the leakage reactance flux. The terminal quantities, voltage, current, and power, will then give directly the leakage reactance of the armature. This method is applicable only to small machines, since a copper cylinder for a large machine is prohibitive economically. A thin copper cylinder may be employed provided the frequency of the supply is raised to increase the effectiveness of the shielding. However, for very high frequencies there will be additional shielding in the iron of the machine that will decrease the slot and differential components, introducing errors in the results.

From time to time the suggestion has been made that armature leakage reactance could be determined directly from an analysis of the air-gap flux wave under conditions of sustained 3-phase short circuit. The fundamental component of flux so

Table I—Armature Leakage Reactance, 7.5 Kva Alternator

Test Determinations	
Air core without test coil	0.1621
Air core with test coil	0.0923
Copper cylinder	
60 cycles 3 phase with test coil	0.0992
120 cycles 3 phase with test coil	0.0949
60 cycles 1 phase with test coil	0.0904
Zero power factor	
Unsaturated	0.0935
Twice rated voltage (saturated)	0.0892
Other methods	
Static counter-magnetomotive force	0.0907
Copper sheet shielding	0.0933
Calculated Values	
Aiger	0.0837
Kilgore	0.0775

obtained is to be considered as that flux effective in forcing the short-circuit current through the armature against the resistance and the leakage reactance.

All of these methods give values of armature leakage reactance obtained well below the break in the saturation curve, and it is impractical to extend any one of them into the region of saturation because of armature heating due to the high currents. In order to include the effect of saturation upon the armature leakage reactance it is necessary to determine values of that reactance under actual conditions of operation.

The definition of armature leakage reactance suggests a method of test that not only may be applied to the unsaturated machine but may be extended into the region of high saturation. If a test coil may be placed on the armature surface spanning a pole pitch and including only the stacking length, the voltage induced in it will include that due to the space fundamental of flux and that due to the space harmonics caused by irregularities in the main field, such as those due to the pole form and to amortisseur slots.

At zero power factor there will be no distortion in the main field due to any angular displacement between the armature magnetomotive force and the main field magnetomotive force. If the harmonics due to the amortisseurs are less than 10 per cent of the fundamental, the voltage measured by the test coil will be practically the same as that generated by the space fundamental of the air gap flux. The vector difference between the air gap voltage and the terminal voltage plus the armature resistance drop, will be the voltage due to the armature leakage reactance. However, since in this case the resistance drop is perpendicular to the terminal voltage, the algebraic difference between the air gap voltage and the terminal voltage may be taken, for practical purposes, to give the armature leakage reactance drop. In other words, the difference between the voltage induced in the test coil at no-load and that

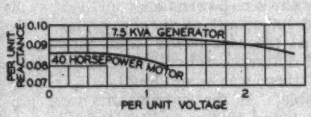

Fig. 3. Armature leakage reactance versus voltage, for the 2 machines

for full load current, zero power factor, taken as a ratio of the no-load value is the leakage reactance drop as a decimal fraction of the no-load voltage. This procedure may be repeated for voltages above and below the rated value to obtain a curve of armature leakage reactance as a function of voltage.

Experimental Results

The investigation on armature leakage reactance was centered about 2 machines, one an alternator rated at 7.5 kva, 220 volts, 19.7 amperes, 1,200 rpm, 60 cycles, and the other a synchronous motor rated at 40 horsepower, 440 volts, 44.5 amperes, 1,200 rpm,

Table II—Armature Leakage Reactance, 40 Horsepower Motor

Test Determinations	
Zero power factor	
Unsaturated	0.0860
Rated voltage (saturated)	0.0835
Other methods	
Static counter-magnetomotive force	0.0852
Copper sheet shielding	0.0833 direct axis
	0.0808 quadrature axis
Calculated Values	
Alger	0.0861
Kilgore	0.0834

60 cycles. The saturation curves for these machines (figure 2) indicate that they are admirably adapted to a study on the effect of saturation upon armature leakage reactance. The machines also differed somewhat in other respects; in the 7.5-kva alternator, the stacking length was equal to the inner radius of the stator, and the armature winding was 2-circuit, full pitch; in the 40 horsepower motor, the stacking length was 45 per cent of the inner stator radius, and the armature winding was single circuit, 75 per cent pitch. In both machines the straight portion of the end turns was very small, and the end connections were formed at an angle much less than the conventional 60 degrees, actually 51 degrees for the 40 horsepower motor and 50 degrees for the 7.5 kva generator.

It was impossible to remove the rotor from the 40 horsepower motor as the machine constituted one unit of a semi-permanent set. On the other hand, the 7.5 kva generator allowed of easy dismantling, and those methods applicable to the stator windings alone were tried on this machine.

The results of both the air-core method and that of using the copper cylinder are shown in table I. It is apparent both from physical considerations and from the test data, that neglect of the air core flux introduces large errors. The effect of increased shielding at higher frequencies is also indicated by the results at 60 and 120 cycles. Both of these methods serve as an indication of the unsaturated value of reactance, and while they may not be extended into the saturated region the values obtained are the limiting points that a curve of reactance as a function of voltage will approach with decreasing voltage.

The results of the zero power-factor method as applied to the 2 machines are given in figure 3. Both curves are flat over the region in which the machines are unsaturated, but the reactance decreases with increasing saturation. The decrease in reactance is due to a decreased leakage flux per ampere in the various leakage paths in the stator iron, the major portion occurring in the stator teeth.

In all of the past discussions on armature leakage reactance, in its application to synchronous machine operation, it has been customary to neglect completely the effect of saturation on this reactance, or to state that it is unaffected by saturation. The effect is not too great and for many problems may be neglected. However, with increasing refinements in the treatment on synchronous machines it is necessary at times to consider the effect of saturation on

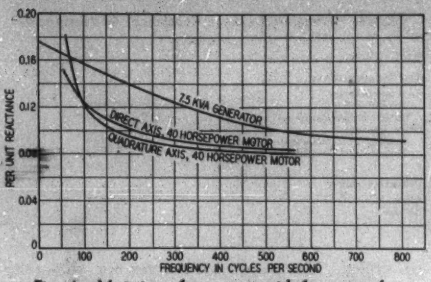

Fig. 4. Variation of reactance with frequency for the 2 machines, each with thin copper sheet in air-gap

all of the reactances, including armature leakage reactance.

Additional Test Methods

Two other test procedures have been devised to determine armature leakage reactance, which, while not consistent with the definition of the reactance, serve to indicate the approximate limiting values that it may have. The methods are presented here because of the consistent results obtained from their application to the 2 machines under consideration.

In one method, the machine rotor is so oriented that the pole axis is in line with the magnetomotive force axis on the armature, the armature magnetomotive force being produced by a single phase voltage applied to the terminals. A test coil, identical in shape with the armature coil, is fastened to the stator surface so that the coil sides are midway between the poles, and the end turns follow the contour of the armature winding end turns. Single phase voltage is then applied to both the stator and the rotor circuits and adjusted in magnitude and phase until there is zero voltage generated in the test coil on the armature surface.

Zero voltage in the test coil indicates that there is no space fundamental of flux crossing the air gap and that the flux produced by the armature current may be considered as leakage flux. This leakage flux is not the same as that defined as armature leakage flux for the synchronous machine because there are greater components of the space harmonics present within the stacking length, and a smaller component of armature reaction flux in the end turns. In application, this method requires considerable apparatus that is not required for the other methods, and the test technique is not so simple. The results are shown in tables I and II.

The other method consists in placing thin copper sheeting around the air gap of the machine, the copper sheeting extending out to the plane of the end turns, and applying a single phase source of variable frequency voltage to the armature terminals. The curve of equivalent 60 cycle reactance for the 7.5 kva machine is shown in the upper curve of figure 4 and indicates that the armature reaction flux within the stacking length decreases as the frequency increases, but does not go to zero because the thickness of copper is not sufficient for complete shielding. The increase in reactance due to the remaining armature reaction flux within the stacking length is offset by a decrease in the end turn flux due to the adjacent copper. The 2 effects tend to counterbalance each other at the higher frequencies, as indicated by the flattening out of the reactance curve for values above 500 cycles.

The results obtained on the 40 horsepower motor (the 2 lower curves of figure 4) are similar, even though the rotor was in place. Both curves of subtransient reactance drop to approximately the same value at higher frequencies.

Summary

Because armature leakage reactance is not a specific quantity, measurable directly as an overall effect, there have been many test methods suggested to determine approximate values of it. The most notable is that suggested by Potier,[14] in 1900, to aid in determining alternator regulation. It was soon recognized that the reactance obtained by the Potier method contained not only armature leakage reactance but a large component of field pole leakage as well. The Potier reactance, because of its simplicity of test determination, has maintained its place in the literature and has only recently[15] been modified to give a reactance which in the limit approaches very closely the calculated values of armature leakage reactance. It is impossible, even with the recently proposed modifications of Potier reactance, to determine the variation in armature leakage reactance because of the large masking effect of the pole leakage. The method proposed here makes possible a direct determination of the leakage reactance drop, and as a consequence small variations in this quantity due to an increased voltage may be detected.

While the other methods discussed do not indicate saturated values of the reactance, they serve as additional confirmation of the projected value of the curve found by the zero power-factor method. This was considered important at the beginning of the investigation, as the zero power-factor method involved a small difference between 2 relatively large quantities and there was some doubt as to the accuracy obtainable. As the experimental work progressed, it was found that very little difficulty was encountered due to this cause, for a curve of this difference as a function of armature current at constant terminal voltage gave a straight line having practically the same value of reactance for both the over-excited and the under-excited machine.

The saturated value of armature leakage reactance together with the effective armature resistance make possible a more exact determination of the air gap voltage under all conditions of loading. The air gap voltage in turn determines not only the saturated values of the synchronous reactances but also the additional field ampere-turns necessary to account for both the stator and rotor iron saturation. The field excitation amperes and the torque-angle of the loaded machine, both being of considerable im-

portance in system stability calculations, are obtained as the results of the calculations.

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Tests on Armature Resistance of Synchronous Machines

Armature resistance of synchronous machines, although usually disregarded when making torque-angle and excitation calculations, must be taken into account when making an accurate analysis. Values of armature resistance obtained in a series of tests are presented in this paper, which is a companion paper to "Test Values of Armature Leakage Reactance" in this issue, pages 700–5. Discussion of test methods, the effect of pole form on losses, and the use of effective armature resistance in determining the vector diagram of the machine are included herein.

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ALTHOUGH it was known very early in the history of synchronous machines that the apparent resistance of the armature did not agree with the d-c resistance, but was always greater in magnitude, little information is available on it from the practical standpoint. In most analyses on synchronous machines it has been customary for many years to disregard armature resistance upon the assumption that its magnitude is very small in comparison with the machine reactances, and hence will not appreciably alter results obtained by neglecting it. Such an approximation may be permissible for some machines, or for certain investigations where qualitative results only are desired. However, in many instances, particularly those involving detailed analyses, and those treating with machines of rather small ratings, armature resistance must be taken into account.

It is the aim of this paper to present some test results on armature resistance of synchronous machines. The paper includes a discussion on methods of test, the effect of pole form on additional losses, and the application of effective armature resistance in the vector diagram for the unsaturated synchronous machine operating under steady state conditions. The test results indicate that the effective armature resistance is independent of saturation.

Nature of Effective Armature Resistance

Resistance, as usually defined in d-c work, is the ratio of the voltage consumed by that part of the circuit under consideration to the current passing through that part of the circuit. This is called the true ohmic resistance. In a-c circuits this ratio gives the impedance rather than the resistance, hence a new definition is required. Resistance now becomes the ratio of the power expended in the circuit to the square of the current, a much broader definition.

For low frequency alternating currents in conductors surrounded by nonmagnetic materials, the conductors themselves being stranded, the resistance obtained by the second definition is the pure ohmic value, so far as can be determined. However, with increase in frequency, with massive conductors having no stranding, and with increased magnetic permeability of the medium surrounding the conductors, the apparent resistance of the circuit obtained by the second definition becomes greater than the true

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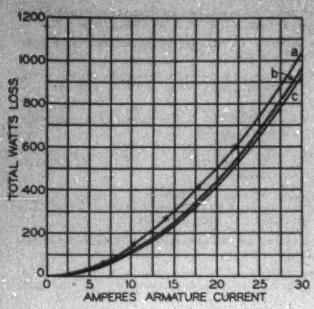

Fig. 1. Resistance loss curves for the salient pole machine

a. From dynamometer and V-curve tests; crosses show air-core measurements

b. Short-circuit core loss

c. Calculated from d-c resistance

ohmic resistance. Higher frequencies produce the phenomenon of skin effect which is of decided importance in a few rotating machines.

In the synchronous machine, as with all rotating apparatus, the armature copper is embedded in iron. The slots are relatively narrow and extend rather deeply into the magnetic body, due to practical design methods which call for double layer windings and a vertical arrangement of the conductors. Considerable flux therefore surrounds the conductors when carrying current, its effect being observed in several ways. It produces the slot leakage reactance as a consequence, it creates skin effect, and it aids in giving rise to eddy currents with their attending losses. A 60 cycle current in solid copper may induce eddy currents of a very harmful nature and greatly magnify the heating over that calculated by using the pure ohmic resistance.

It is thus observed that not only is power expended in the armature conductors due to the ohmic resistance, but also in them because of eddy currents set up by induction of the flux produced by the load current, and in addition outside of the copper by induction currents and some hysteresis by this localized flux. Differential leakage flux produces further losses, in the pole faces, that are proportional to the square of the armature current and are therefore chargeable to the armature as an increased resistance. These secondary losses are dependent upon the magnitude of the current, and give rise to the concept of *effective resistance*. Briefly defined, the effective resistance of an a-c circuit is that resistance which when multiplied by the square of the current will give the total losses attending that current, the ohmic resistance loss plus the secondary losses of eddy currents, hysteresis, etc., caused by its changing flux.

To reduce the effective resistance as much as possible, and to minimize heating effects, armature conductors are stranded, and often transposed. About $^3/_8$ of an inch is the usual design limit on the height of any single strand in the slot. Stranding eliminates much of the eddy current loss that otherwise would be obtained, but even at that the effective resistance yet may be considerably greater than the ohmic value. Arnold[1] has stated that the effective resistance of a 3-phase machine may be from 1.3 to 2.0 times the ohmic resistance, but present practice when considering it is to use a factor of from 1.1 to perhaps 1.5.

The d-c resistance of the armature copper may be calculated easily by usual methods, but the attending strand losses, and the core losses produced by eddy currents in the windings and in the iron, cannot be obtained so readily. They form the so-called load losses[2] which very often are assumed to be a given percentage of the machine rating. Some proposals have been made now and then for calculating them, or at least part of them, but the results do not appear in general use in the practicing field. The strand loss component has been given most attention in the past, and is probably the one most open to quantitative analysis, but to the writer's knowledge there is no method for determining the iron loss portion.

Methods of Test

It was shown very early by Steinmetz,[3] in his studies on the synchronous machine, that the power output of the motor is the armature input minus the sum of stator copper, windage and friction, core, and excitation (for direct connected exciter) losses. That is,

$$\text{power output} = \text{stator input} - \text{stator } i^2r - (\text{windage and friction} + \text{core loss} + \text{excitation loss}) \quad (1)$$

Upon the assumption that the group of losses enclosed in the parentheses is constant, it follows that any variation in the total losses under load then is included in the stator copper loss, the d-c resistance being modified accordingly. Hence,

$$P = ei\cos\theta - i^2r - \text{constant losses} \quad (2)$$

The assumption with respect to the so-called constant losses is carried out in practice with the exception that the internal voltage is determined by correcting the terminal voltage for the resistance drop.

For the generator, similar relations may be written:

$$\text{shaft input} - \text{constant losses} = \text{stator output} + i^2r = - \text{terminal input} + i^2r \quad (3)$$

If the shaft input is maintained equal to the constant

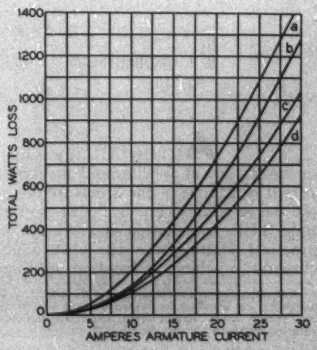

Fig. 2. Resistance loss curves for the cylindrical rotor machine

a. Dynamometer and V-curve tests
b. Short-circuit core loss
c. Air-core and salient pole effective resistance
d. Calculated from d-c resistance

1. For all numbered references see list at end of paper.

losses existing for zero armature current at the desired excitation, all i^2r losses then are supplied from the a-c lines as implied from the last equation.

This relation has suggested a method of test for effective armature resistance. The constant losses are supplied by an auxiliary driver and held at the value found under the conditions of the required a-c voltage with no power exchange between the a-c machine and its supply system. The excitation of the a-c machine then is varied, causing circulating current to flow, the effective resistance per leg of the a-c machine being given by the ratio of the a-c power input to 3 times the square of the current.

A variation of the foregoing method of test, and one which is quite practical, is that of measuring the machine input when it is operated as a motor under the conditions for the V-curve determination. In this case the wattmeters read also the constant losses. These losses are determined at unity power factor, i. e., minimum armature current, and are subtracted from the total power found for given values of circulating current. Obviously, these 2 methods of test give the same results, the only difference in calculating the resistance being the subtraction of the no-load wattmeter readings in the case of the V-curve test.

The methods involving resistance determination from circulating currents lead to the approximate measurement of resistance under conditions of short circuit. Results obtained from the short-circuit test of necessity will be lower than those found under the other methods just described because in this last case the flux in the machine is very low.

The method of test in which the rotor of the machine is removed[4] may be used at times to give approximate results on effective armature resistance. However, the method neglects the construction of the rotor, and is applicable only to machines having air-gap wave shapes which are purely sinusoidal.

An objection to the first method of test is that there is required an auxiliary machine to drive the alternator, the input to the driver to be held constant. If the machine is a dynamometer the torque arm must be kept in balance. For the V-curve method the synchronous machine runs as a motor, and if amortisseur windings are not present an auxiliary motor is needed to bring the test machine up to speed. Insufficient damping action of the secondary rotor circuits may lead to hunting, but this effect may be reduced greatly by inserting reactances in the supply lines. Both methods may involve somewhat small differences between fairly large wattmeter readings, but no difficulty was experienced in this respect in any of the runs, nor was there any trouble in reading the no-load input to the machine under the V-curve method of test. Wattmeters designed for ordinary power factors were used, in that the 2-wattmeter method of power measurement limits the angle for the wattmeters to 60 degrees, a power factor angle which is not too low. Limitations on the short-circuit method are the requirement of a dynamometer or a calibrated driver, and the low flux within the machine which leads to results below those for the first 2 methods. The air-core manner of test is practicable only during construction of the machine, or when the rotor may be removed easily. Practically, the V-curve test is to be recommended.

Fig. 4. No-load air-gap wave shape for the cylindrical rotor machine showing harmonics due to rotor teeth

Fig. 3. No-load air-gap wave shape for the salient pole machine

Test Results

The results of these various methods of test are shown in figures 1 and 2, together with the loss curves calculated from the d-c resistance. The test data were taken on a 7.5-kva 220-volt 1,200-rpm experimental alternator having 2 rotors, one a salient pole rotor and the other a wound rotor which carried direct current in the windings to make of it a cylindrical rotor machine.

Figure 1, which gives the loss curves for the salient pole machine, shows the deviations between the results obtained by the described test methods. Curve *a* is that for both the dynamometer and V-curve runs, the data from these methods giving exactly the same smooth curve. The crosses show the loss measurements for the air-core test, the points also falling on curve *a*. Curve *b*, for the short-circuit test, lies below, as it should, and is closer to the d-c resistance calculations than to curve *a*.

At normal current of 19.7 amperes the d-c armature resistance increases 22.2 per cent to give the effective armature resistance, a representative increase for a machine of this size. It will be observed that the difference between the d-c and effective armature resistance losses appears not to change very greatly from approximately normal current to 150 per cent of normal value. Measurements were taken on the machine for several conditions of terminal voltage, from half voltage to $2^1/_2$ times rated value at which the iron magnetomotive force is 30 per cent of the air-gap magnetomotive force, but no discernible variation was found in the resistance loss curve. Furthermore, over-excitation and under-excitation also gave no apparent deviations, hence

curve *a* represents the single result of the many runs.

Figure 2, for the cylindrical rotor machine, shows an effective armature resistance of approximately 175 per cent of the d-c resistance, at rated current. Again, both dynamometer and V-curve measurements produced the same results, curve *a*. In this case, however, the curve obtained from the short-circuit test lies closer to that for the effective resistance, the reason for this fact, and for the much higher resistance loss of the cylindrical rotor machine, lying in the form of the air-gap wave shape. Whereas the air-gap wave shape for the salient pole machine is smooth and close to a sine wave, as shown by figure 3, the air-gap wave shape for the cylindrical rotor machine has a high harmonic content, figure 4. These harmonics are due to the rotor teeth. Again, it was not found that voltage or change in excitation gave measurable deviations from a single curve.

Table I—Comparison Between Calculated and Test Values of Torque-Angle and Excitation for the Salient Pole Machine

e_t Volts	i_{avg} Amperes	W_1 Watts	W_2 Watts	Angle, Degrees Calc.	Angle, Degrees Test	I_f Amperes Calc.	I_f Amperes Test
Motor, 0.8 Power Factor Lagging							
220	0.0	0	0	0.0	0.0	3.37	3.37
220	5.15	460	1,120	5.2	5.2	2.83	2.85
220	10.75	920	2,330	12.4	12.2	2.45	2.44
220	15.2	1,255	3,320	18.5	18.5	2.22	2.18
220	19.9	1,730	4,345	26.8	26.4	2.19	2.14
220	24.15	2,135	5,280	34.7	34.5	2.27	2.23
220	29.7	2,570	6,480	45.0	44.5	2.57	2.43
Motor, 0.8 Power Factor Leading							
220	0.0	0	0	0.0	0.0	3.37	3.37
220	4.60	1,060	420	5.2	5.4	3.75	3.70
220	11.2	2,480	980	11.8	11.7	4.37	4.33
220	16.0	3,625	1,425	15.7	16.0	4.93	4.92
220	19.1	4,270	1,680	18.0	18.0	5.28	5.25
220	23.6	5,280	2,090	21.0	21.2	5.82	5.81
220	30.1	6,780	2,710	25.0	25.5	6.59	6.58
220	40.0	8,950	3,550	30.0	30.5	7.94	7.90

W_1 and W_2 are the wattmeter readings in the 2-wattmeter method of measuring 3 phase power

The 3 major factors contributing to harmonics in the air-gap wave shape are armature reaction, pole form, and the presence of slots for windings or amortisseurs in the pole faces. All of the above tests were made at zero power factor, hence any distortion in the main flux wave due to armature reaction was a minimum. At other than zero power factor, harmonics caused by armature reaction are present, and for this reason zero power factor tests may not be exactly comparable to actual load conditions. In spite of this, it is believed that the results presented here indicate very closely the actual conditions.

Harmonics in the no-load flux wave, introduced by pole form, will be present in all load conditions, although their magnitudes may change somewhat. These harmonics are productive of additional armature losses. In the same way, slots in the rotor, either for the d-c field winding, or for pole face windings, may give harmonics of relatively high frequency and of considerable magnitude.

The salient pole machine had a smooth pole face and was of such a shape that the no-load flux wave had no appreciable harmonic content. Under all conditions of load the wave shape remained smooth even though distortion due to armature reaction was present. The result of such a wave shape is not to increase additional armature losses to a very high percentage of the d-c resistance losses. On the other hand, the cylindrical rotor machine had 9 rotor slots per pole, thus introducing the 9th harmonic in the air-gap wave shape. Its magnitude was about 25 per cent of the fundamental. The increase in armature losses is evident from figure 2. Slots for amortisseurs give similar results.

Application

The application toward which this work has been pointed is a more exact determination of torque-angle and excitation of the synchronous machine. It has been general practice in most treatments on such machines to neglect armature resistance entirely, this forming one of the assumptions in the analyses. For many machines the assumption of zero resistance is justifiable, at least where approximate or qualitative results only are desired, or for many large machines where resistance is relatively small and neglect of it will not introduce any serious errors. On the other hand, for many machines, particularly smaller ones, the resistance drop may be an appreciable percentage of rated voltage, in which case it must be considered, in order to obtain correct results.

To show the agreement between calculated and test data when armature resistance is taken into account, tables I and II are given. The data were obtained under conditions of no saturation. It will be observed that the agreement between calculation and test is very good, indicating the accuracy obtained when the effect of resistance is included in the vector diagram. Load tests were taken on these machines at various other values of power factor than the ones presented here, similar good agreement between calculation and test being found. The writer does not recall having seen tabular data of

Table II—Comparison Between Calculated and Test Values of Torque-Angle and Excitation for the Cylindrical Rotor Machine

e_t Volts	i_{avg} Amperes	W_1 Watts	W_2 Watts	Angle, Degrees Calc.	Angle, Degrees Test	I_f Amperes Calc.	I_f Amperes Test
Motor, Unity Power Factor							
220	0.0	0	0	0.0	0.0	26.7	26.7
220	3.90	744	744	30.2	30.5	29.8	29.6
220	7.95	1,515	1,515	50.8	51.5	39.1	39.0
220	12.40	2,365	2,365	63.0	63.5	52.8	52.2
220	16.00	3,045	3,045	68.9	70.0	65.7	65.1
220	20.05	3,910	3,910	73.4	74.5	80.7	80.0
Motor, 0.8 Power Factor Leading							
220	0.0	0	0	0.0	0.0	26.7	26.7
220	4.23	960	360	20.7	21.0	38.9	39.2
220	8.95	1,930	716	31.0	31.2	54.7	54.5
220	13.30	2,880	1,080	36.9	37.2	70.5	70.3
220	18.30	4,000	1,585	41.3	41.5	89.4	89.3

(See footnote of table I.)

this kind presented before to show the relation of actual machine performance to the theory of its steady state operation as given by the complete vector diagram. The additional losses occurring under load, and chargeable to the armature, properly should be included in the vector diagram. The power-angle equation for the synchronous machine does not include constant losses but does take into account all i^2r effects, hence the vector diagram method of determining machine performance should consider the same losses, these to include the d-c resistance and all load losses. The vector diagram is directly related to the power-angle equation.

Physically, resistance connotes a loss of power. For the generator, it means that the power which crosses the air-gap is greater than the machine output, to the extent at least of the equivalent i^2r of the armature. In the motor, the terminal power is always greater than the air-gap power by the amount of the armature copper loss. Obviously, then, resistance will affect machine performance in the same general manner as will load impedance, and will require some changes in torque-angle and excitation over those which obtain for no resistance.

The effect of armature resistance in altering torque-angle and in changing excitation requirements depends largely upon the power factor. In a general way, resistance increases the angle and decreases the excitation for the unity power factor and over-excited synchronous motor, and decreases the angle and increases the excitation for the under-excited motor. The converse statements apply to the generator. With constant terminal voltage and excitation, increase in resistance results in a greater torque-angle for either generator or motor action. Resistance has a greater effect, by way of a greater angle, for the motor than for the generator, the reason lying in the fact that in the first case the ir drop is subtractive with respect to the terminal voltage, and in the second case is additive.

Summary

Armature resistance may have an appreciable effect upon the torque-angle and excitation of the synchronous machine operating under steady state conditions of loading. In general, it must be taken into account when accuracy of calculation is desired. Certainly, the exact effects of armature resistance must be known for the unsaturated machine before the saturated machine can be treated correctly, because resistance influences the air gap voltage as well as does armature leakage reactance. Neglect of the effective resistance may lead to large errors in the corrections for saturation.

The effective resistance of a synchronous machine may be obtained practically from wattmeter readings while the machine is run as for the V-curve determination. For a normally designed machine having a smooth air-gap voltage wave shape, the effective resistance will not increase greatly over the d-c resistance of the armature, but may be from perhaps 15 to 30 per cent higher in magnitude. Slots in the rotor, such as induction motor slots or slots for pole face windings, produce harmonics which increase greatly the apparent armature resistance. The losses caused by the harmonics may be several times the increased losses created otherwise, and it is possible for some machines to show an effective resistance of 2 or more times the d-c resistance. From the data presented it appears that saturation does not influence effective armature resistance to a determinable degree, or that under-excitation gives results which differ in recognizable amounts from conditions of over-excitation.

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Elliptic Integrals of Large Moduli

Tables of complete elliptic integrals of the first kind for large moduli are presented in this paper. While elliptic integrals are used in various kinds of engineering work, these tables are particularly useful in calculating mutual and self-inductances of cylindrical coils.

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COMPLETE elliptic integrals often are used in electrical engineering problems, as well as in other types of work. For example, in chapter III of reference 1 (see list at end of paper) are 9 formulas for the magnetic field of a cylindrical coil and 1 for the force between coils involving these quantities. Also, in reference 2 are 3 formulas for self-inductance of coils and 10 for mutual inductance

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Table I—Values of $K/\log_e(4 \sec \Theta)$

Θ 86 Deg Min	K / $\log_e(4 \sec \Theta)$	Difference	Θ 87 Deg Min	K / $\log_e(4 \sec \Theta)$	Difference	Θ 88 Deg Min	K / $\log_e(4 \sec \Theta)$	Difference	Θ 89 Deg Min	K / $\log_e(4 \sec \Theta)$	Difference
0	1.000 918 4		0	1.000 527 6		0	1.000 240 4		0	1.000 063 15	
		−73			−56			−38			−202
1	1.000 911 1		1	1.000 522 0		1	1.000 236 6		1	1.000 060 13	
		−73			−56			−39			−198
2	1.000 903 8		2	1.000 516 4		2	1.000 232 7		2	1.000 058 15	
		−73			−56			−38			−195
3	1.000 896 5		3	1.000 510 8		3	1.000 228 9		3	1.000 056 20	
		−73			−56			−38			−191
4	1.000 889 2		4	1.000 505 2		4	1.000 225 1		4	1.000 054 29	
		−72			−55			−38			−189
5	1.000 882 0		5	1.000 499 7		5	1.000 221 3		5	1.000 052 40	
		−72			−55			−37			−185
6	1.000 874 8		6	1.000 494 2		6	1.000 217 6		6	1.000 050 55	
		−72			−55			−37			−182
7	1.000 867 6		7	1.000 488 7		7	1.000 213 9		7	1.000 048 73	
		−71			−55			−37			−178
8	1.000 860 5		8	1.000 483 2		8	1.000 210 2		8	1.000 046 95	
		−71			−54			−36			−176
9	1.000 853 4		9	1.000 477 8		9	1.000 206 6		9	1.000 045 19	
		−71			−54			−36			−172
10	1.000 846 3		10	1.000 472 4		10	1.000 203 0		10	1.000 043 47	
		−71			−53			−36			−169
11	1.000 839 2		11	1.000 467 1		11	1.000 199 4		11	1.000 041 78	
		−70			−54			−35			−165
12	1.000 832 2		12	1.000 461 7		12	1.000 195 9		12	1.000 040 13	
		−70			−53			−35			−163
13	1.000 825 2		13	1.000 456 4		13	1.000 192 4		13	1.000 038 50	
		−70			−52			−35			−159
14	1.000 818 2		14	1.000 451 2		14	1.000 188 9		14	1.000 036 91	
		−69			−53			−35			−156
15	1.000 811 3		15	1.000 445 9		15	1.000 185 4		15	1.000 035 35	
		−70			−52			−34			−152
16	1.000 804 3		16	1.000 440 7		16	1.000 182 0		16	1.000 033 83	
		−69			−52			−34			−150
17	1.000 797 4		17	1.000 435 5		17	1.000 178 6		17	1.000 032 33	
		−68			−51			−34			−146
18	1.000 790 6		18	1.000 430 4		18	1.000 175 2		18	1.000 030 87	
		−69			−52			−33			−142
19	1.000 783 7		19	1.000 425 2		19	1.000 171 9		19	1.000 029 45	
		−68			−51			−33			−140
20	1.000 776 9		20	1.000 420 1		20	1.000 168 6		20	1.000 028 05	
		−68			−50			−33			−136
21	1.000 770 1		21	1.000 415 1		21	1.000 165 3		21	1.000 026 69	
		−67			−51			−32			−133
22	1.000 763 4		22	1.000 410 0		22	1.000 162 1		22	1.000 025 36	
		−67			−50			−32			−129
23	1.000 756 7		23	1.000 405 0		23	1.000 158 9		23	1.000 024 07	
		−67			−50			−32			−127
24	1.000 750 0		24	1.000 400 0		24	1.000 155 7		24	1.000 022 80	
		−67			−49			−31			−122
25	1.000 743 3		25	1.000 395 1		25	1.000 152 6		25	1.000 021 58	
		−66			−49			−32			−120
26	1.000 736 7		26	1.000 390 2		26	1.000 149 4		26	1.000 020 38	
		−67			−49			−30			−116
27	1.000 730 0		27	1.000 385 3		27	1.000 146 4		27	1.000 019 22	
		−65			−49			−31			−113
28	1.000 723 5		28	1.000 380 4		28	1.000 143 3		28	1.000 018 09	
		−66			−48			−30			−110
29	1.000 716 9		29	1.000 375 6		29	1.000 140 3		29	1.000 016 99	
		−65			−48			−30			−106
30	1.000 710 4		30	1.000 370 8		30	1.000 137 3		30	1.000 015 93	
		−65			−48			−30			−103
31	1.000 703 9		31	1.000 366 0		31	1.000 134 3		31	1.000 014 90	
		−65			−47			−29			−99
32	1.000 697 4		32	1.000 361 3		32	1.000 131 4		32	1.000 013 91	
		−65			−48			−29			−96
33	1.000 690 9		33	1.000 356 5		33	1.000 128 5		33	1.000 012 95	
		−64			−47			−29			−93
34	1.000 684 5		34	1.000 351 8		34	1.000 125 6		34	1.000 012 02	
		−64			−46			−28			−89
35	1.000 678 1		35	1.000 347 2		35	1.000 122 8		35	1.000 011 13	
		−63			−46			−28			−86
36	1.000 671 8		36	1.000 342 6		36	1.000 120 0		36	1.000 010 27	
		−64			−46			−28			−83
37	1.000 665 4		37	1.000 338 0		37	1.000 117 2		37	1.000 009 440	
		−63			−46			−27			−792
38	1.000 659 1		38	1.000 333 4		38	1.000 114 5		38	1.000 008 648	
		−62			−45			−27			−758
39	1.000 652 9		39	1.000 328 9		39	1.000 111 8		39	1.000 007 890	
		−63			−46			−27			−724
40	1.000 646 6		40	1.000 324 3		40	1.000 109 1		40	1.000 007 166	
		−62			−44			−27			−689
41	1.000 640 4		41	1.000 319 9		41	1.000 106 4		41	1.000 006 477	
		−62			−45			−26			−656
42	1.000 634 2		42	1.000 315 4		42	1.000 103 8		42	1.000 005 821	
		−62			−44			−26			−621
43	1.000 628 0		43	1.000 311 0		43	1.000 101 2		43	1.000 005 200	
		−61			−44			−25			−586
44	1.000 621 9		44	1.000 306 6		44	1.000 098 69		44	1.000 004 614	
		−61			−44			−252			−552
45	1.000 615 8		45	1.000 302 2		45	1.000 096 17		45	1.000 004 062	
		−61			−43			−249			−518
46	1.000 609 7		46	1.000 297 9		46	1.000 093 68		46	1.000 003 544	
		−60			−43			−246			−482
47	1.000 603 7		47	1.000 293 6		47	1.000 091 22		47	1.000 003 062	
		−61			−43			−243			−448
48	1.000 597 6		48	1.000 289 3		48	1.000 088 79		48	1.000 002 614	
		−59			−42			−239			−413
49	1.000 591 7		49	1.000 285 1		49	1.000 086 40		49	1.000 002 201	
		−60			−42			−237			−378
50	1.000 585 7		50	1.000 280 9		50	1.000 084 03		50	1.000 001 823	
		−59			−42			−233			−343
51	1.000 579 8		51	1.000 276 7		51	1.000 081 70		51	1.000 001 480	
		−60			−41			−230			−308
52	1.000 573 8		52	1.000 272 6		52	1.000 079 40		52	1.000 001 172	
		−58			−42			−227			−272
53	1.000 568 0		53	1.000 268 4		53	1.000 077 13		53	1.000 000 899 9	
		−59			−41			−224			−2368
54	1.000 562 1		54	1.000 264 3		54	1.000 074 89		54	1.000 000 663 1	
		−58			−40			−220			−2010
55	1.000 556 3		55	1.000 260 3		55	1.000 072 69		55	1.000 000 462 1	
		−58			−40			−217			−1652
56	1.000 550 5		56	1.000 256 3		56	1.000 070 52		56	1.000 000 296 9	
		−58			−40			−214			−1291
57	1.000 544 7		57	1.000 252 3		57	1.000 068 38		57	1.000 000 167 8	
		−57			−40			−211			−928
58	1.000 539 0		58	1.000 248 3		58	1.000 066 27		58	1.000 000 075 04	
		−57			−40			−208			−5611
59	1.000 533 3		59	1.000 244 3		59	1.000 064 19		59	1.000 000 018 93	
		−57			−39			−204	90 Deg	1.0	−1893

of coils, which are in terms of complete elliptic integrals.

The usual way to obtain the values of these integrals is to use tables of them, but when the modulus becomes large, that is, when it approaches unity, the complete elliptic integral of the first kind, K, becomes large, approaching infinity, and the steps between the tabulated values are also large, making accurate interpolation difficult. This is stated on page 7 of reference 2 and it readily is experienced by anyone who uses the formulas for various shapes and positions of coils. Alternative formulas and series frequently are used to avoid this difficulty.

In this paper, 2 tables are given that are supplementary to those of Legendre which usually are used (see reference 3, volume 2, tables I and VIII). They are for the purpose of assisting in the determination of accurate values of the complete elliptic integral of the first kind,

$$K = \int_0^{\pi/2} \frac{d\phi}{\sqrt{(1 - \sin^2 \Theta \sin^2 \phi)}}$$

where the modulus is sin Θ, often denoted by k.

The tables are for values of θ from 86 to 90 degrees.

Values of K are given in table II for each minute of θ, while Legendre's table gives them, in the logarithmic form, for each 6 minutes. Even then, the steps in the one-minute table at 89 degrees 0 minutes are 1/320 and the last step of the table is 1/13.

It is well known that for values of θ nearly equal to 90 degrees, K can be expressed by a convergent series the first term of which is $\log_e (4 \sec \theta)$, where $\log_e$ denotes natural logarithm. This series was used for computing tables I and II. (See pages 46 and 54 of reference 4, and equation 3, page 8 of reference 2.) In table I are given values of $K/\log_e (4 \sec \theta)$. This table is much more precise than table II, the coarsest step being 1/136,000 at 86 degrees. Very complete tables are, of course, available for finding $\log_e \sec \theta$, the easiest method probably being to multiply the tabulated common logarithm of $\sec \theta$ by 2.302 585. The addition of $\log_e 4 = 1.386\ 294$ can be made directly.

Then, multiplying the value of $\log_e (4 \sec \theta)$ by the tabulated quantity, which is slightly greater than unity, the precise value of K is found. The table is arranged equally well for multiplying by a calculating machine or by a logarithm table.

As an example of the use of table I, let $\theta = 89$ degrees 0 minutes. Then

$$\log_e \sec \theta = 1.758\ 1447 \times 2.302\ 585$$
$$= 4.048\ 28$$
$$\log_e 4 = 1.386\ 29$$
$$\log_e (4 \sec \theta) = 5.434\ 57$$

Multiplying by 1.000 062 15 from table I, the value of K, 5.434 91 is obtained, which agrees with the value in table II and with the value tabulated by Legendre.

In most practical cases, the precision of the result depends on how accurately θ or $\sec \theta$ is known. If it be desired to obtain elliptic integrals to more decimal places than are given by logarithmic tables (tables giving 10 places are available), use may be made of series of which several types are available.

In preparing the tables, the computations were performed a second time to check their correctness. The computations were carried out to more decimal places than are tabulated here. Columns of second differences were made as an additional check on the accuracy.

Table II—Complete Elliptic Integrals of the First Kind, K

θ 86 Deg Min	K	Difference	θ 87 Deg Min	K	Difference	θ 88 Deg Min	K	Difference	θ 89 Deg Min	K	Difference
0	4.052 76	414	0	4.339 65	555	0	4.742 72	835	0	5.434 91	1680
1	4.056 90	416	1	4.344 20	557	1	4.751 07	842	1	5.451 71	1708
2	4.061 06	418	2	4.349 77	561	2	4.759 49	849	2	5.468 79	1735
3	4.065 24	420	3	4.355 38	564	3	4.767 98	856	3	5.486 17	1769
4	4.069 44	421	4	4.361 02	567	4	4.776 54	864	4	5.503 86	1800
5	4.073 65	423	5	4.366 69	571	5	4.785 18	871	5	5.521 86	1834
6	4.077 88	425	6	4.372 40	573	6	4.793 89	880	6	5.540 20	1868
7	4.082 13	427	7	4.378 13	578	7	4.802 69	887	7	5.558 88	1904
8	4.086 40	429	8	4.383 91	580	8	4.811 56	895	8	5.577 92	1941
9	4.090 69	431	9	4.389 71	584	9	4.820 51	903	9	5.597 33	1979
10	4.095 00	432	10	4.395 55	587	10	4.829 54	911	10	5.617 12	2019
11	4.099 32	435	11	4.401 42	591	11	4.838 65	920	11	5.637 31	2061
12	4.103 67	436	12	4.407 33	595	12	4.847 85	928	12	5.657 92	2105
13	4.108 03	438	13	4.413 28	598	13	4.857 13	937	13	5.678 97	2149
14	4.112 41	441	14	4.419 26	602	14	4.866 50	946	14	5.700 46	2197
15	4.116 82	442	15	4.425 28	605	15	4.875 96	956	15	5.722 43	2247
16	4.121 24	444	16	4.431 33	609	16	4.885 52	964	16	5.744 90	2298
17	4.125 68	447	17	4.437 42	613	17	4.895 16	974	17	5.767 88	2352
18	4.130 15	448	18	4.443 55	617	18	4.904 90	983	18	5.791 40	2409
19	4.134 63	450	19	4.449 72	620	19	4.914 73	994	19	5.815 49	2468
20	4.139 13	453	20	4.455 92	625	20	4.924 67	1003	20	5.840 17	2531
21	4.143 66	455	21	4.462 17	628	21	4.934 70	1014	21	5.865 48	2597
22	4.148 21	456	22	4.468 45	633	22	4.944 84	1023	22	5.891 45	2666
23	4.152 77	459	23	4.474 78	636	23	4.955 07	1035	23	5.918 11	2739
24	4.157 36	461	24	4.481 14	641	24	4.965 42	1046	24	5.945 50	2816
25	4.161 97	463	25	4.487 55	645	25	4.975 88	1056	25	5.973 66	2898
26	4.166 60	466	26	4.494 00	649	26	4.986 44	1068	26	6.002 64	2985
27	4.171 26	467	27	4.500 49	654	27	4.997 12	1079	27	6.032 49	3076
28	4.175 93	470	28	4.507 03	657	28	5.007 91	1092	28	6.063 25	3175
29	4.180 63	472	29	4.513 60	662	29	5.018 83	1103	29	6.095 00	3278
30	4.185 35	474	30	4.520 22	667	30	5.029 86	1116	30	6.127 78	3389
31	4.190 09	477	31	4.526 89	671	31	5.041 02	1128	31	6.161 67	3509
32	4.194 86	479	32	4.533 60	676	32	5.052 30	1142	32	6.196 76	3636
33	4.199 65	481	33	4.540 36	680	33	5.063 72	1154	33	6.233 12	3773
34	4.204 46	484	34	4.547 16	685	34	5.075 26	1168	34	6.270 85	3922
35	4.209 30	486	35	4.554 01	690	35	5.086 94	1182	35	6.310 07	4082
36	4.214 16	489	36	4.560 91	694	36	5.098 76	1196	36	6.350 89	4255
37	4.219 05	491	37	4.567 85	700	37	5.110 72	1211	37	6.393 44	4445
38	4.223 96	493	38	4.574 85	704	38	5.122 83	1225	38	6.437 89	4651
39	4.228 89	496	39	4.581 89	710	39	5.135 08	1241	39	6.484 40	4879
40	4.233 85	498	40	4.588 99	714	40	5.147 49	1257	40	6.533 19	5128
41	4.238 83	501	41	4.596 13	720	41	5.160 06	1272	41	6.584 47	5407
42	4.243 84	504	42	4.603 33	725	42	5.172 78	1289	42	6.638 54	5715
43	4.248 88	506	43	4.610 58	731	43	5.185 67	1306	43	6.695 69	6062
44	4.253 94	508	44	4.617 89	736	44	5.198 73	1323	44	6.756 31	6454
45	4.259 02	512	45	4.625 25	741	45	5.211 96	1341	45	6.820 85	6899
46	4.264 14	514	46	4.632 66	747	46	5.225 37	1359	46	6.889 84	7410
47	4.269 28	516	47	4.640 13	752	47	5.238 96	1378	47	6.963 94	8004
48	4.274 44	520	48	4.647 65	759	48	5.252 74	1397	48	7.043 98	8701
49	4.279 64	522	49	4.655 24	764	49	5.266 71	1417	49	7.130 99	9531
50	4.284 86	525	50	4.662 88	770	50	5.280 88	1438	50	7.226 30	10535
51	4.290 11	528	51	4.670 58	776	51	5.295 26	1459	51	7.331 65	11778
52	4.295 39	530	52	4.678 34	782	52	5.309 85	1480	52	7.449 43	13353
53	4.300 69	534	53	4.686 16	789	53	5.324 65	1502	53	7.582 96	15415
54	4.306 03	536	54	4.694 05	795	54	5.339 67	1526	54	7.737 11	18232
55	4.311 39	539	55	4.702 00	801	55	5.354 93	1549	55	7.919 43	22314
56	4.316 78	543	56	4.710 01	807	56	5.370 42	1574	56	8.142 57	28769
57	4.322 21	545	57	4.718 08	815	57	5.386 16	1598	57	8.430 26	40548
58	4.327 66	548	58	4.726 23	821	58	5.402 14	1625	58	8.835 72	69315
59	4.333 14	551	59	4.734 44	828	59	5.418 39	1652	59	9.528 87	∞
									90 Deg		

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Production of Steam From Electric Energy

In localities where hydroelectric power is abundant and steam loads are readily available, the production of steam from electric energy has proved to be a highly satisfactory means of utilizing surplus and off-peak power. This method of producing steam is particularly advantageous where cleanliness is important and in small establishments having intermittent demand for steam. Although the production of steam by this method has had a wider application in Canada, where the total installed capacity of such equipment exceeds 1,500,000 kw, numerous installations, totalling about 200,000 kw, also have been made in the United States. The design and operation of the principal types of equipment used for this purpose are discussed in this paper.

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ELECTRIC production of steam has proved to be the most economical and generally satisfactory means for the utilization of surplus and off-peak power in parts of the world where hydroelectric power is abundant and steam loads are readily available. This is because of the low unit cost of electric steam generating plants, the ease of control, and the satisfactory characteristics of the load. It should be understood, however, that the installation of hydroelectric generating capacity to be utilized for the production of steam is economically justifiable only under extremely unusual conditions. It is apparent that electric energy generated from fuel cannot be used economically for steam production in substantial amount under any circumstances. Surplus hydroelectric power may be available because of development beyond current needs, an economic depression, or the failure of bulk power customers at times to take their allotments. If off-peak power be available for as much as an 8 hour period regularly, it may be utilized profitably for steam production.

The earlier electric steam generators were of the immersion type, which consists of a pressure vessel in which are inserted electric heaters in such a manner that the heater element will be immersed in the water. This type is particularly useful in capacities up to 100 kw and, where power rates are favorable, is used in hospitals, dairies, cleaning establishments, etc., for the production of small and intermittent supplies of steam. The cost per unit of capacity of the immersion generator is relatively high; consequently, for large installations the electrode type generally is used.

In the electrode steam generator, as the name indicates, the electric current is introduced into the vessel by means of insulated electrodes and flows through the water from one electrode to another or to the shell of the vessel. Thus the water itself is the resistance element, inexpensive and durable. Various types of electrode generators have been developed. These might be classified roughly as the baffle, the 2-compartment, and the single-compartment generators. The baffle type contains ceramic blocks so arranged that the water passages for the flow of electric current between electrodes are restricted. The object is to secure a higher resistance between electrodes and provide a low current density at the electrodes. Too great a current density will cause overheating of the electrodes, oxidation of the metal, and release of hydrogen gas. A baffle type of steam generator is shown in figure 1. It may be noted that porcelain bushings are utilized to insulate the conductor rods passing through the top end of

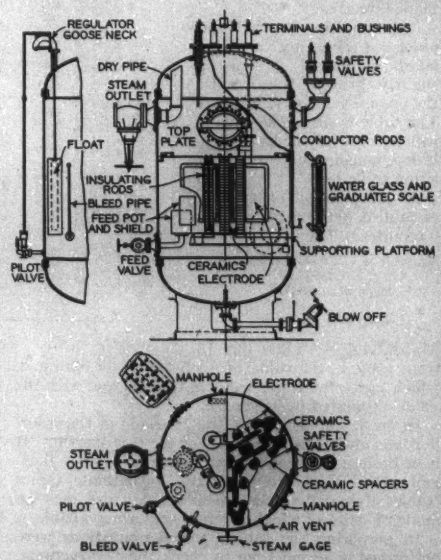

Fig. 1. Baffle type of electric steam generator

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the pressure vessel; 2 of these in parallel are used on each of the 3 phases, the 2 conductor rods of each phase supporting a V-shaped electrode. The 3 electrodes are separated and surrounded by stacks of ceramic material which serve to limit and to direct the flow of electric current between the electrodes. The other features illustrated, with the exception of the bleed valve, are the same as are to be found on an ordinary fuel fired steam boiler.

A baffle type steam generator equipped with a water level regulator is shown in figure 2. It is necessary to control the water level in order to maintain the desired load. The device shown provides for manual adjustment of the water level, which, together with the proper variation in the amount of bleed water, will permit any desired load to be carried.

The 2-compartment type of generator contains an upper compartment within the shell of the pressure vessel, the shell itself forming the lower compartment. The electrodes are immersed in the water of the upper compartment. Water is conveyed from the lower to the upper compartment by means of a centrifugal pump. A return connection between the 2 compartments is provided with a regulating valve, by means of which the water level in the upper compartment, and the consequent depth of immersion of the electrodes, may be varied; this furnishes a ready means of varying the power input to the generator.

The 2-compartment type of generator is illustrated in figure 3. The electrodes, which are segmental in cross section, are suspended in the upper compartment by means of the conductor rods. Current flows between the electrodes and from the electrodes to the shell of the upper compartment, which is at ground potential. When greater current carrying capacity is desired, a grounded cylinder is installed inside the circle of the electrodes.

The single-compartment or Kaelin type of electric steam generator illustrated in figure 5 is constructed with the 3 electrodes of the 3 phase generator in a single compartment inside the pressure shell. It may be observed that each electrode is supported from a conductor rod passing through the top of the pressure vessel. The electrodes are circular in cross section, tapering downward to a hemispherical tip at the bottom, and are surrounded by a steel shell of

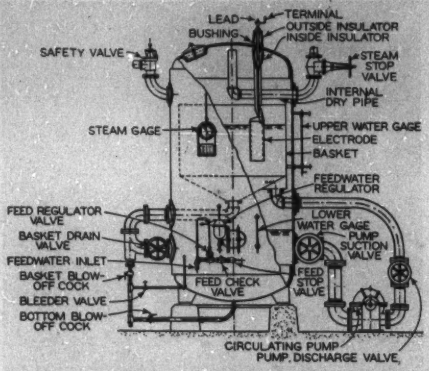
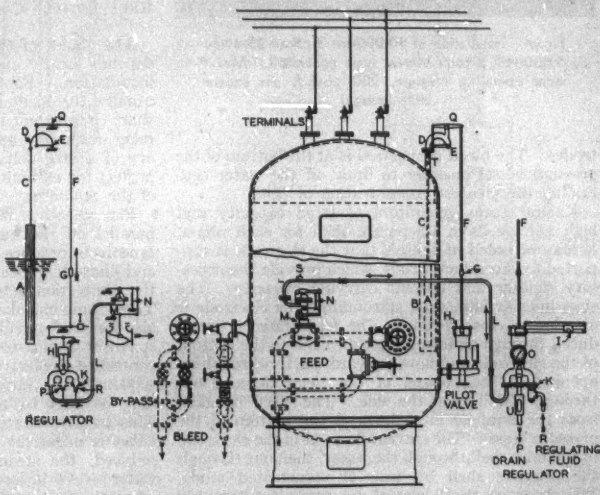


Fig. 3. Generator of the 2-compartment type with circulating pumps

Fig. 2. Baffle type generator equipped with water level regulator

For simplicity, the regulator is shown in schematic form at the left; letters on this diagram indicate the same points as corresponding letters on the main diagram



trefoil cross section; this arrangement is intended to distribute the current evenly over the surfaces of the electrodes. The feed water enters the vertical pipe at the bottom of the pressure vessel and flows upward, distributing the fresh water around the electrodes. The bleed connection is at the bottom of the pressure vessel in order to draw off the water containing the greatest concentration of salts.

Fig. 4. Installation of 30,000-kw 3-phase 25-cycle 6,600-volt 2-compartment type generators. Maximum operating pressure, 200 pounds per square inch (gauge)

Kaelin steam generators of large capacity and high voltage have a separate shell for each phase. It may be noted in figure 6 that the electrode is supported by 3 conductor rods, which provide the necessary rigidity and current carrying capacity. The steel liner or false shell surrounding the electrode is circular in cross section. The feed water is introduced through an insulating tube close to the bottom of the electrode and flows upward, partly through an opening in the bottom of the electrode and out through openings in the side. The bleed is taken from the sump or mud drum at the bottom of the pressure vessel. The current flows from the electrode to the false shell through the water, then out through the pressure shell by way of uninsulated studs. The studs on the 3 phases are connected together by copper bars to form a neutral which is well grounded.

Operating Voltages

The electric steam generator may readily be designed to operate on any voltage up to 6,600 volts. For higher voltages it is necessary to have a feed water of high resistivity in order to secure reasonable operating efficiency. In general, capacities up to 1,000 kw can be designed most readily for 550 volt operation, up to 12,000 kw at 2,200 volts, and higher capacities at 6,600 volts. The higher the voltage the longer the required path through the water with a consequent increase in electrode areas and current capacity. It has been found that an average current density of one ampere per square inch is the maximum that can be used with carbon steel or cast iron electrodes without erosion and formation of hydrogen gas.

In several instances, the location of the steam generator has been near enough to the generating station so that power could be transmitted directly from the low voltage bus. The only major electrical apparatus required is a circuit breaker which may be in the generating station or at the load. Such an arrangement provides a grounded neutral on the bus. Sometimes the steam generator is supplied from the low voltage bus in the customer's substation, either in parallel with the primary load or from a spare transformer bank.

The usual arrangement for a large installation consists of a transformer bank connected to the high voltage line stepping down to 6,600 volts to supply one or more steam generators. The switching equipment may be either on the high voltage or low voltage side of the transformers.

Relaying and Control

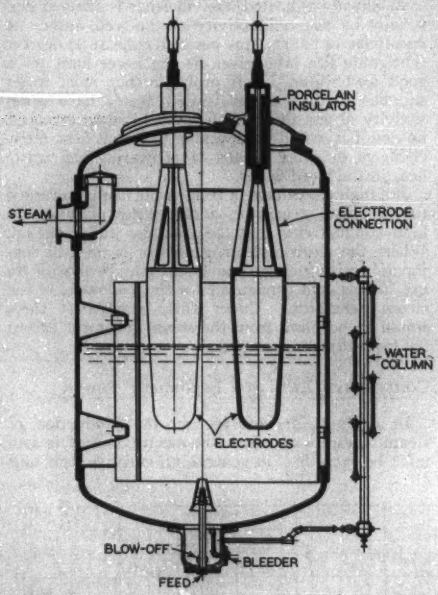
The choice of the most suitable relay protection depends largely upon the specific conditions of each installation. For the isolated steam generator, usually the instantaneous excess current relay for short circuits and the instantaneous residual voltage relay, connected across the open corner delta secondary of a star/delta potential transformer set, will protect for all faults throughout the operating range of the generator.

For selective relaying of steam generators in parallel off the same low voltage bus, the instantaneous impedance relay, connected for phase current and phase-to-ground voltage, is used to assure selective protection between the units for ground faults. These same impedance relays usually are satisfactory also for short-circuit protection.

Power input to the steam generator may be controlled by varying the water level and consequently the immersion of the electrodes, which may be done by adjusting the feed water supply. This method has the disadvantage that the initial effect is negative; that is, when the feed water is reduced, the steam output is increased until the water level is lowered considerably, and the contrary when the feed water rate is increased. In some installations a closed tank is provided in which water from the steam generator is stored when operating at reduced load. This water is returned to the generator whenever it is desired to pick up load. The 2-compartment generator, as previously noted, is designed to operate on water level control, and storage space is provided in the lower compartment.

An unstable element is introduced into the control, however, by the negative temperature-resistance characteristic of water. With increasing pressure the temperature of saturated steam will increase correspondingly. The temperature of the water will follow closely that of the steam, with resultant decrease in resistivity and increased power input.

Another method is known as the conductivity control. The conductivity of the water in the generator depends upon the concentration of salts therein. This concentration can be reduced readily by bleeding a small amount of water from the generator and replacing it with fresh water. The concentration, and hence the conductivity, can be increased



by feeding a salt solution into the generator. To control rapid fluctuations in load in this way it is necessary to bleed heavily for a drop in steam demand, at the same time maintaining a practically constant water level by increasing the amount of feed. The cooling effect of this feed water counteracts the tendency to pick up load with increased pressure.

A special method of control not generally applicable is obtained by varying the voltage impressed on the terminals of the steam generator. In one instance the steam generator was operated on a separate bus in the power house and the attendant given control over the voltage. This method proved to be highly satisfactory.

The majority of electric steam generators at present in operation are controlled manually. Various forms of automatic control have been developed, however, the one most generally used being known as the Eaton control. This is a conductivity control with provision for automatically reducing the conductivity by bleeding and increasing the conductivity by feeding salt solution. Water level is maintained automatically, but is adjustable manually.

Feed Water

The principal loss of heat in the operation of an electric steam generator is that resulting from the bleed from the generator to maintain the proper conductivity. For a concentration of dissolved salts of not more than 60 parts per million or a resistivity of not less than 6,000 ohms per inch cube at 20 degrees centigrade, the generator will operate without excessive bleed. The formation of scale is not harmful except that, if allowed to accumulate in the bottom of the tank, it may clog the bleed outlet.

In some localities where organic matter is present in the feed water, the scale may adhere to the electrodes and interfere with the flow of the electric current. In some such instances, the electrodes are cleaned as often as once a month. The electric steam generator is subject to corrosion and pitting the same as fuel fired boilers. It has the disadvantage that

Fig. 5 (left). Single-compartment generator, 3 phases in one tank

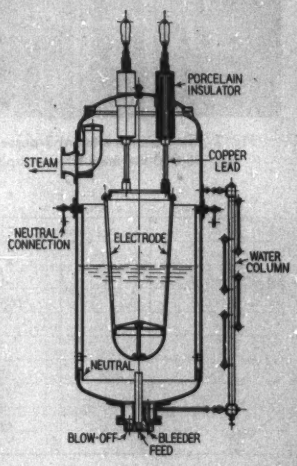


Fig. 6 (right). Single-compartment generator, one phase per tank

dissolved salts may not be used so freely in treating the water, and the advantage that the pressure shell may be protected by scale or other suitable coating.

Efficiency

Thermal losses of the electric steam generator are caused by radiation and by the bleed or discharge

of water from the generator to maintain the proper conductivity, as already explained. The radiation loss may be taken at 2 per cent. For a feed water of the characteristics mentioned, the bleed would be approximately 20 per cent of the feed. This would mean a reduction in efficiency of 4 per cent on account of the bleed or an operating efficiency of 94 per cent under these conditions. Several electric steam generators are operating at efficiencies varying from between 90 and 98 per cent.

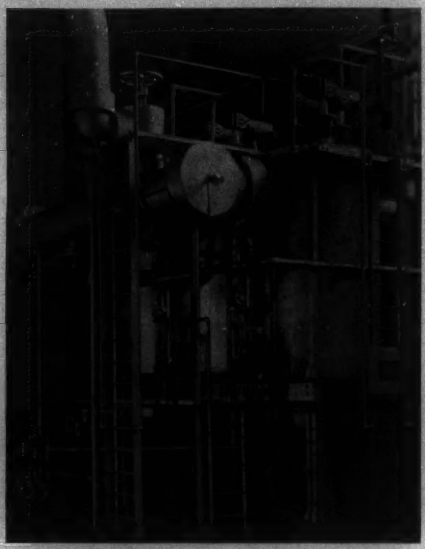


Fig. 7. Single-compartment 3-phase 3-tank, 6,600-volt 35,000-kw manually controlled generator

The efficiency is affected to a considerable extent by the design of the generator. For a given impressed voltage, electrode area, and spacing of electrodes, the water in the generator must have a conductivity suitable to carry the desired load. The higher this conductivity, the less the percentage of bleed and consequently the higher the efficiency.

The efficiency will be affected also to some extent by the character of the steam demand, particularly where conductivity control is used. A sudden drop in demand will require a heavy blowdown in order to prevent the safety valves from blowing. A sudden increase in demand will require the feeding of salt solution to maintain pressure. If this cycle be repeated frequently, it will result in a decrease in efficiency of from 2 to 5 per cent below that obtained under steady load conditions.

As already indicated, the efficiency is affected materially by the conductivity of the feed water. A resistivity of 6,000 ohms per inch cube at 20 degrees centigrade has been given as the lower limit for a good feed water. It is probable that most water supplies in the eastern United States have a resistivity of less than this figure. In such instances, no doubt it would be desirable to install heat interchangers or other means of recovering the waste heat in the bleed water.

If a high percentage of condensate can be returned to the steam generator, a raw water of relatively high conductivity may be used for the make-up. Where the electric steam generator is used in conjunction with fuel fired boilers, it may be possible to use 100 per cent condensate for the feed water of the steam generator. Under these conditions there would be no bleed from the steam generator except for load adjusting purposes.

Competitive Rate for Secondary Power

In order to replace fuel in the production of steam, the rate at which the electric energy is sold must be such that, in general, an effective heat unit will cost the same from the 2 sources. This relationship is expressed by the proportion

$$\frac{\text{Cost of electric energy}}{\text{Btu} \times \text{conversion efficiency}} = \frac{\text{Cost of fuel}}{\text{Btu} \times \text{furnace efficiency}}$$

Assuming coal at $5 per ton of 2,000 pounds

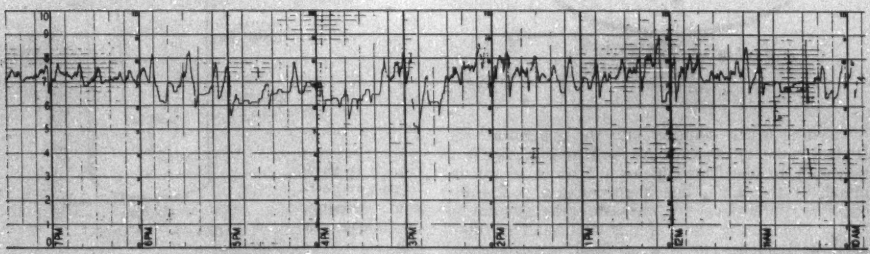


Fig. 8. Graph of load on 2 35,000 kw steam generators, one automatically controlled, in a newsprint mill. Full scale is 100,000 kw

on the grates, 13,600 effective Btu per pound, a furnace efficiency of 80 per cent, and a conversion efficiency in the electric steam generator of 95 per cent, the proportion would be

$$\frac{\text{Cost of a kilowatt-hour}}{3{,}415 \times 0.95} = \frac{\$5.00}{2{,}000 \times 13{,}600 \times 0.80}$$

or

$$\text{Cost of a kilowatt-hour} = \$0.000745 = 0.745 \text{ mill}$$

At an annual load factor of 75 per cent, the annual earning of 1 kw of capacity would be $4.90 In general, a kilowatt-year at 75 per cent load factor will be equal in value to a ton of coal.

Other considerations, aside from the cost of fuel, may affect the competitive price of electric energy. Some of these are: (1) saving on operating costs, (2) saving on maintenance, (3) cleanliness, and (4) convenience.

In a large steam plant a single operator is required for the electric steam generators. The control may be made automatic, if desired. The treatment of feed water for scale prevention ordinarily would not be necessary. The maintenance cost of steam genera-

Table I—Baffle Type Electric Steam Generators Installed in Canada

User	Location	No. Units	Size of Units, Kw	Total Kw
Interlake Tissue Mills	Merriton, Ont.	1	7,500	7,500
Provincial Paper Co.	Thorold, Ont.	1	7,500	7,500
Howard Smith Paper Co.	Cornwall, Ont.	1	20,000	20,000
Bathurst Paper Co.	Bathurst, N. B.	1	7,500	7,500
		4		42,500

Table II—Installations of 2-Compartment Type Electric Steam Generators in Canada

User	Location	No. Units	Size of Units, Kw	Total Kw
Pacific Mills Ltd.	Ocean Falls, B. C.	1	5,000	5,000
Corp. of Sherbrooke	Sherbrooke, Que.	1	750	750
City of Winnipeg	Winnipeg, Man.	2	7,500	15,000
Bennett's Ltd.	Chambly, Que.	1	600	600
Can. Gen. Elec. Co. Ltd.	Peterboro, Ont.	1	1,000	1,000
Quaker Oats Co.	Peterboro, Ont.	1	4,000	4,000
Gulf Pulp & Paper Co.	Clarke City, Que.	1	500	500
Donnacona Paper Co.	Donnacona, Que.	1	5,000	5,000
Cons. Mining & Smelting Co.	Trail, B. C.	3	1,500	4,500
Powell River Co.	Powell River, B. C.	1	5,000	5,000
Abitibi Pwr. & Paper Co.	Sturgeon Falls, Ont.	1	5,000	5,000
Abitibi Pwr. & Paper Co.	Iroquois Falls, Ont.	1	20,000	20,000
Can. Internat. Paper Co.	Temiskaming, Que.	2	8,000	16,000
Can. Cottons, Ltd.	Milltown, N. B.	1	1,500	1,500
Abitibi Pwr. & Paper Co.	Espanola, Ont.	1	5,000	5,000
Anglo Can. Pulp & Paper Co.	Limoilou, Que.	1	5,000	5,000
City of Winnipeg	Winnipeg, Man.	1	7,500	7,500
Spruce Falls Pulp & Paper Co.	Kapuskasing, Ont.	2	10,000	20,000
Toronto Hydro-Elec. System	Toronto, Ont.	1	1,000	1,000
Gatineau Pwr. Co.	Hawkesbury, Ont.	2	20,000	40,000
Spruce Falls Pwr. & Paper Co.	Kapuskasing, Ont.	1	10,000	10,000
Thunder Bay Paper Co.	Fort William, Ont.	1	5,000	5,000
Abitibi Pwr. & Paper Co.	Sault Ste. Marie, Ont.	1	5,000	5,000
Powell River Co.	Powell River, B. C.	1	6,000	6,000
H. E. P. C.* for Ont. Paper Co.	Thorold, Ont.	3	30,000	90,000
Great Lakes Pwr. Co. Ltd.	Sault Ste. Marie, Ont.	1	5,000	5,000
H. E. P. C. for Provincial Paper Mills Ltd.	Port Arthur, Ont.	2	12,000	24,000
Pacific Mills Ltd.	Vancouver, B. C.	1	1,000	1,000
Winnipeg Electric Co. Ltd. for Can. Packers Ltd.	Winnipeg, Man.	1	6,000	6,000
Receiver for Minnesota and Ontario Paper Co. for Pt. Frances Pulp & Paper Co.	Fort Frances, Ont.	1	10,000	10,000
H. E. P. C. for Abitibi Pwr. & Paper Co. Ltd.	SmoothRockFalls, Ont.	2	25,000	50,000
		41		374,350

* Hydro-Electric Power Commission of Ontario.

Table III—Installations of Single-Compartment Type Electric Steam Generators in Canada

User	Location	No. Units	Size of Units, Kw	Total Kw
Abitibi Pwr. & Paper Co. Ltd.	Iroquois Falls, Ont.	2	20,000	40,000
	Beaupre, Que.	2	5,000	10,000
	Smooth Rock Falls, Ont.	2	2,000	4,000
	Fort Alexander, Man.	2	15,000	30,000
Aluminum Co. of Can., Ltd.	Arvida, Que.	1	8,000	8,000
Anglo Can. Pulp & Paper Co.	Limoilou, Que.	1	35,000	35,000
Ayers, Ltd.	Lachute, Que.	1	4,000	4,000
Beaver Wood Fibre Co.	Thorold, Ont.	1	3,000	3,000
Brown Corp. Ltd.	Latuque, Que.	1	35,000	35,000
Can. Car & Foundry Co. Ltd.	(Turcot) Montreal, Que.	1	5,000	5,000
Can. Cottons, Ltd.	Cornwall, Ont.	1	2,000	2,000
Can. Electro Products, Ltd.	Shawinigan Falls, Que.	1	5,000	5,000
Can. Industries, Ltd.	Shawinigan Falls, Que.	2	10,000	20,000
Can. Internat. Paper Co.	Three Rivers, Que.	2	12,000	24,000
	Gatineau, Que.	3 1	42,000 21,000	147,000
N. B. Internat. Paper Co.	Dalhousie, N. B.	1	16,000	16,000
Internat. Pulp & Paper Co. of Nfld.	Corner Brook, Nfld.	1	20,000	20,000
Cascade Inn	Shawinigan Falls	1 1	300 500	800
Consolidated Paper Corp.	Grand Mere, Que.	2	25,000	50,000
	Shawinigan Falls, Que.	1 1	30,000 35,000	65,000
	Three Rivers	1 1	3,750 35,000	38,750
Dawson Elec. Lt. & Pwr. Co.	Dawson City, Yukon	1	500	500
Donnacona Paper Co. Ltd.	Donnacona, Que.	1 1	25,000 10,000	35,000
Goodyear Tire & Rubber Co.	New Toronto, Ont.	1	4,000	4,000
Lake St. John Pwr. & Paper Co.	Dolbeau, Que.	2	20,000	40,000
James McLaren & Co. Ltd.	Masson, Que.	1 4	300 16,000	64,300
Montreal Cottons, Ltd.	Valleyfield, Que.	2	1,500	3,000
Montreal Lt. Ht. & Pwr. Cons.	Montreal, Que.	1 1	3,000 5,000	8,000
	Ville LaSalle, Que.	2	8,000	16,000
News Pulp & Paper Co.	Desbiens, Que.	1	1,800	1,800
Ontario Paper Co.	Thorold, Ont.	1	3,000	3,000
Port Alfred Pulp & Paper Co.	Port Alfred, Que.	1	35,000	35,000
Price Bros. & Co. Ltd.	Kenogami, Que.	1	7,000	7,000
	Kenogami, Que.	3	28,000	84,000
	Riverbend, Que.	2	32,000	64,000
Quebec Ry. Lt. Ht. & Pwr. Co.	Quebec, Que.	1 1	1,500 750	2,250
St. Lawrence Paper Mills Co. Ltd.	Three Rivers, Que.	1 1	5,000 25,000	30,000
Shawinigan Chemicals, Ltd.	Shawinigan Falls, Que.	2	5,000	10,000
Howard Smith Paper Mills, Ltd.	Crabtree Mills, Que.	1	10,000	10,000
Spruce Falls Pulp & Paper Co. Ltd.	Kapuskasing, Ont.	1	1,500	1,500
Installations in Winnipeg	Winnipeg, Man.	28	100 and over	12,200
St. Justine Hospital	Montreal, Que.	1	1,500	1,500
Dominion Silk Dyeing & Finishing Co.	Drummondville, Que.	1	10,000	10,000
Northern B. C. Pwr. Co.	Prince Rupert, B. C.	1	500	500
Montreal Cottons, Ltd.	Valleyfield, Que.	1	1,700	1,700
Winnipeg Electric Co.	Winnipeg, Man.	1	2,000	2,000
J. R. Booth, Ltd. (paper mill)	Ottawa, Ont.	1	5,000	5,000
Dominion Rubber Co.	Montreal, Que.	1	8,000	8,000
Great Lakes Paper Co.	Fort William, Ont.	2	8,000	16,000
Winnipeg Heating Co.	Winnipeg, Man.	1	10,000	10,000
McGill University	Montreal, Que.	1	2,000	2,000
Boswell's Brewery	Quebec, Que.	1	2,500	2,500
J. J. Joubert Dairy	Montreal, Que.	1	2,000	2,000
Consolidated Paper Corp. (Belgo Mill)	Shawinigan Falls, Que.	1	35,000	35,000
Associated Textiles of Can.	Louiseville, Que.	1	10,000	10,000
Montreal Lt. Ht. & Pwr. Co.	Cedar Rapids, Que.	1	1,500	1,500
Other installations		8		13,100
		118		1,114,900

Table IV—Summary of Electric Steam Generator Installations in Canada

Type	Range in Kw. Capacity of Units	No.	Total Kw.
Baffle	7,500–20,000	4	42,500
Two Compartment	500–30,000	41	374,350
Single Compartment	300–42,000	118	1,114,900
Total		163	1,531,750

tors may be taken at $1 per million pounds of steam produced. The maintenance cost of one coal fired steam plant producing one billion pounds of steam per year is stated to be $38 per million pounds of steam produced.

It is difficult to evaluate the elimination of coal dust, smoke, and soot. In the manufacture of fine papers, textiles, etc., the improved cleanliness is of

Table V—Partial List of Electric Steam Generators Installed in the United States

User and Location	Capacity
Internat. Paper Co., Niagara Falls, N. Y.	5,000
Niagara Falls Pwr Co., Niagara Falls, N. Y.	19,000
Oxford Paper Co., Rumford, Maine	16,000
Aluminum Co. of America, Massena, N. Y.	7,000
Washington Pulp & Paper Co., Port Angeles, Wash.	5,000
Miller Falls Paper Co., Miller Falls, Mass.	350
Rochester Gas & Elec. Corp., Rochester, N. Y.	3,000
Ford Motor Co. (Green Island), Detroit, Mich.	3,200
Brown, Co., Berlin, N. H. (paper)	18,000
Washburn-Crosby Co. (flour)	3,000
Montana Pwr. Co., Missoula, Mont.	5,000
Washington Water Pw . Co., Spokane, Wash.	10,000
Mosiner Paper Mills Co., Mosiner, Wis.	2,500
St. Croix Paper Co., St. Croix, Me.	6,000
Union Bag & Paper Co., Hudson Falls, N. Y.	5,000
Hearts Delight Farm, Chazy, N. Y.	2,000
Red River Lumber Co., Westwood, Calif.	2,000
Keyes Fibre Co., Waterville, Me.	7,500

undoubted value in reducing costs and improving the quality of the product. In small establishments having intermittent demand for steam, such as dairies and laundries, the convenience of electric steam generation may outweigh all other considerations.

Cost of Installation

The cost of a large installation of electric steam generators with housing should not exceed $2 per kilowatt of capacity, including piping and electrical connections, switching equipment, and relaying. If transformers be required, the total cost ordinarily will not be more than $5 per kilowatt of installed capacity. These costs are based upon the assumption that no high voltage line construction will be required.

Operating Experience

Since 1921, more than 100 electric steam generators have been installed in Canada with a total rated capacity of 1,500,000 kw. Observations made on the operating results obtained on approximately 25 per cent of this total may be summarized as follows:

1. The electric steam generator is equal in operating reliability to electrical apparatus in general. Electrical breakdown is most likely to take place at the bushings that insulate the conductors passing through the pressure shell of the generator. Porcelain generally has been used for these bushings and has had a life of from 6 months to a year on the parts exposed to steam. A new type of ceramic material has been developed that has been found especially suitable for use in contact with steam. It is unglazed, free from thermal cracks, and promises to give long service.

2. Considered as a pressure vessel, the electric steam generator has given satisfactory service. The design is such that strains resulting from varying temperature are minimized. The pressure shell readily is protected from erosion caused by the passage of the current. Some pitting has been observed similar in character to that found in fuel fired boilers. Because of the comparatively small dimensions of the electric steam generator, it is feasible to design the pressure shell to have a high factor of safety and thus compensate for a considerable amount of pitting.

3. Because of its relatively small storage capacity, the electric steam generator is not as well adapted to carry a rapidly fluctuating load as the ordinary fuel fired boiler. It is advisable to provide an accumulator where the load is variable; however, several electric steam generator installations are handling such loads without the aid of an accumulator.

4. Maintenance on the electric steam generator is a matter of keeping joints steam tight, renewing gauge glasses, etc. Electrodes require renewing at intervals from 1 to 5 years.

5. Sufficient time has not elapsed since the general introduction of the electric steam generator to determine with any accuracy the rate at which depreciation takes place. However, it is reasonable to expect that an installation may be operated at least 10 years at full pressure rating.

In figure 8 is reproduced a section of a graphic wattmeter chart showing the total power input to 2 35,000 kw steam generators supplying a newsprint mill in which there are rapid fluctuations in the

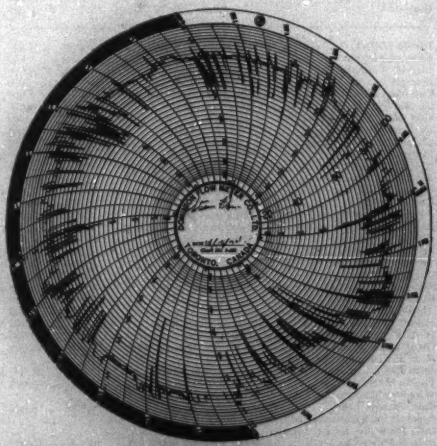


Fig. 9. Chart showing steam demand of newsprint mill of figure 8 for same day. Full scale equals 266,150 pounds of steam per hour at a pressure of 120 pounds per square inch, gauge

steam demand. One of the generators is controlled automatically and the other manually. The output for the day was 5,255,320 pounds of steam from and at 212 degrees Fahrenheit, and the input 1,675,200 kwhr; this corresponds to a conversion efficiency of 89.3 per cent. The chart reproduced in figure 9 shows the steam demand of the mill on the same day.

In tables I, II, and III are listed the electric steam generators of various types installed in Canada to date and table IV gives a summary of pertinent data on these installations. Complete information regarding installations in the United States was not available to the author; however, the best information available indicates that there are no installations of the baffle type, and that the total capacity of the 2-compartment and single-compartment types is in the neighborhood of 100,000 kw each. Table V gives a partial list of installations in the United States.

Transmission Line Catenary Calculations

A simple and accurate method is described for compiling stringing charts for overhead transmission lines, for either horizontal or inclined spans. All calculations can be carried out with a 20 inch slide rule, and no tables of functions are required other than those included in this paper. The procedure is the same for horizontal and for oblique spans. Moreover, no loss of accuracy is suffered as the inclination of the span is increased. The final result is obtained by means of a graphical solution which, in principle, is based upon the Thomas chart.

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THE method for carrying out sag and tension calculations for overhead transmission lines described in this paper was developed when the U. S. Bureau of Reclamation was confronted with the problem of designing a number of steep spans between the transformers on the roof of the Boulder Canyon power plant and the switch yard on the rim of the canyon. In this case it was found that the procedures commonly used in sag and tension calculations lacked either simplicity or accuracy, or both.

In the proposed method, the length, sag, and tension are calculated in terms of an arbitrary parameter z. All formulas are first rigorously derived from catenary relations, and then simplified by neglecting small quantities. The accuracy of the calculations is made consistent with good designing practice, on the one hand, and with the limitations of field measurements on the other.

Although originally intended only for steep spans, the method is applicable to spans of any inclination whatever. The only limitation is that the parameter z should be less than 0.5 if accuracy and simplicity are to be maintained. However, in practical problems of transmission line design z is always well within this limiting value.

In order to use the method intelligently, it is not necessary to follow all derivations in this paper. It will be sufficient to read from "Graphical Solution" to "Example 2," inclusive.

A paper recommended for publication by the A.I.E.E. committee on power transmission and distribution. Manuscript submitted June 4, 1934; released for publication Sept. 5, 1934.

The investigation described in this paper was carried out under the supervision of R. E. Glover, engineer. All design work and design studies for the Bureau are under the direction of J. L. Savage, chief designing engineer. All engineering and construction work is under the direction of R. F. Walter, chief engineer, Denver, Colo. All activities of the Bureau are under the general charge of Dr. Elwood Mead, commissioner, Washington, D. C.

Notation and Units

T	= tension at any point in cable	pounds
H	= horizontal component of tension	pounds
T_1	= tension at upper support	pounds
T_2	= tension at lower support	pounds
T_e	= effective (or average) tension of cable	pounds
w	= weight of cable per unit length	pounds per foot
h	= wind load per unit length of cable	pounds per foot
v	= ice load per unit length of cable	pounds per foot
w'	= $\sqrt{(w+v)^2+h^2}$, resultant force per unit length	pounds per foot
ϕ	= angle between w and w'	
S	= actual length of cable	feet
S_0	= unstressed length of cable	feet
c	= straight-line distance between supports	feet
d	= sag of cable	feet
D	= deflection of cable	feet
x, y	= co-ordinates of any point on cable	feet
x_1, y_1	= co-ordinates of upper support	feet
x_2, y_2	= co-ordinates of lower support	feet
x', y'	= co-ordinates of any point on line of supports	feet
a	= horizontal spacing of supports	feet
b	= vertical spacing of supports	feet
a'	= spacing of supports in plane of w', at right angles to vector w'	feet
b'	= spacing of supports in plane of w', in the direction of vector w'	feet
A	= area of cross-section of cable	AE pounds
E	= modulus of elasticity of cable	

θ = temperature of cable — degrees fahrenheit

α = coefficient of linear expansion of cable — feet per foot per degree fahrenheit

$z = aw/2H$, a parameter — pure number

$F(z) = \left(\frac{\sinh z}{z}\right)^2 - 1$ — pure number

$(z) = \frac{1}{6}\left(z^2 + \frac{z^4}{20}\right)$ — pure number

Length, Tension, and Sag

The length, tension, and sag will be written as functions of the parameter z. It will be assumed for the time being that there is no wind load or ice load.

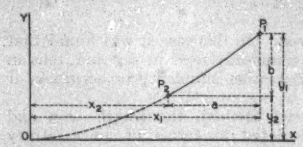

Fig. 1. Representation of the cable arc

Standard Formulas. Let the cable be represented by the arc P_1P_2 of any catenary drawn through the points P_1 and P_2. The horizontal and vertical spacings are a and b, respectively (see figure 1). The equation of the catenary, referred to the point O where it has a horizontal tangent, is

$$y = \frac{H}{w}\left(\cosh \frac{x}{H/w} - 1\right) \tag{1}$$

The length of arc from (0, 0) to (x, y) is given by

$$s = \frac{H}{w} \sinh \frac{x}{H/w} \tag{2}$$

The tension at the point (x, y) is

$$T = H \cosh \frac{x}{H/w} \tag{3}$$

Locating the End Points. Before one can actually make use of equations 1, 2, and 3, the end points x_1, y_1 and x_2, y_2 must be located with respect to the co-ordinate axes (see figure 1).

From equation 1

$$\frac{y_1}{H/w} - \frac{y_2}{H/w} = \cosh \frac{x_1}{H/w} - \cosh \frac{x_2}{H/w}$$

By transforming and making the substitutions

$$x_1 - x_2 = a,\ y_1 - y_2 = b \tag{4}$$

one obtains:

$$\frac{b}{H/w} = 2 \sinh \frac{aw}{2H} \sinh \frac{2x_1 - a}{2H/w}$$

Upon solving this for x_1 and putting

$$z = \frac{aw}{2H}, \tag{5}$$

one has

$$\frac{x_1}{H/w} = \text{arc sinh} \frac{bz}{a \sinh z} + z, \tag{6}$$

and

$$\frac{x_2}{H/w} = \frac{x_1 - a}{H/w} = \text{arc sinh} \frac{bz}{a \sinh z} - z \tag{7}$$

Length of Cable. By virtue of equation 2 one has at once (see figure 1):

$$S = \text{arc } P_1P_2 = \text{arc } OP_1 - \text{arc } OP_2 = \frac{H}{w}\left(\sinh \frac{x_1}{H/w} - \sinh \frac{x_2}{H/w}\right)$$

Transform and make use of the first equation 4. Then:

$$S = \frac{2H}{w} \sinh \frac{aw}{2H} \cosh \frac{x_1 + x_2}{2H/w}$$

Use equations 5, 6, and 7, and then simplify. This gives:

$$S = \sqrt{a^2\left(\frac{\sinh z}{z}\right)^2 + b^2} \tag{8}$$

By putting

$$F(z) = \left(\frac{\sinh z}{z}\right)^2 - 1$$

one has:

$$S = \sqrt{a^2(1 + F) + b^2} = \sqrt{c^2 + a^2F}$$

where c is the straight-line distance between supports.

Expand $F(z)$ into a power series:

$$F(z) = \frac{2^2}{4!}z^2 + \frac{2^4}{6!}z^4 + \frac{2^7}{8!}z^6 + \ldots$$

and:

$$S^2 = c^2 + a^2F(z) = c^2 + \frac{2^2}{4!}a^2z^2 + \frac{2^4}{6!}a^2z^4 + \frac{2^7}{8!}a^2z^6 + \ldots \tag{9}$$

Assume that

$$\sqrt{c^2 + a^2F} = c + m_2z^2 + m_4z^4 + m_6z^6 + \ldots \tag{10}$$

By squaring both sides of equation 10 and comparing with equation 9, one evaluates the coefficients m. Remembering that $c^2 = a^2 + b^2$, one finally obtains:

$$S = \sqrt{c^2 + a^2F} = c + \frac{a^2}{6c}z^2 + \frac{a^2}{6c}\left[\frac{1}{20} + \frac{(b/c)^2}{12}\right]z^4 + \ldots$$

Since this series converges at least as rapidly as the right-hand side of equation 9, one can neglect

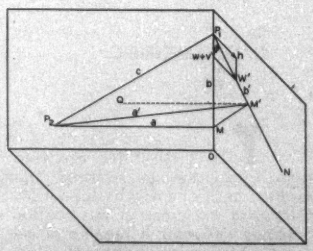

Fig. 2. Components of forces on cable

$b = MP_1$ $\quad b' = M'P_1$ $\quad \phi$ = the angle MP_1M'

Draw P_2M' perpendicular to P_1N

Draw $M'Q$ parallel to MP_2

P_1M' is perpendicular to P_2M' by construction

P_1M' is perpendicular to $M'Q$, since $M'Q$ is parallel to MP_2

Therefore P_1M' is perpendicular to the plane of $MM'P_2$

Therefore P_1M' is perpendicular to MM'

Therefore the angle $MM'P_1$ = 90 degrees

Therefore $b' = b \cos \phi$

all terms beginning with the fourth. One then has, upon rearranging:

$$S - c = \frac{a^2}{6c}\left(z^2 + \frac{z^4}{20}\right) + \frac{a^2b^2}{72c^3}z^4 \tag{11}$$

The quantity $S - c$ is the slack of the cable, or the length of the cable in excess of the span length c.

By putting

$$f(z) = \frac{1}{6}\left(z^2 + \frac{z^4}{20}\right), \tag{12}$$

one has:

$$S - c = \frac{a^2}{c}\, f(z) + \frac{a^2b^2}{72c^3}z^4 \tag{13}$$

Values of $f(z)$ and z^4 are given in table I. In most cases it will be found that the term involving z^4 can be neglected.

Upper-Support Tension. By virtue of equation 3,

$$T_1 = H \cosh \frac{x_1}{H/w}$$

By making use of equation 6, and then simplifying, one has:

$$T_1 = \frac{w}{2}\left\{\sqrt{a^2\left(\frac{\sinh z}{z}\right)^2 + b^2}\,\coth z + b\right\}$$

or, by equation 8,

$$T_1 = \frac{w}{2}\,(S \coth z + b) = {}^1/_2(wS)\coth z + {}^1/_2wb \tag{14}$$

Lower-Support Tension. Proceeding as above, one finds:

$$T_2 = \frac{w}{2}\,(S \coth z - b) = {}^1/_2(wS)\coth z - {}^1/_2wb \tag{15}$$

Values of coth z are given in table I.

Note that the product wS is a constant, equal to the total weight of the cable.

Effective Tension. Divide the unstressed length of the cable into elements ΔS_0. When the cable is suspended the length of each element becomes

$$\Delta S = \Delta S_0\left(1 + \frac{T}{AE}\right) \tag{16}$$

where A is the area of cross section and E is the modulus of elasticity. Then:

$$S = \int_0^{S_0} dS_0 + \frac{1}{AE}\int_0^{S_0} T dS_0 = S_0 + \frac{1}{AE}\int_0^{S_0} T dS_0 \tag{17}$$

By transforming, one obtains

$$\frac{\frac{1}{S_0}\int_0^{S_0} T dS_0}{S - S_0} = \frac{AE}{S_0} \tag{18}$$

The effective tension T_e is defined as that value of the tension T which satisfies Hooke's law in its simple form: $\frac{T}{S - S_0} = \frac{AE}{S_0}$

It follows at once from equation 18 that the effective tension of the cable is

$$T_e = \frac{1}{S_0}\int_0^{S_0} T dS_0 \text{ or, very nearly}$$

$$T_e = \frac{1}{S}\int_0^{S} T dS \tag{19}$$

Table I—Functions of z

z	f(z)	coth z	1/z	z^4	z^2
0.010	0.00001667	100.003	100.000	0.00000001	0.0000010
0.020	0.0000666	50.007	50.000	0.00000016	0.0000080
0.030	0.0001500	33.343	33.3333	0.00000081	0.0000270
0.040	0.0002667	25.013	25.0000	0.00000256	0.0000640
0.050	0.0004167	20.017	20.0000	0.00000625	0.0001250
0.060	0.0006001	16.687	16.6667	0.00001296	0.0002160
0.070	0.0008169	14.309	14.2857	0.00002401	0.0003430
0.080	0.001067	12.527	12.5000	0.00004096	0.0005120
0.090	0.001351	11.141	11.1111	0.00006561	0.0007290
0.100	0.001668	10.0333	10.0000	0.0001000	0.001000
0.110	0.002018	9.1275	9.0909	0.0001464	0.001331
0.120	0.002402	8.3733	8.3333	0.0002074	0.001728
0.130	0.002819	7.7356	7.6923	0.0002856	0.002197
0.140	0.003270	7.1895	7.1429	0.0003842	0.002744
0.150	0.003754	6.7166	6.6667	0.0005063	0.003375
0.160	0.004272	6.3032	6.2500	0.0006554	0.004096
0.170	0.004824	5.9389	5.8824	0.0008352	0.004913
0.180	0.005409	5.6154	5.5556	0.001050	0.005832
0.190	0.006028	5.3263	5.2632	0.001303	0.006859
0.200	0.006680	5.0665	5.0000	0.001600	0.008000
0.205	0.007019	4.9462	4.87805	0.001766	0.008615
0.210	0.007366	4.8317	4.76190	0.001945	0.009261
0.215	0.007722	4.7226	4.65116	0.002137	0.009938
0.220	0.008086	4.6186	4.54545	0.002343	0.010648
0.225	0.008459	4.5192	4.44444	0.002563	0.01139
0.230	0.008840	4.4242	4.34783	0.002798	0.01217
0.235	0.009230	4.3334	4.25532	0.003050	0.01298
0.240	0.009628	4.2464	4.16667	0.003318	0.01382
0.245	0.010034	4.1630	4.08163	0.003603	0.01471
0.250	0.010449	4.0830	4.00000	0.003906	0.01563
0.255	0.010873	4.0062	3.92157	0.004228	0.01658
0.260	0.011305	3.9324	3.84615	0.004570	0.01758
0.265	0.011745	3.8615	3.77358	0.004932	0.01861
0.270	0.012194	3.7933	3.70370	0.005314	0.01968
0.275	0.012652	3.7276	3.63636	0.005719	0.02080
0.280	0.013118	3.6643	3.57143	0.006147	0.02195
0.285	0.013592	3.6033	3.50877	0.006598	0.02315
0.290	0.014076	3.5444	3.44828	0.007073	0.02439
0.295	0.014567	3.4876	3.38983	0.007573	0.02567
0.300	0.015068	3.4327	3.33333	0.008100	0.02700
0.305	0.015578	3.3797	3.27860	0.008654	0.02837
0.310	0.016094	3.3285	3.22581	0.009235	0.02979
0.315	0.016620	3.2789	3.17460	0.009846	0.03126
0.320	0.017154	3.2309	3.12500	0.01049	0.03277
0.325	0.017697	3.1845	3.07692	0.01116	0.03433
0.330	0.018249	3.1395	3.03030	0.01186	0.03594
0.335	0.018809	3.0959	2.98507	0.01259	0.03760
0.340	0.019378	3.0538	2.94118	0.01336	0.03930
0.345	0.019956	3.0126	2.89855	0.01417	0.04106
0.350	0.020542	2.9729	2.85714	0.01501	0.04288
0.355	0.021137	2.9343	2.81690	0.01588	0.04374
0.360	0.021740	2.8968	2.77778	0.01680	0.04666
0.365	0.022352	2.8603	2.73973	0.01775	0.04863
0.370	0.022973	2.8249	2.70270	0.01874	0.05065
0.375	0.023602	2.7905	2.66667	0.01978	0.05273
0.380	0.024240	2.7570	2.63158	0.02085	0.05487
0.385	0.024887	2.7245	2.59740	0.02197	0.05707
0.390	0.025543	2.6928	2.56410	0.02313	0.05932
0.395	0.026207	2.6620	2.53165	0.02434	0.06163
0.400	0.026880	2.6319	2.50000	0.02560	0.06400
0.405	0.027562	2.6027	2.46914	0.02690	0.06643
0.410	0.028252	2.5742	2.43902	0.02826	0.06892
0.415	0.028951	2.5464	2.40964	0.02966	0.07147
0.420	0.029659	2.5193	2.38095	0.03112	0.07409
0.425	0.030376	2.4929	2.35294	0.03263	0.07677
0.430	0.031102	2.4672	2.32558	0.03419	0.07951
0.435	0.031856	2.4421	2.29885	0.03581	0.08232
0.440	0.032579	2.4175	2.27273	0.03748	0.08518
0.445	0.033331	2.3936	2.24719	0.03921	0.08812
0.450	0.034092	2.3702	2.22222	0.04101	0.09113
0.455	0.034861	2.3474	2.19780	0.04286	0.09420
0.460	0.035640	2.3251	2.17391	0.04477	0.09734
0.465	0.036427	2.3033	2.15054	0.04675	0.1005
0.470	0.037223	2.2821	2.12766	0.04880	0.1038
0.475	0.038028	2.2613	2.10526	0.05091	0.1072
0.480	0.038842	2.2409	2.08333	0.05308	0.1106
0.485	0.039665	2.2210	2.06186	0.05533	0.1141
0.490	0.040497	2.2016	2.04082	0.05765	0.1176
0.495	0.041338	2.1826	2.02020	0.06004	0.1213
0.500	0.042188	2.1640	2.00000	0.06250	0.1250

By making use of equations 2 and 3, one obtains:

$$T_e = \frac{H}{S}\int_{x_2}^{x_1} \cosh^2 \frac{x}{H/w}\, dx \tag{20}$$

Now, integrate equation 20:

$$T_e = \frac{H^2}{2wS}\left\{\sinh \frac{x_1}{H/w}\cosh \frac{x_1}{H/w} - \sinh \frac{x_2}{H/w}\cosh \frac{x_2}{H/w} + \frac{x_1 - x_2}{H/w}\right\}$$

Substitute from equations 5, 6, and 7, and simplify:

$$T_e = \frac{wS}{4z}\left\{\frac{S^2 + b^2}{S^2}\, z \coth z + \frac{a^2}{S^2}\right\} \tag{21}$$

Expand $z \coth z$ into a power series:

$$z \coth z = 1 + \frac{1}{3} z^2 - \frac{1}{45} z^4 + \ldots \tag{22}$$

Since z is always less than one-half, all terms beginning with the third can be neglected. Substituting the first 2 terms into equation 21, one has:

$$T_e = \frac{wS}{4z}\left\{1 + \frac{c^2}{S^2} + \frac{1}{3} z^2 + \frac{b^2}{3S^2} z^2\right\}$$

From equation 9, by long division, one obtains

$$\frac{c^2}{S^2} = 1 - \frac{1}{3}\frac{a^2}{c^2} z^2 + \ldots = 1 + \frac{1}{3}\left(\frac{b^2}{c^2} - 1\right) z^2 + \ldots$$

Substitute this for the second term in braces, but replace S^2 by c^2 in the last term in braces (which is small). Then:

$$T_e = {}^1/_2(wS) \cdot \frac{1}{z} + \frac{(wS)b^2}{6c^2} \cdot z \tag{23}$$

Values of $1/z$ are given in table I. In most cases it will be found that the term involving z can be neglected.

As mentioned before, the product wS is equal to the total weight of the cable, and therefore remains

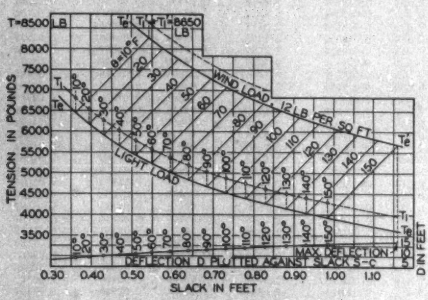

Fig. 3. Tension-temperature chart

512,000 circular mil, 1.4 inch diameter, type HH hollow copper conductor
Horizontal spacing = 475 feet
Vertical spacing = 435 feet
Maximum tension = 8,650 pounds
Minimum temperature = 10 degrees fahrenheit
Maximum load = 12 pounds per square foot—wind load

EXPLANATION

T'_1 = Upper support tension, 12 pounds per square foot wind load
T'_e = Effective tension, 12 pounds per square foot wind load
T_1 = Upper support tension, light
T_e = Effective tension, light

constant (for a given load). To establish the value of wS, one must know the values of w and S at the same temperature and same tension. Since w is generally measured in the laboratory, at zero tension and room temperature, one should, in calculating the weight of the cable, use the zero-tension room-temperature value of S, that is, the unstressed length S_0 at 60 to 70 degrees fahrenheit.

In the "Summary of Formulas," which follows, wS has been replaced by wS_0, where w denotes the weight per foot of the cable at zero tension and room temperature.

Deflection and Sag. Deflection is defined as the maximum deviation of the cable from the line of supports, measured at right angles to the line of supports.

Sag is defined as the maximum deviation of the cable from the line of supports, measured in the direction of the resultant force acting on the cable. (In case there is no wind, the sag is vertical.) A mathematical relation between the deflection D and the sag d is given in equation 28.

The equation of the line of supports is

$$y' = y_1 + \frac{b}{a}(x - x_1) \tag{24}$$

From equations 6 and 5, one obtains

$$x_1 = \frac{a}{2z} \operatorname{arc\,sinh} \frac{bz}{a \sinh z} + \frac{a}{2} \tag{25}$$

By equations 1 and 3,

$$y = \frac{T}{w} - \frac{H}{w} \tag{26}$$

and, therefore, one has

$$y_1 = \frac{T_1}{w} - \frac{H}{w} = \frac{T_1}{w} - \frac{a}{2z} \tag{27}$$

The deflection is given by

$$D = \max.\left[\frac{a}{c}(y' - y)\right] = \frac{a}{c}\left\{\max.\,[y' - y]\right\} = \frac{a}{c} \cdot d \tag{28}$$

where y and y' are defined by equations 1 and 24, respectively, and d is the sag. The difference $y' - y$ is maximum when

$$x = \frac{a}{2z} \operatorname{arc\,sinh} \frac{b}{a} \tag{29}$$

Substitute equations 25, 27, and 29 into equations 1 and 24, subtract equation 1 from 24 and simplify:

$$\max.\,[y' - y] = \frac{1}{2z}\left[Sz \coth z - c + b \operatorname{arc\,sinh} \frac{bz(S - c)}{a^2 \sinh z}\right] \tag{30}$$

Now simplify equation 30 in the following manner:

Substitute for S from equation 11, for $z \coth z$ from equation 22, and for the ratio $z/\sinh z$ as follows:

$$\frac{z}{\sinh z} = 1 - {}^1/_6 z^2 + \ldots.$$

The sinh being small, replace the arc sinh by the sinh.
Drop all terms containing powers of z higher than the third.

One then has:

$$d = \max.\,[y' - y] = \frac{c}{4} \cdot z + \frac{3a^2 - 2b^2}{144c} \cdot z^3 \tag{31}$$

and:

$$D = \frac{a}{c} \cdot d = \frac{a}{4} \cdot z + \frac{3a^2 - 2b^2}{144c^2} \cdot a \cdot z^3 \tag{32}$$

Values of z^3 are given in table I.

For short spans the second term in equations 31 and 32 may be dropped (see "Example 1," which follows). Then:

$$\text{Sag} = d = {}^1/_4\, c \cdot z\,, \qquad \text{Deflection} = D = {}^1/_4\, a \cdot z$$

For long spans with a relatively small difference in elevation between supports, b^2 is negligible compared to a^2 (see "Example 2," which follows) and therefore:

$$d = {}^1/_4\, c \cdot z + {}^9/_{16}\, c \cdot z^2, \qquad D = {}^1/_4\, a \cdot z + {}^9/_{16}\, a \cdot z^2 \tag{33}$$

Correction for Wind Load and Ice Load

If the cable is covered with ice, the force of gravity per unit length of the cable is $w + v$, where w is the weight of the conductor (in pounds per foot) and v is the weight of ice (in pounds per foot of cable).

If the cable is acted upon by a horizontal wind exerting a force h per unit length of the cable (at right angles to the no-wind plane of the cable), the cable will hang in an oblique plane determined by the line of supports and the direction of the resultant w' of the gravity force $w + v$ and the wind force h.

The formulas developed above are still applicable in case of the wind load and ice load, provided one replaces:

w by w', where $w' = \sqrt{(w + v)^2 + h^2}$
a and b by a' and b', respectively, where:
b' is the spacing between supports in the oblique plane, measured in the direction of the force w';
a' is the spacing between supports in the oblique plane, measured at right angles to the direction of w'.

It is easily seen from figure 2 that:

$$b' = b \cos \phi = b \frac{w + v}{w'} \tag{34}$$

$$a' = \sqrt{c^2 - b'^2} \tag{35}$$

Graphical Solution

By assigning arbitrary values to the parameter z, mutually corresponding values of $S - c$, T_e, and D can be calculated. The effective tension T_e can then be plotted against the slack $S - c$. Such a length-tension chart is shown in figure 3. However, before one can make use of the chart, the elastic properties of the cable must be taken into consideration.

Hooke's Law. When the temperature is constant, the effective tension and the length of the cable are related by Hooke's law. In differential notation, one has

$$\frac{\partial T_e}{\partial S} = \frac{AE}{S_0} \qquad (\theta = \text{constant}) \tag{36}$$

The unstressed length S_0 is, strictly speaking, a function of temperature. However, since the quantity AE is only approximately constant, the temperature variation of S_0 may be neglected entirely. The symbol S_0 may be taken to denote unstressed length at room temperature.

Change of Load. Assume that one is given a point $(S - c,\ T_e')$ on the wind load curve in figure 3, and that subsequently the wind load is removed. Here one has a change at constant temperature, and therefore equation 36 applies. Draw a straight line

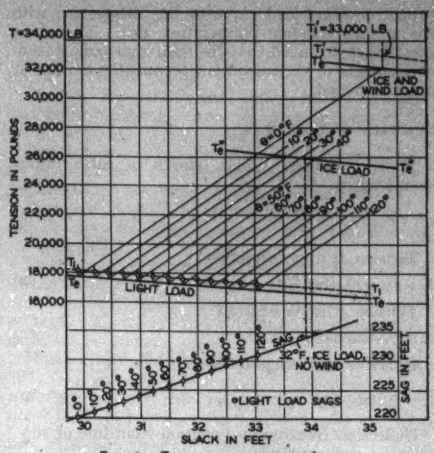

Fig. 4. Tension-temperature chart

Stranded aluminum conductor with steel core
Horizontal spacing = 4,279 feet
Vertical spacing = 185.5 feet
Maximum tension = 33,000 pounds
Minimum temperature = zero degrees fahrenheit
Maximum load = 12 pounds per square foot wind and $^1/_2$ inch ice

EXPLANATION
T_1 = Upper support tension
T_e = Effective tension
Unprimed = light load
Primed = 12 pounds per square foot wind and $^1/_2$ inch ice load
Double primed = $^1/_2$ inch ice load

through $(S - c,\ T_e')$ with slope AE/S_0. The intersection of this line with the light load curve locates the new point.

Change of Temperature. Now, assume that one is given a point $(S - c,\ T_e)$ on the light load curve in figure 3 and that the temperature rises by $\Delta\theta$ degrees fahrenheit. Since the length S, tension T_e, and temperature θ all vary simultaneously, one can write:

$$dS = \frac{\partial S}{\partial \theta}\, d\theta + \frac{\partial S}{\partial T_e}\, dT_e \tag{37}$$

Obviously, one may analyze dS into 2 components which can be accounted for one at a time. First, let S vary with θ only. Then, one is following a constant-tension path, that is, a horizontal line. This shifts the point to the position

$$[(S + S\alpha\Delta\theta) - c,\ T_e],$$

where α is the thermal coefficient of expansion. Now, let θ remain constant and let S vary with T_e only. This time one is following a constant-temperature line, to its intersection with the light load curve (since the point *must* be on the light load curve).

Construction of Chart. In practice, a number of constant-temperature lines are drawn, as in figure 3 or figure 4. Changes in length and tension due to varying temperature are found by following the

proper constant-load curve to the intersection with the proper constant-temperature line. The chart must be so arranged that the minimum temperature corresponds to the maximum permissible tension at maximum load.

Summary of Formulas

Basic Formulas. Slack (length of cable minus span length):

$$s - c = \frac{a^2}{c} f(z) + \frac{a^2 b^2}{72c^3} z^4 \tag{A}$$

Tension at upper support:

$$T_1 = (^1/_2 wS_0) \coth z + {}^1/_2 wb \tag{B}$$

Tension at lower support:

$$T_2 = (^1/_2 wS_0) \coth z - {}^1/_2 wb \tag{C}$$

Effective or average tension:

$$T_e = (^1/_2 wS_0) \cdot \frac{1}{z} + (^1/_2 wS_0) \frac{b^2}{3c^2} \cdot z \tag{D}$$

Deflection (maximum deviation from line of supports, at right angles):

$$D = {}^1/_4 a \cdot z + \frac{3a^2 - 2b^2}{144c^2} az^3 \tag{E}$$

Sag (maximum deviation from line of supports, in direction of force):

$$d = {}^1/_4 c \cdot z + \frac{3a^2 - 2b^2}{144c} \cdot z^3 \tag{F}$$

Slope of constant-temperature lines:

$$\frac{\partial T_e}{\partial S} = \frac{AE}{S_0} \tag{G}$$

To Correct for Wind and Ice. Replace a, b, and w by a', b', and w', where:

$$w' = \sqrt{(w + v)^2 + h^2} \tag{H}$$

$$b' = b \cdot \frac{w + v}{w'} \tag{I}$$

$$a' = \sqrt{c^2 - b'^2} \tag{J}$$

Calculations

The practical application of the equations given under "Summary of Formulas" will now be explained.

Initial Value of Parameter. The initial value of z is that value for which T_1' is equal or nearly equal to the maximum permissible tension ("working tension").

To establish the initial value of z, use the relation

$$\coth z = \frac{\Delta}{1 + \frac{1}{6}\left(\frac{a'}{c}\right)^2 \frac{1}{\Delta^2}} \tag{38}$$

where

$$\Delta = \frac{\text{max. } [T_1'] - {}^1/_2 w'b'}{{}^1/_2 w'c} \tag{39}$$

For nearly horizontal spans, the ratio a'/c may be taken equal to unity (see "Example 2," which follows).

For short spans (see "Example 1"), equation 38 can be replaced by:

$$z = \frac{1}{\Delta} = \frac{{}^1/_2 w' \cdot c}{\text{max. } [T_1'] - {}^1/_2 w'b'} \tag{40}$$

Unstressed Length. It will be noted that formulas B, C, D, and G involve the quantity S_0, which is the unstressed length at room temperature.

If the tension of the cable is low, the maximum-load minimum-temperature value of S, or that value of S which corresponds to the initial z, can be used in place of S_0 (see "Example 1").

In case of high tension, one can easily estimate the value of S_0 by applying a correction to the maximum-load minimum-temperature value of S, as illustrated in "Example 2."

Tables. The equations in "Summary of Formulas" involve the following functions of z:

$$(z) = \frac{1}{6}\left(z^2 + \frac{z^4}{20}\right),$$

$\coth z$,

$\frac{1}{z}$, z^4, and z^3

These functions are given in table I, for values of z from 0 to 0.5.

Illustrative Examples. The details of the calculations are illustrated in 2 practical examples (see below).

1. Example 1 deals with a proposed span at the Boulder Canyon power plant, and illustrates the calculations for a short span of considerable inclination.

2. Example 2 is based upon published data of an actually existing river crossing, and illustrates the calculations for a long span with a relatively small angle of inclination.

Table II—Sample Calculations, Example 1

Proposed Span at Boulder Canyon Power Plant

Parameter z	Slack $S - c$: $\frac{a^2}{c} f(z) = 460\, f(z)$	Upper-Support Tension: $^1/_2 w' S_0 \coth z = 680 \coth z$	Upper-Support Tension: $^1/_2 w' S_0 \coth z + {}^1/_2 b'w' =$ item + 340	Effective Tension: $^1/_2 w' S_0 \cdot \frac{1}{z} = 680 \cdot \frac{1}{z}$	Deflection: $^1/_4 a' \cdot z = 130z$
Wind Load					
0.08	0.512	8,520	8,860	8,500	11.1
0.09	0.648	7,580	7,920	7,560	12.5
0.10	0.800	6,820	7,160	6,800	13.9
0.12	1.153	5,690	6,030	5,670	16.7
Light Load					
Parameter z	$\frac{a^2}{c} f(z) = 350\, f(z)$	$^1/_2 w S_0 \coth z = 505 \coth z$	$^1/_2 w S_0 \coth z + {}^1/_2 bw =$ item + 340	$^1/_2 w S_0 \cdot \frac{1}{z} = 505 \cdot \frac{1}{z}$	$^1/_4 a' \cdot z = 119z$
0.07	0.286	7,270	7,610	7,260	8.3
0.08	0.373	6,380	6,700	6,350	9.5
0.09	0.473	5,660	6,000	5,640	10.7
0.10	0.584	5,100	5,440	5,080	11.9
0.12	0.841	4,250	4,590	4,230	14.3
0.14	1.144	3,650	3,990	3,630	16.7

Example 1—Proposed Span at Boulder Canyon Power Plant

Given the following:

512,000 circular mil, 1.4 inch diameter, type *HH* hollow copper conductor
E = 16,000,000 pounds per square inch
α = 0.0000096 foot per foot per degree fahrenheit
Maximum tension = 8,650 pounds
w = 1.577 pounds per foot
a = 475 feet
b = 435 feet
Maximum wind load = 12 pounds per square foot
Minimum temperature 10 degrees fahrenheit, maximum 150 degrees fahrenheit
No ice or sleet.

Tension to be measured at upper support with dynamometer.

Wind Load Curve.

h = 12 pounds per square foot times the projected area

$$h = 12 \times 1 \times \frac{1.4}{12} = 1.40 \text{ pounds per foot}$$

$$w' = \sqrt{w^2 + h^2} = 2.11 \text{ pounds per foot}$$

$$\frac{w + v}{w'} = 0.748$$

$$c^2 = a^2 + b^2 = 414{,}900$$

c = 644.1 feet
b' = 325.3 feet (by equation *I*)
b'^2 = 105,800
a'^2 = 309,100 (by equation *J*)
a' = 556 feet

To find the initial value of z:

$$\tfrac{1}{2}w'b' = 340, \qquad \tfrac{1}{2}w'c = 680$$

$$z = \frac{680}{8{,}650 - 340} = 0.082$$

Let z be 0.080, then 0.090, etc. (see table II).

To calculate $\frac{1}{2}w'S_0$: from table II, when z = 0.080,

$S - c = 0.5$
$S = 644.1 + 0.5 = 644.6$ feet

In this case, it will be sufficiently accurate to let

S_0 = 644.6 feet. Then, $\frac{1}{2}w'S_0$ = 680 pounds

Remaining calculations are in table II.

Light-Load Curve. To calculate $\frac{1}{2}wS_0$:

$$\tfrac{1}{2}wS_0 = \tfrac{1}{2} \times 1.577 \times 644.6 = 508 \text{ pounds}$$

Remaining calculations are in table II.

Constant-Temperature Curves. To calculate horizontal interval of the constant-temperature lines for $\Delta\theta$ = 10 degrees fahrenheit:

$$\Delta S = \frac{\partial S}{\partial \theta}\Delta\theta = S\alpha \times 10$$

$$\Delta S = 644.6 \times 0.0000096 \times 10 = 0.062 \text{ foot,}$$

or, very nearly, $\Delta S = \frac{6^1/_4}{100}$ foot

To calculate slope of constant-temperature lines:

A = 512,000 circular mils = 0.402 square inch
AE = 0.402 × 16,000,000 = 6,430,000 pounds

$$\text{Slope} = \frac{\partial T_s}{\partial S} = \frac{AE}{S_0} = \frac{6{,}430{,}000}{644.6} = 9{,}980 \text{ pounds per foot,}$$

or, very nearly, $\text{slope} = \frac{1{,}000 \text{ pounds}}{0.1 \text{ foot}}$

Construction of Chart. From the data in table II, the tension at the upper support at light load T_1 and at wind load T_1' and the effective tension at light load T_s and at wind load T_s' are plotted against the slack $S - c$.

The 10 degree fahrenheit line is drawn through that point on the T_s' curve which is directly under the 8,650 pounds point on the T_1' curve.

The deflection D is also plotted against the slack. As in most cases, the deflection curves for light load and wind load are found to coincide (see figure 3).

Stringing Chart. The points marked by circles on the T_1 curve in figure 3 comprise the data for the stringing chart.

In this case it is assumed that the cable will be strung at no wind (or, during a relapse of the wind), and that the dynamometer will be used at the upper support. Therefore, the stringing chart should be made up as follows:

Horizontally, plot temperature in degrees fahrenheit.

Vertically, plot the upper-support tension T_1 (light load) in pounds, and, if desired, also the light load deflection D or sag $d = \frac{a}{c}D$.

(Note that the horizontal scale is the temperature of the cable, not air temperature.)

Example 2—Mississippi River Crossing

(Compare with "Mississippi River Crossing of Crystal City Transmission Line," by H. W. Eales and E. Ettlinger, A.I.E.E. Transactions, volume 44, 1925, pages 378–97.)

AE = 11,860,000 pounds
α = 0.00000662 foot per foot per degree fahrenheit
Maximum tension = 33,000 pounds
w = 1.684 pounds per foot
a = 4,279 feet
b = 185.5 feet
Maximum load = 12 pounds per square foot wind and $\frac{1}{2}$ inch ice.
Minimum temperature 0 degrees fahrenheit, maximum 120 degrees fahrenheit.

Maximum Load Curve. (Compare with "Example 1.")

$w + v$ = 2.623 pounds per foot
w' = 3.322 pounds per foot
$\frac{w + v}{w'} = \frac{2.623}{3.322} = 0.7896$

c = 4,283 feet
b' = 146.5 feet
a' = 4,280 feet

To find initial value of z:

$$\tfrac{1}{2}w'b' = 240, \qquad \tfrac{1}{2}w'c = 7{,}114$$

$$\Delta = \frac{33{,}000 - 240}{7{,}114} = 4.61, \qquad \Delta^2 = 21.25$$

$$\coth z = \frac{\Delta}{1 + \frac{1}{6}\frac{1}{\Delta^2}} = 4.57$$

From table I, the initial value of z = 0.220.

To calculate $\frac{1}{2}w'S_0$: from table III, when z = 0.220,

$S - c = 34.6$
$S = 4{,}283 + 35 = 4{,}318$ feet

This length corresponds to about 0 degree fahrenheit and 33,000 pounds tension. If the tension is released, the cable will shrink by some 12 feet (since

AE = 11,860,000 pounds). If the temperature is raised to 60 degrees fahrenheit, it will gain some 2 feet (see below). One may take:

S_0 = 4,310 feet, $\quad {}^1/_2 w' S_0$ = 7,160 pounds

Remaining calculations are in table III.

Light Load Curve. To calculate ${}^1/_2 w S_0$:

${}^1/_2 w S_0 = {}^1/_2 \times 1.684 \times 4{,}310 = 3{,}630$ pounds

Remaining calculations are in table III.

Constant-Temperature Curves. To calculate horizontal interval of the constant-temperature lines for $\Delta\theta$ = 10 degrees fahrenheit:

$$\Delta S = \frac{\partial S}{\partial \theta}\,\Delta\theta = S\alpha \times 10$$

$$\Delta S = 4{,}318 \times 0.00000662 \times 10 = 0.286 \text{ foot,}$$

or, very nearly, $\Delta S = \dfrac{28.5}{100}$ foot

To calculate slope of constant-temperature lines:

$$\text{Slope} = \frac{\partial T_s}{\partial S} = \frac{AE}{S_0} = \frac{11{,}860{,}000 \text{ pounds}}{4{,}310 \text{ feet}}$$

$$\text{Slope} = 2{,}750 \text{ pounds per foot} = \frac{11{,}000 \text{ pounds}}{4 \text{ feet}}$$

Construction of Chart. See figure 4.

Appendix I—Effect of Insulators

No attention has been paid so far to the effect of insulators. However, in short dead-ended spans of high voltage lines the influence of the insulators on the mechanical performance of the cable may be appreciable. To gain a general idea of the effect of insulators, a correction will be worked out for the span considered in "Example 1." For the sake of simplicity, only the insulator at the lower support will be taken into account.

Notation. The following notation will be used in this appendix:

a, b = projections of cable span

$\bar{a}, \bar{b}$ = projections of insulator span

$\bar{S}$ = length of insulator

S_0 = unstressed length of cable

w = weight of cable per unit length

$\bar{w}$ = weight of insulator per unit length

$\bar{T}_1$ = tension at cable end of insulator

T_2 = tension at insulator end of cable

$\bar{c} = \sqrt{\bar{a}^2 + \bar{b}^2}$, $\bar{z} = \bar{a}\bar{w}/2H$

$c = \sqrt{a^2 + b^2}$, $z = aw/2H$

$g = \sqrt{(a + \bar{a})^2 + (b + \bar{b})^2} - \sqrt{a^2 + b^2}$

Data. Let $\bar{w}$ = 52 pounds per foot, $\bar{S}$ = 14.5 feet.

From "Example 1" it follows that:

$a + \bar{a}$ = 475 feet $\qquad c + g$ = 644.1 feet

$b + \bar{b}$ = 435 feet $\qquad S_0 + S$ = 644.6 feet, very nearly

Condition for Equilibrium. Obviously, for equilibrium $\bar{T}_1 = T_2$. Using equations B and C, one has:

$$\bar{w}\bar{S}\coth \bar{z} + \bar{w}\bar{b} = wS_0 \coth z - wb$$

In this particular case, it is permissible to use the approximate relations

$$\coth z = \frac{1}{z}, \quad \coth \bar{z} = \frac{1}{\bar{z}} = \frac{aw}{\bar{a}\bar{w}} \cdot \frac{1}{z}$$

Solving for z one then has:

$$z = \frac{w[\bar{a}(S_0 + \bar{S}) - (a + \bar{a})\bar{S}]}{\bar{a}[(\bar{w} - w)\bar{b} + w(b + \bar{b})]} \tag{41}$$

Calculations. As a first approximation for $\bar{b}$, one can take

$$\bar{b}_1 = \sqrt{\bar{S}^2 - \bar{a}^2} \tag{42}$$

which is sufficiently accurate to use in equation 41. As a second approximation, one has, by virtue of equation 9,

$$\bar{b}_2 = \bar{b}_1 - \frac{\bar{a}^2}{6\bar{b}_1}\bar{z}^2 \tag{43}$$

The slack can be calculated from the relation

$$S - c = \frac{a^2}{6c} \cdot z^2, \tag{44}$$

where average values of a and c may be used.

By definition of g, one has

$$g = 644.1 - \sqrt{(475 - \bar{a})^2 + (435 - \bar{b})^2},$$

or, approximately,

$$g = \frac{475}{644.1}\,\bar{a} + \frac{435}{644.1}\,\bar{b} \tag{45}$$

By assigning arbitrary values to $\bar{a}$, the following table of values is obtained:

$\bar{a}$	11.50	11.70	12.00	12.30	12.60
$\bar{b}_1$	8.83	8.56	8.14	7.68	7.17
z	0.0637	0.0789	0.1017	0.1244	0.1474
$\bar{b}_2$	8.82	8.55	8.11	7.65	7.03
g	14.43	14.39	14.31	14.21	14.09
$S - c$	0.230	0.353	0.586	0.879	1.230
T_s	7,800	6,300	4,890	4,000	3,370

Graphical Solution. To establish a better comparison between

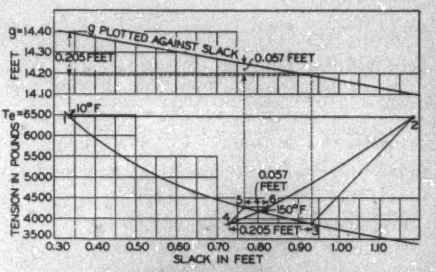

Fig. 5. Study of insulator effect

512,000 circular mil, 1.4 inch diameter, type HH conductor
Horizontal spacing = 475 feet
Vertical spacing = 435 feet
Weight of insulator = 754 pounds

the performances with and without the insulator, it will be assumed that the effective tension at no-wind and 10 degrees fahrenheit is T_s = 6,450 pounds (the same as in figure 3).

Since c in this case is a variable, one has

$$d(S - c) = dS - dc = \frac{\partial S}{\partial \theta}\,d\theta + \frac{\partial S}{\partial T_s}\,dT_s - dc$$

By definition of g,

$$c = 644.1 - g, \qquad dc = -dg,$$

and therefore:

$$d(S - c) = \frac{\partial S}{\partial \theta}\,d\theta + \frac{\partial S}{\partial T_s}\,dT_s + dg \tag{46}$$

Table III—Sample Calculations, Example 2

Mississippi River Crossing

Parameter z	Slack $S - c$	Upper-Support Tension	Effective Tension	Sag
Wind Load and Ice Load				
	$\frac{a^2}{c} f(z) = 4277 f(z)$	$\frac{1}{2} w'' S_0 \coth z = 7160 \coth z$	$\frac{1}{2} w'' S_0 \coth z + \frac{1}{2} b w'' =$ last item $+ 240$	$\frac{1}{2} w'' S_0 \cdot \frac{1}{z} \cdot \frac{1}{z} = 7160 \frac{1}{z^2}$
0.220	34.6	33,070	33,310	32,540
0.225	36.2	32,360	32,600	31,820
Light Load				
Parameter z	$\frac{a^2}{c} f(z) = 4275 f(z)$	$\frac{1}{2} w S_0 \coth z = 3630 \coth z$	$\frac{1}{2} w S_0 \coth z + \frac{1}{2} b w =$ last item $+ 160$	$\frac{1}{2} w S_0 \cdot \frac{1}{z} \cdot \frac{1}{z} = 3630 \frac{1}{z^2}$	$\frac{1}{2} c \cdot z = 1071 z$	$\frac{1}{2} w c \cdot z^2 = 892 z^2$	Sum of last 2 items
0.205	30.0	17,950	18,110	17,710	219.6	0.8	220.4
0.210	31.5	17,540	17,700	17,290	224.9	0.8	225.7
0.215	33.0	17,140	17,300	16,880	230.3	0.9	231.2
0.220	34.6	16,770	16,930	16,500	235.6	0.9	236.5
Ice Load ($w'' = w + v$)							
Parameter z	$\frac{a^2}{c} f(z) = 4276 f(z)$	$\frac{1}{2} w'' S_0 \cdot \frac{1}{z} \cdot \frac{1}{z} = 5653 \frac{1}{z^2}$	See "light load" above				
0.215	33.0	26,290	231.2				
0.220	34.6	25,690	236.5				

At 10 degrees fahrenheit, the slack and tension of the cable are given by point 1 in figure 5. Assuming the span length c constant for the time being and letting $d\theta = 140$ degrees, one follows the path 1–2–3 to the point 3 on the T_s curve. As a result, there is a change in g ($dg = -0.205$ foot) and consequently one follows the path 3–4–5 (see figure 5). Again there is a change in g ($dg = 0.057$ foot), and an infinite process results. However, the final position of the point on the T_s curve is found with sufficient accuracy by drawing a smooth line through the points 2, 6, and 4.

At 150 degrees fahrenheit, the effective tension is seen to be 4,200 pounds, as compared to 3,930 pounds in "Example 1," a difference of less than 300 pounds.

Another calculation was carried out in exactly the same manner, for a much steeper span, 516 feet long. The difference due to the lower insulator at 150 degrees fahrenheit was found to be 550 pounds.

Conclusions. The following conclusions may be drawn concerning the effect of insulators:

1. The insulator has a tendency to act as a counterweight, decreasing the range of variation of tension.
2. In compiling stringing charts, it is generally permissible to neglect the effect of insulators.

Appendix II—Profile Data

In providing for clearances and in designing towers, it is often necessary to calculate a profile of the conductor. Several formulas pertaining to the geometry of the cable will now be derived.

Point of Maximum Deviation. It has been shown that the point of maximum vertical deviation is also the point of maximum normal deviation from the line of supports.

In a horizontal span, the point of maximum deviation from the line of supports is exactly in the middle of the span. In an inclined span, the point of maximum deviation is offset from the middle-point *toward the upper support.* By equations 6, 7, and 29, the horizontal offset is:

$$\frac{a}{2z}\left\{\text{arc sinh}\,\frac{b}{a} - \text{arc sinh}\,\frac{bz}{a \sinh z}\right\}$$

By transforming and making use of equation 8, one has:

$$\text{Offset} = \frac{a}{2z}\,\text{arc sinh}\left[\frac{bz(S-c)}{a^3 \sinh z}\right]$$

or, very nearly:

$$\text{Offset} = \frac{b(S-c)}{2az} \qquad (47)$$

Point of Horizontal Tangency. If the cable has a horizontal tangent, the point of horizontal tangency is the lowest point of the cable.

In a horizontal span, the horizontal tangent occurs exactly in the middle of span. In an inclined span, the point of horizontal tangency moves *toward the lower support.*

By means of equation 47, the point of maximum deviation can be located with considerable accuracy. By equation 29, the distance from the latter point to the point of horizontal tangency can be found at once:

$$\text{Distance from point of maximum deviation} = \frac{a}{2z}\,\text{arc sinh}\,\frac{b}{a} \qquad (48)$$

Angle of Inclination. The cosine of the angle which the cable makes with the horizontal at the upper support is

$$\cos\,(\text{angle of inclination}) = \frac{H}{T_1} = \frac{aw}{2T_1} \cdot \frac{1}{z}$$

Sample Calculations

Required: clearance to water, Mississippi River crossing in "Example 2," at 32 degrees fahrenheit, ice load, no wind.

(*a*) Data:
From figure 4, at 32 degrees fahrenheit, ice load, no wind:
Sag = 234 feet
$T_s'' = 25{,}950$ pounds
$S - c = 33.9$ feet

(*b*) To establish value of z:
In this case,

$$T_s'' = \tfrac{1}{2} w'' S_0 \cdot \frac{1}{z}$$

and therefore

$$z = \frac{\tfrac{1}{2} w'' S_0}{T_s''} = \frac{\tfrac{1}{2} \times 2.623 \times 4310}{25{,}950} = 0.2178$$

(*c*) To calculate horizontal distances:
Point of maximum deviation to middle-point:

$$\frac{b(S-c)}{2az} = \frac{185.5 \times 33.9}{2 \times 4279 \times 0.2178} = 3.4 \text{ feet}$$

Point of maximum deviation to point of horizontal tangency:

$$\frac{a}{2z}\,\text{arc sinh}\,\frac{b}{a} = \frac{b}{2z}\left[1 - \frac{1}{6}\frac{b^2}{a^2}\right] = 425.7 \text{ feet}$$

Middle point to point of horizontal tangency:

425.7 − 3.4 = 422.3 feet

Point of horizontal tangency to lower support:

$x_2 = 2{,}139.5 - 422.3 = 1{,}717.2$ feet

(*d*) To calculate elevation of lower support above point of horizontal tangency:

$$y_2 = \frac{a}{2z}\left(\cosh\frac{x_2}{a/2z} - 1\right) = \frac{a}{2z} \cdot \frac{1}{2}\left(\frac{x_2}{a/2z}\right)^2 = 150 \text{ feet}$$

(e) Conclusion: at 32 degrees fahrenheit, ice load, the lowest point of the cable is 150 feet below the lower support.

According to H. W. Eales and E. Ettinger (page 396 of "Mississippi River Crossing of Crystal City Transmission Line," A.I.E.E. TRANSACTIONS, volume 44, 1925) this value should be 151 feet.

Steady State Solution of Saturated Circuits

Methods of steady state power calculation developed specifically for: (1) systems having more machines than can be handled conveniently by existing methods; and (2) systems consisting of a line with magnetically saturated synchronous machines at both ends are outlined in this paper. Two general methods are given: (1) that involving the use of equivalent reactance or impedance, and (2) that involving the superposition of current diagrams. Methods of determining the equivalent reactance and impedance of any unknown system from measurements at the terminals of that system, whether magnetically saturated or not, also are given. When a complete solution is desired, superposition of current diagrams of saturated circuits is shown to be better than the method involving the use of either equivalent reactance or impedance.

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THE METHODS of steady state power calculation here outlined are the outgrowth of 2 specific problems. One problem was to find the steady state limit of a system (figure 14) having more machines than could be handled by existing methods without detrimental preliminary simplification. The other problem was to find the steady state limit of a system consisting of a transmission line with synchronous machines at both ends, accurately evaluating the effects of magnetic saturation on power and on voltage.

In steady state problems changes are assumed to take place slowly enough so that inertia forces can be neglected. Consequently any relative shift in phase position of the voltages in different parts of a system can be neglected; and if the voltage is known for all currents and power factors at any point of a system, the stability of any steady load connected to the system at that point can be calculated without knowing more about the system. The current diagram (figures 8 and 9) was adopted as the best way to show the relation between these variables. It must be remembered that if the action of voltage regulators is to be considered, a transient and not a steady state problem will result. Two methods of calculating stability from a current diagram are discussed. One involves the use of equivalent impedance, and the other involves the placing of one diagram upon another.

The solution of the first problem was accomplished by the use of equivalent impedances calculated from current diagrams, and the solution of the second problem was obtained best by the superposing of current diagrams. Although the method of superposing current diagrams to take account of saturation is given only small space here because of its simplicity, it is thought to be the best method for most problems, as it is rigorous when test data for the machines are available, and it enables a complete solution to be obtained with less effort than by the use of equivalent reactances.

EQUIVALENT REACTANCE

If the terminals of a power system are available, but nothing is known about the system behind the

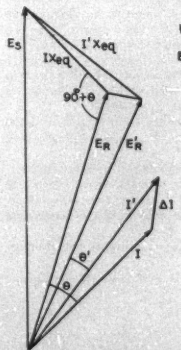

Fig. 1. Vector diagram with respect to sending end with E_S constant

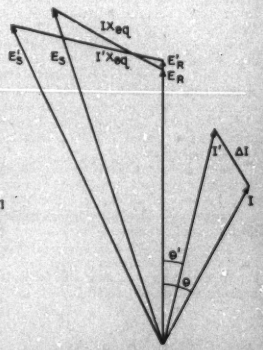

Fig. 2. Vector diagram with respect to receiving end with E_S constant

Note that ΔI does not equal the ΔI of figure 1 even though the diagram is for the same set of conditions

A paper recommended for publication by the A.I.E.E. committee on power transmission and distribution, and scheduled for discussion at the A.I.E.E. Pacific Coast convention, Seattle, Wash., August 27–30, 1935. Manuscript submitted January 2, 1935; released for publication March 4, 1935.

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terminals, it is possible to make a simple test to determine the maximum steady state load that can be connected to the terminals.

In principle the test consists of finding a combination of impedance and fictitious internal voltage that will give the same magnitude of terminal voltage as the actual system, both before and after an arbitrary increment of load. There will be an infinite number of such combinations unless (1) the impedance angle is restricted to a definite value, or (2) two increments of load are considered, that is, 3 instead of 2 conditions of system operation. If, in the first case, the increment of load is small and a 90 degree impedance angle is chosen, equivalent reactance,[1] X_{eq}, is obtained; and if, in the second case, the increments of load are small, equivalent impedance, Z_{eq}, is obtained. The equivalent reactance or impedance and the voltage behind it probably will be different for different increments of load and will not be a true representation of the system for transient calculations, since equivalent values do not always give true angular displacements. Nevertheless, they lead to valuable simplifications in steady state calculations and to an exact method of testing synchronous machines to determine their steady state stability characteristics, including effects of magnetic saturation.

Equivalent Reactance From Vector Diagrams

Equations for an equivalent reactance in terms of the initial and final circuit conditions can be obtained from the vector diagrams of figure 2. Considering the initial conditions, and expressing E_S (for definitions of all symbols see list at end of paper) in terms of the 2 opposite sides and included angle of the voltage triangle,

$$E_S^2 = (IX_{eq})^2 + E_R^2 - 2E_RIX_{eq}\cos(90^\circ + \theta)$$

Similarly, for the final conditions,

$$(E_S')^2 = (I'X_{eq})^2 + (E_R')^2 - 2E_R'I'X_{eq}\cos(90^\circ + \theta')$$

1. For all numbered references see list at end of paper.

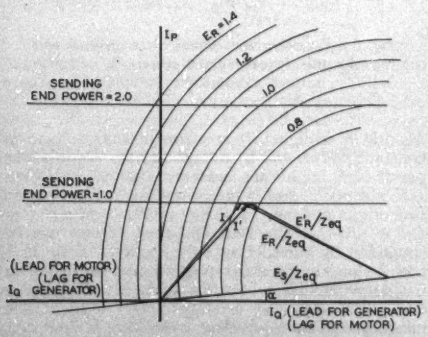


Fig. 3. Sending end current circle diagram, with loci of constant sending end power; E_S = 1.1 = constant

Equating the 2 expressions, since the magnitudes of E_S and E_S' are equal,

$$[(I'X_{eq})^2 - (IX_{eq})^2] + [(E_R')^2 - E_R^2] - [2E_R'I'X_{eq}\sin\theta' - 2E_RIX_{eq}\sin\theta] = 0$$

$$X_{eq}^2[(I')^2 - I^2] - 2X_{eq}[E_R'I'\sin\theta' - E_RI\sin\theta] + [(E_R')^2 - E_R^2] = 0 \qquad (1)$$

$$X_{eq}^2[\Delta(I^2)] - 2X_{eq}[\Delta(RVA)] + [\Delta(E_R^2)] = 0 \qquad (2)$$

$$X_{eq} = \frac{\Delta(RVA)}{\Delta(I^2)} \pm \sqrt{\left[\frac{\Delta(RVA)}{\Delta(I^2)}\right]^2 - \frac{\Delta(E_R^2)}{\Delta(I^2)}} \qquad (3)$$

If curves of reactive volt-amperes and of voltage squared be plotted against current squared for the

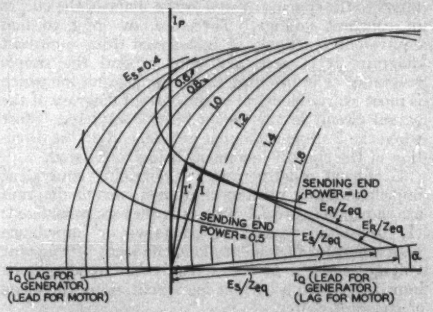


Fig. 4. Sending end current circle diagram, with loci of constant sending end power; E_R = 1.0 = constant

type of system change considered, and the slopes of these curves designated as S_{RVA} and S_{EE}, the expression becomes,

$$X_{eq} = S_{RVA} \pm \sqrt{S_{RVA}^2 - S_{EE}} \qquad (4)$$

This gives one means of determining exactly the equivalent reactance for any condition for which the proper test data are available, subject to the difficulty that at certain points of the diagram the slopes may pass through infinity, making it necessary to take a small difference between 2 large quantities.

It is interesting to note that for constant power factor and small changes equation 3 can be converted to equation E-6 of reference 1. It is interesting to note also that X_{eq} is not the same as $X_{d(eq)}$ (equivalent direct axis reactance, see reference 1) of a salient pole machine, but is the X_{eq} that would be obtained if a salient pole machine were tested as though it had a round rotor.

Another method, less direct, but easier to picture over a wide range of conditions, is the current diagram method to follow.

Equivalent Reactance or Impedance From Current Diagrams

The behavior of a circuit consisting of an impedance between 2 infinite busses can be represented by a current diagram which will consist of circles

and will appear as shown in figures 3 and 4 or figures 5 and 6, depending on whether the current is plotted with respect to the sending or receiving end voltage and on whether the sending or receiving end voltage is varied.[2] If similar diagrams be plotted for a saturated circuit such as a synchronous machine or for a network, they may not consist of circles (see figure 8), but often they are near enough to circle diagrams so that over an appreciable range they may be replaced approximately by circles.

It can be shown that any circuit can be replaced by another one, as far as steady state is concerned, if the 2 circuits have identical current diagrams over the range of operation considered, where "identical" refers to the spacing as well as the shape of the curves of constant voltage. Therefore, in order to find equivalent reactance or impedance from a current diagram, it is necessary only to find the simple reactance or impedance, the circle diagram for which is most nearly identical to the current diagram of the actual circuit in the region being considered. Just when the 2 are most similar will depend on the direction of the current increment being considered.

Graphical constructions for obtaining equivalent impedances and reactances from a current diagram are shown in figure 7. Two examples are considered: (1) to obtain equivalent reactance or impedance with a current increment along the locus of constant voltage, and (2) to obtain equivalent reactance or impedance with a current increment along the locus of constant power.

In the first example, the 3 points (such as A, B, and C in figure 7) chosen to represent the given

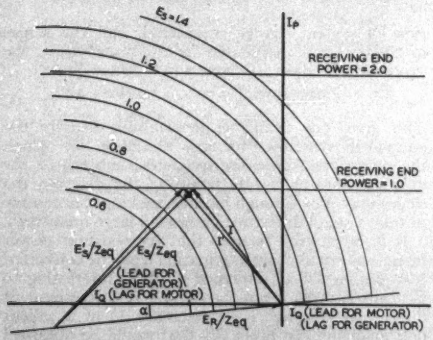


Fig. 5. Receiving end current circle diagram, with loci of constant receiving end power, $E_R = 1.0$ = constant

region are chosen along a locus of constant voltage, and a circle is drawn through them. The impedance and internal voltage that would give this same circle are then the equivalent impedance and fictitious internal voltage that represent the system. In figure 7, the center of the circle is at D, the magnitude of the impedance is such that $DO = |E_T| \div |Z|$,

Table 1—Comparison of Calculated and Test Pull-Out Data for a Laboratory Setup With Saturated Machines

Test (1 and 2) and Calculated (3 to 6) Conditions	Per Cent Margin	Per Cent Voltage at Pull-Out
1. Normal power = 9.5 kw at 130 volts		
2. P_{max} on basis of test = 11.8 kw at 111 volts	24.2	85.4
3. P_{max} on basis of A.I.E.E. synchronous reactance = 10.5 kw at 110 volts	10.5	84.6
4. P_{max} on basis of X_{sq} at normal operating point = 12.7 kw at 107 volts	33.7	82.2
5. P_{max} on basis of X_{sq} at pull-out point = 11.5 kw at 109 volts	21.0	83.8
6. P_{max} on basis of $\frac{\text{operating } X_{sq} + \text{pull-out } X_{sq}}{2}$ = 12.0 kw at 109 volts	26.3	83.8

Line 1 corresponds to point P in figure 8; line 2 to curve B; line 3 to curve E; line 4 to curve C; and line 5 to curve D.

See description under figure 8 for conditions of test. Equivalent reactances used were those corresponding to current increments along lines of constant power, and were read from the dotted curves of figure 8.

the angle of the impedance is β_2, and the magnitude of the internal voltage is such that $DA = |E_{NL}| \div |Z|$. (Compare figure 6.) If an equivalent reactance is desired instead of an equivalent impedance only 2 points should be chosen to represent the region; and of the infinite number of circles possible through these 2 points, the one with a center on the axis of quadrature current should be chosen.

In the second example, the 3 points (such as L,

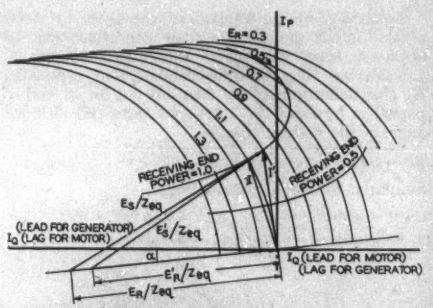


Fig. 6. Receiving end current circle diagram, with loci of constant receiving end power, $E_S = 1.1$ = constant

M, and N in figure 7) are chosen along a locus of constant power, and by a "cut and try" process the points G, H, and J are located so that $GL = JM = HN$ when G, J, and H are on a straight line through the origin and $GO \div |E_T| = JO \div |E_T''| = HO \div |E_T'|$. The "cut and try" process can be simplified by considering only 2 points, such as L and N, on the constant power curve and making GL perpendicular to the curve ACL, still keeping $GL = HN$ and $|E_T| \div GO = |E_T'| \div HO$. The magnitude of the equivalent impedance is such that $GO = |E_T| \div |Z|$, and the angle of Z is β_1. If an equivalent reactance be desired, β_1 must be 90 degrees and consequently only 2 points, such as

L and N, can be considered if a singular solution be desired.

If the choosing of different pairs or triads of points to represent a given region causes appreciable variation in the equivalent impedance obtained, as in the case of complex or saturated circuits, the points chosen should be as nearly as possible along the

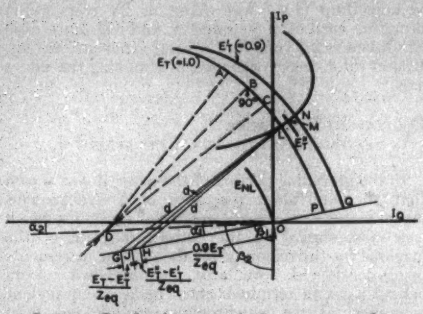


Fig. 7. Graphical means of obtaining equivalent reactance

The 3 curves of constant voltage and the 1 curve of constant power are the assumed data from which the reactance is to be obtained

increment of current expected during the changes for which the equivalent system is used to represent the actual system.

Reactances obtained by the foregoing procedure are the same as would be obtained from equation 3. The constructions were extended to include impedances because, in general, accuracy over a greater region can be obtained from an equivalent impedance than from an equivalent reactance.

Equivalent Reactance in Synchronous Machine Steady State Calculations

Considering equivalent reactance as a constant instead of a variable in circuits where synchronous machines constitute most of the system reactance is not always justifiable if an accurate answer be desired. However, in special cases the desired accuracy may be obtained with a constant equivalent reactance if it is chosen properly to represent the actual varying reactance for the system changes being considered. An illustration of this can be taken from a typical system involving saturated machines which actually was set up and tested in the laboratory of the California Institute of Technology. Comparisons of test and calculations are shown by curves B, C, D, and E in figure 8 and by table I. It may be noted that the margin between the power at the assumed normal operating condition at point P and the maximum power was 24 per cent with constant excitation. However, calculation of this margin starting with the test current, voltage, and

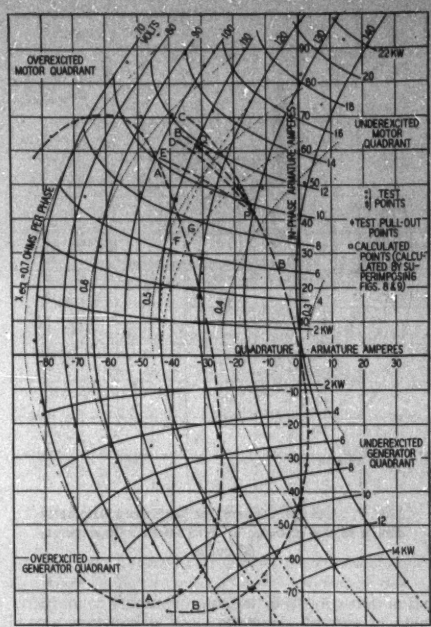


Fig. 8. Current diagram for laboratory alternator, field current = 12 amperes, 60 cycles

Alternator name plate rating: 15 kva, 110 volts, 1,200 rpm, 60 cycles

Curve A is for pulling apart of 2 identical alternators, one having a field current of 6 amperes and the other 12 amperes

Curve B is same as Curve A except that both machines have field current of 12 amperes and there is a series impedance of 0.108 + j 0.64 ohms between the 2 machines

Curves C, D, and E are calculated pull-out curves assuming constant field excitations and: (C) X_{eq} corresponding to point P; (D) X_{eq} corresponding to point Q; (E) A.I.E.E. synchronous reactance

Curve F is curve of constant voltage behind Potier reactance (assuming R + jXp = 0.025 + j 0.18 ohms per phase)

Curve G is a curve of constant direct axis component of the voltage behind Potier reactance

Curves of constant X_{eq} are for constant power current increments

power factor at point P and using different values of X_{eq} gave the variation in margin and voltage dip shown in table I. The only reasonably accurate calculation is that of line 6 where an average value of X_{eq} was used.

Values of X_{eq} in table I were read from the dotted curves in figure 8, which were calculated by the method of equation 4 using current increments along lines of constant power. The justification for assuming current increments along lines of constant power is that for both motors and generators pull-out usually occurs when power is constant during an increase in displacement, and this is true regardless of the amount of system reactance. Consequently, the saturated synchronous reactance effective at pull-

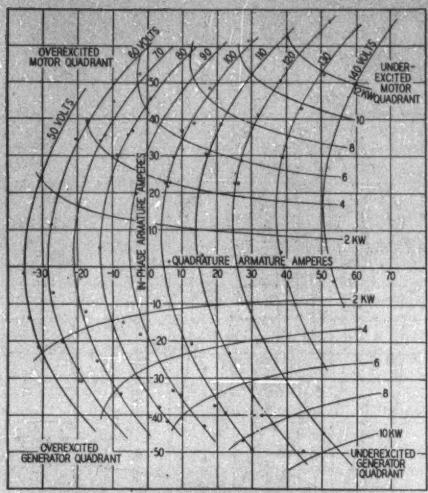


Fig. 9. Current diagram for laboratory alternator similar to that of figure 8; field current = 6 amperes; 60 cycles

out is that corresponding approximately to an increment of current along the locus of constant motor power.

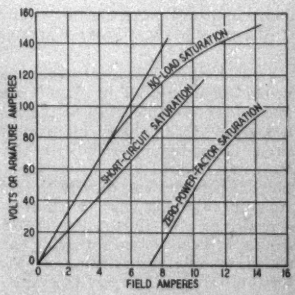
Tests of Equivalent Reactance of a Synchronous Machine. An exact test for the equivalent reactance of a synchronous machine can be made if 2 machines can be coupled together with an adjustable angle coupling and connected as in figure 11. Data needed are those necessary to plot a current diagram, which consist of reactive volt-amperes and current (or power) for different terminal voltages and field currents. By adjusting the bus voltage supplying the losses, it is possible to obtain data for any desired voltage. Output power can be obtained by subtracting losses from input power. The equivalent reactance for constant output power then can be calculated from equation 3, or by the graphical method of figure 7. If curves of constant equivalent reactance be plotted, as in figure 8, accuracy will be improved.

Several approximate methods of testing equivalent reactance have been suggested.[1] When zero power factor saturation curves are available, the method suggested by J. W. Butler in a discussion of the paper listed in reference 1 appears to be best, although calculations made in collaboration with L. A. Kilgore show that using direct axis component, rather than numerical value of voltage behind leakage reactance, gives more conservative and usually more accurate results. When only a no-load saturation curve is available, the method of reference 5 (correcting demagnetizing reactance by the ratio of slope of saturation curve to slope of air gap line) is only slightly less accurate than Butler's method, although the same qualification should be made that direct axis component of voltage behind leakage reactance be used as the voltage at which the slopes are taken. Curve F on figure 8 shows, for a salient pole laboratory machine, how a curve of voltage behind Potier reactance follows curves of constant equivalent reactance, and curve G shows the same comparison for the direct axis component of the voltage behind Potier reactance. Potier reactance voltage drop (IX_p) was taken as 25 volts at an armature current of 80 amperes, and resistance drop was taken as 3.5 volts for the same armature current. Round rotor theory was used in obtaining the direct axis.

Equivalent Reactance in System Steady State Calculations

In the preceding portion of the paper it was shown that the equivalent reactance of a synchronous machine was a reactance the circle diagram for which was most similar to the current diagram of the machine for the region or for the current increments being considered. Similarly, any unknown system behind a set of terminals must have an equivalent reactance, as the synchronous machine has been treated only as such a system. This principle can be used to solve approximately any system made up of an impedance with shunt loads at various points between its 2 extremities. The process is to represent the first shunt load plus the impedance preceding it by an equivalent impedance without a shunt load, and then repeat the process, eliminating a shunt load with each repetition, until the system to the load is represented by a single impedance. Because of the variation of equivalent impedance with direction of current increment, it is necessary to estimate carefully the direction and magnitude of the expected increment in each part of the system, and then choose each equivalent reactance corresponding to the proper current increment. One advantage of this method of eliminating shunt loads is that in order to replace a line with a complex shunt load by a reactance, only the current-voltage characteristic of the load need be known.

Fig. 10. Saturation curves of the laboratory alternator of figures 8 and 9; 60 cycles



By means of this process, an impedance with a

shunt load at the receiving end is replaced by an equivalent impedance without a shunt load. By carrying on this process step by step, any circuit without loop connections can be reduced to a simple impedance.

Test for Equivalent Reactance of a System. A means of determining the approximate magnitude of the equivalent impedance of a system is to throw on a low power factor load, such as the starting current of a synchronous machine, and measure the change of voltage produced. Assuming that the low power factor current has the same angle as the equivalent impedance of the system, the magnitude of the equivalent impedance is simply $|\Delta E| \div |\Delta I|$. For example, if in figure 7 the current increment were PQ instead of LN, then $|Z_{eq}| = (E_T' - E_T) \div GH = (E_T' - E_T) \div PQ = |\Delta E| \div |\Delta I|$. Because of the action of the regulators, the maximum change of voltage will be less than it would have been if the transient reactance had been allowed to decay to synchronous reactance. Therefore, if the regulators have appreciable effect on maintaining voltage, they should be blocked, or the measurements no longer will apply to steady state conditions.

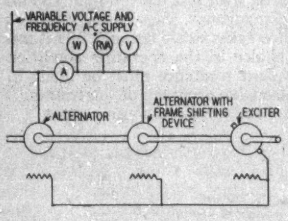


Fig. 11. Diagram of connections for test of equivalent reactance

A—ammeter
W—wattmeter
RVA—reactive volt-ampere meter
V—voltmeter

A means of accurately measuring a small dip in voltage, such as that produced by a motor starting current on an ordinary distribution system, is to use a vacuum tube for a voltage cut-off device so that an oscillograph can be made to show only the top of a voltage wave. One suitable circuit that will enable a voltage dip of 3 per cent to be shown as one centimeter change of deflection is that shown in figure 12.

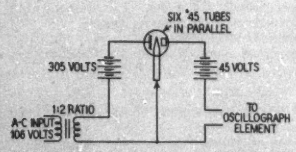


Fig. 12. Vacuum tube amplifier circuit for measuring voltage dip with oscillograph

Two tests have been made on actual systems to check the equivalent reactances as calculated by the current diagram method. The first system is that of the Southern California Edison Company. The tests were made at Colton, which is distant about 50 miles of 66 kv network from the main 220 kv substation, by switching on and off a 30,000 kva synchronous condenser and measuring the maximum ratio of $|\Delta E|$ to $|\Delta I|$. The reactance measured was 0.25 per unit; using the simplified system of figure 13, the reactance calculated was $0.32\underline{/33°}$,

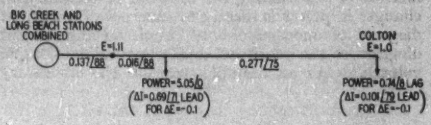


Fig. 13. Simplification of Southern California Edison Company system; 100,000-kva 66-kv base

which is as good a check as could be expected considering the complexity of the system. The series reactance, to Colton, calculated without correction for the effect of shunt load, would have been $0.42\underline{/5°}$. Thus the load actually made the system more nearly an infinite bus than the same system would have been without the load.

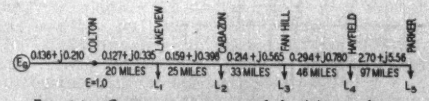


Fig. 14. Construction system of the Metropolitan Water District of Southern California at time of tests of X_{eq}; 100,000-kva 63-kv base

L_1, L_2, etc., designate loads at various points
I_1, I_2, etc., designate currents to respective loads

$L_1 = 0.00400 + j0.01030$ kva $\Delta I_1 = 0.00023 + j0.00474$ for $\Delta E = -0.1$
$L_2 = 0.00575 + j0.00925$ kva $\Delta I_2 = 0.00035 - j0.00060$ for $\Delta E = -0.1$
$L_3 = 0.01550 + j0.00345$ kva $\Delta I_3 = 0.00060 + j0.00559$ for $\Delta E = -0.1$
$L_4 = 0.00620 + j0.00160$ kva $\Delta I_4 = 0.00019 - j0.00150$ for $\Delta E = -0.1$
$L_5 = 0.00320 + j0.00350$ kva $\Delta I_5 = 0.00021 + j0.00017$ for $\Delta E = -0.1$

The second system, shown in figure 14, is that built by the Metropolitan Water District of Southern California to furnish construction power along the route of the Colorado River Aqueduct. Tests were made by switching on and off a 5,000 kva synchronous condenser at Parker. The reactance measured was $8.05\underline{/65°}$, the reactance calculated was $8.67\underline{/68°}$ and the series reactance (shunts neglected) was $8.00\underline{/81°}$.

It might be noted that both tests give lower values of reactance than do the calculations, as expected, because the effect of the regulators is included in the tests but not in the calculations; also it can be noted that the effect of regulators and machine saturation is greater for the first system than for the second, as expected, because of the smaller proportion of line reactance.

Current Diagram Method of Steady State Power Calculations

Previous sections of the paper have dealt with equivalent reactance because it is a customary and

simple procedure to represent a machine by reactance. However, steady state problems often can be solved more easily and more completely by the use of current diagrams than by the use of reactances when the effect of saturation is appreciable and is to be evaluated accurately. The general method of determining the behavior of current with changes in power is merely to superpose the current diagram of one end of any circuit on the current diagram of the other end and select points of equal voltage.[6,7] As an example, suppose the laboratory

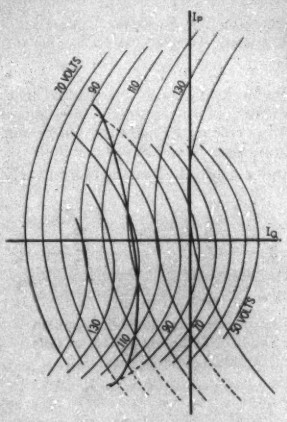


Fig. 15. Simultaneous solution of the 2 current diagrams of figures 8 and 9

alternator, for which the current diagram with a field current of 12 amperes is shown in figure 8, is connected directly to a duplicate machine with a field current of 6 amperes, the current diagram for 6 amperes being shown in figure 9. To find the behavior as the angular displacement is increased, it is necessary only to rotate the motor current diagram 180 degrees about the origin (i. e., plot it as in figure 4) and superpose it on the other diagram. The points represented by the intersection of lines of equal voltage, as shown in figure 15, then give the behavior of the current and voltage as functions of power output.

In essence, this process of superposing diagrams and selecting points of equal voltage is similar to the method of plotting curves and finding their intersection that is sometimes used to solve simultaneous equations. In other words, a current diagram is a plot of an equation between vector current and scalar voltage of the terminals of a system. Pull-out occurs where the current locus becomes parallel to the lines of constant power. Comparison between a curve calculated in this manner and an actual test curve is shown in figure 8, where the calculated points are shown by squares and the test curve is the dashed curve A. The test curves were checked 3 different ways: (1) by coupling the motor shaft to the generator shaft and varying load by means of a frame shifting device as was done for the circle and dot test points in figure 8; (2) by loading with a d-c generator feeding back to a d-c bus as was done for the inverted triangle test points in figure 8; and (3) by loading with a d-c generator supplying resistance load as was done for the 4 triangular test points in figure 8.

If series reactance or shunt load had been placed between the 2 machines, it would have been necessary to correct the diagram of one or the other machine to take account of the intermediate system so that the 2 final diagrams to be superposed would be those of the 2 ends of the system with respect to voltage at the point of division.

The outstanding feature of a current diagram solution made as just outlined is that saturation is taken into account completely and accurately; any method of steady state calculation using equivalent reactance must make use of a step-by-step solution, in order to be exact, because equivalent reactance is not constant.

Approximations assuming constant equivalent reactance are compared with test data in figure 8 and table I. These comparisons show that, although equivalent reactance takes exact account of saturation, a judicious choice of the operating condition determining equivalent reactance must be made in order to assure reasonable accuracy of the results.

Symbols

I = current
I_P = power component of current
I_Q = quadrature component of current
E_S = sending end voltage
E_R = receiving end voltage
E_T = terminal voltage
E_G = generated or internal voltage of a generator
E_M = generated or internal voltage of a motor
Z = impedance $= r + jx$
Z_{eq} = equivalent impedance (see text for definition)
X_{eq} = equivalent reactance (see text for definition)
$X_{d(eq)}$ = direct axis equivalent reactance
β = impedance angle $= \tan^{-1}\frac{x}{r}$
α = $90° - \beta$
θ = power factor angle
δ = displacement angle between E_S and E_R
RVA = reactive volt-amperes
$|Z|$, $|E|$, etc., denote magnitude of Z, E, etc. This symbol is used where the meaning is not clear from the context
I', E', etc., denote conditions after a change
Δ denotes an increment

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Report of the Board of Directors

The board of directors of the American Institute of Electrical Engineers presents herewith to the membership its fifty-first annual report, for the fiscal year ending April 30, 1935. A general balance sheet showing the condition of the Institute's finances on April 30, 1935, together with other detailed financial statements, is included herein. This report contains a brief summary of the principal activities of the Institute during the year, more detailed information having been published from month to month in ELECTRICAL ENGINEERING.

Celebration of Fiftieth Anniversary of the Institute

A fiftieth anniversary meeting was held on Monday morning, June 25, 1934, during the annual summer convention at Hot Springs, Va., immediately after the annual business meeting of the Institute. This was the climax of the celebration of the fiftieth anniversary of the founding of the Institute, in 1884, which had included the publication of the anniversary (May 1934) issue of Electrical Engineering, and the holding of various anniversary meetings by the Sections and Branches. The 2 anniversary addresses were delivered by Dr. W. E. Wickenden, president, Case School of Applied Science, and Dr. William McClellan, past-president of the Institute.

Board of Directors' Meetings

During the year, the board of directors held 5 meetings, 4 in New York City, and one at Hot Springs, Va. The executive committee meetings in December and March were held in place of regular meetings of the board. Information regarding many of the more important activities of the Institute which have been under consideration by the board of directors and the committees is published each month in the section of Electrical Engineering devoted to "News of Institute and Related Activities."

National Conventions

Three national conventions were held during the year, and a brief report on each follows.

Summer Convention. The fiftieth summer convention was held at Hot Springs, Va., June 25–29, 1934. Thirty papers were presented during the 7 technical sessions. Other parts of the convention were the annual business meeting of the Institute, fiftieth anniversary meeting, conference of officers, delegates, and members, golf and tennis tournaments, president's reception and dance, banquets, and ladies events. The Lamme Medal for 1933 was presented to Dr. Lewis B. Stillwell, past-president of the Institute. The registration was 351.

Annual Meeting. The annual business meeting of the Institute was held on Monday morning June 25, as part of the opening session of the summer convention. The annual report of the board of directors for the fiscal year ending April 30, 1934, was presented in abstract, and the committee of tellers reported upon the election of officers for the administrative year beginning August 1, 1934. President-elect Johnson responded with a brief address.

Pacific Coast Convention. The twenty-second Pacific Coast convention of the Institute was held in Salt Lake City, Utah, September 3–7, 1934. The registration was 232, and the attendance at the technical sessions averaged more than 100. The technical program included 25 papers at 5 sessions, and, in addition, 12 student papers at 2 regular sessions held for their presentation and discussion. Especially attractive entertainment events and trips, as well as the excellent technical program, kept enthusiasm high throughout the convention.

Winter Convention. The twenty-third winter convention, held in New York City, January 22–25, 1935, was opened by a brief general session including an address of welcome by C. R. Jones, chairman of the winter convention committee, an address by President Johnson entitled "The A.I.E.E. as an Educational Institution," read by Vice President W. H. Timbie, and a brief announcement regarding the technical sessions by R. N. Conwell, chairman of the technical program committee. During the 12 sessions held on the first 3 days, 53 papers were presented. At an evening session, the Edison Medal was presented to Dr. Willis R. Whitney, the John Fritz Medal, awarded to the late Frank J. Sprague only a few days before his death, was presented to his son Robert C. Sprague, and A. L. Powell, president of the Illuminating Engineering Society, gave a demonstration lecture on "Artificial Light—The Engineers' Greatest Gift to Mankind." Numerous inspection trips aroused an unusual amount of interest. The registration was 1,114.

District Meetings

Two District meetings were held during the year, and a brief report on each follows.

North Eastern District Meeting. The tenth annual North Eastern District meeting was held in Worcester, Mass., May 16–18, 1934, with a registration of 337, including more than 100 Enrolled Students, 4 sessions at which 13 technical papers were presented, a student session including 7 papers, a fiftieth anniversary address by Past President Charles F. Scott, an address on "An Insight Into the Workings of the Institute," by Vice President J. Allen Johnson, an illustrated lecture on high voltage

by Dr. Robert J. Van De Graff, inspection trips, and entertainment events.

South West District Meeting. The fifth South West District meeting was held in Oklahoma City, Okla., April 24–26, 1935. The total registration was 571, including about 160 students. The program included 12 papers, a demonstration lecture on d-c power transmission, a symposium on engineering education, 12 additional papers by students, inspection trips, and entertainment events.

Sections

Nearly all Sections carried on a normal amount of activity during the year, and efforts to develop plans to maintain and increase the interest of their members resulted in the adoption by a few of them of methods which have been even more successful than anticipated.

The Portland Section organized 3 technical committees: communication, industrial power application, and transmission and distribution, which have held 6, 9, and 6 meetings, respectively, with an average attendance of about 16.

Since early in 1934, the San Francisco Section has held special technical meetings, devoted mainly to informal discussions, between the regular Section meetings. Thus, it has been practicable to plan regular meetings with well balanced programs that have been attractive to a large number of members. A comprehensive report upon the new plan and its place in the activities of the Section was published on page 454 of the April 1935 issue of Electrical Engineering.

The Boston and Lynn Sections held competitions among their members in the writing of papers, choosing 3 papers from each for presentation at a joint meeting. Three prizes based upon the contents of the papers as well as upon the presentations were awarded.

The Toledo Section has been holding "forum meetings" between the regular technical meetings and having addresses by outstanding speakers. It also has had a brief talk on fundamental electrical theory, by a member of the Section, during the first part of each regular meeting.

The New York and Chicago Sections continued their technical group activities with interest well maintained.

The Pittsfield and Schenectady Sections held their annual competition among their younger members.

In co-operation with the national membership committee, the Sections have induced many former members to become reinstated—697 since August 1, 1934.

Early in March, the Sections of the Institute were urged by the committee on student selection and guidance of the Engineers' Council for Professional Development to co-operate with the sections of other engineering societies and with local engineering organizations in the establishment of joint committees which should offer sympathetic advice to boys thinking of entering engineering, and to high school principals, vocational counselors, and others interested in assisting boys in the choice of their careers.

Student Activities

Practically all of the Branches carried on a normal amount of activity, and many had considerable numbers of student papers presented at their meetings.

During the fiscal year, new Branches were organized at Brown University, Providence, R. I., Johns Hopkins University, Baltimore, Md., Tufts College, Medford, Mass., and Union College, Schenectady, N. Y., bringing the total number of Branches to 117.

Students made important contributions to the success of the Pacific Coast convention and the District meetings held in Worcester, Mass., and Oklahoma City, Okla., by their enthusiastic participation in the technical programs and in other events. They conducted 1 session with 7 papers in Worcester, 2 sessions with 12 papers at the Pacific Coast convention, and 2 sessions with 12 papers in Oklahoma City.

About 50 per cent of the Enrolled Students whose terms of enrollment expired on April 30, 1935, applied for admissions as Associates.

During the past fiscal year, 1,983 Students were enrolled, bringing the total number enrolled on April 30 to 3,806, the largest number on that date since 1931 (3,813).

The Sections and Branches have in many cases co-operated closely, and several developments in Section activities described briefly in the paragraphs above under the heading "Sections" are of particular interest to younger members of the Institute.

Section and Branch Statistics

Data on the Sections and Branches are given in table I.

Table I—Section and Branch Statistics

	For Fiscal Year Ending			
	April 30, 1929	April 30, 1931	April 30, 1933	April 30, 1935
Sections				
Number of Sections	54	59	60	61
Number of Section meetings held	460	491	498	521
Total attendance	73,254	108,523	73,806	73,381
Branches				
Number of Branches	100	109	111	117
Number of Branch meetings held	940	1,137	1,026	986
Total attendance	47,408	51,807	59,439	36,629

Technical Program Committee

The principal work of the technical program committee throughout the year has consisted of providing technical papers for the national conventions and the reviewing of papers to determine their suitability for presentation and publication. In addition, the committee has supplied some papers for the District meetings and it has assisted the committee on award of Institute prizes by grading each paper when initially reviewed.

In the arranging of technical programs the committee has endeavored to meet the technical requirements of the membership in so far as possible. Guided by an analysis of the character of material previously presented, 2 symposiums on electronics were held at the last winter convention, as well as a session on illumination. Sessions devoted entirely to the subject of electronics have not been held heretofore and the subject of illumination had not been on a convention program for a number of years.

The committee has raised the standard of papers as a result of grading them when initially reviewed for acceptance. This practice, together with the need to keep within the annual budget during these times, has led the reviewers to be more selective in their acceptance of papers as evidenced by a greater number of rejections. In addition, a number of papers were returned to the authors for revision and condensation to eliminate nonessential material. The average number of pages per paper has been reduced. In this way, the committee has continued to keep within the annual budget of 750 pages for the 3 national conventions, and permit the greatest number of authors to express their views. Progress has also been made toward reducing the time required for review, authors' revisions, and the handling of papers.

The foregoing results can best be seen from a comparison of papers for the past year with those of 5 years ago for the year 1929–30, as presented in table II. The average page length per paper has been reduced from 8.1 to 6.1. During the past year 28 per cent of the papers considered were not accepted, as compared with only 11 per cent 5 years ago. For the summer convention, the average number of days per paper required for review, revision, and handling has been reduced from 61.9 to 30.6. For the winter convention, this time has been reduced from 67 days to 49.2 days, while the Pacific Coast convention and the District meetings show an increase in the time required for review. However, the papers for the winter and summer conventions comprise more than half of the total number of papers for the year. The time required for review, based upon data taken over the entire year, remained about the same due to the long period of time required for authors' revisions of some District meeting papers, several of which were not published until after the meetings.

The committee has co-operated with the publication committee in obtaining papers further in advance of conventions and scheduling them for publication in intervals so that the sizes of the issues of ELECTRICAL ENGINEERING could be kept uniform. A production control board has been installed for this purpose. On this board each paper is posted from the time first received and it is possible to follow the paper through the various steps of review and revision until published. The board is very useful in indicating in which steps the material is not moving smoothly, and it is also helpful in indicating for a period of several months in advance whether or not there will be sufficient material for the succeeding issues.

The committee also has continued its policy of reviewing the discussions and a number of them have been returned to discussers for revision or cancellation. Broader discussion of some papers has been obtained by their re-presentation on later programs in other sections of the country. Thus the material for this department of publication has been kept on a high standard.

The committee has also revised and approved the "Definitions of Scopes of Technical Committees." These definitions, based upon agreements as to the division of work among the technical committees, will bring about a more harmonious and efficient functioning of committee work, and they will be particularly helpful to the incoming chairmen.

Acknowledgment is extended to the members of the committee, the technical committees, reviewers, and members of the headquarters staff for their co-operation, which has brought about the smooth functioning of committee work.

Table II—Comparison of Papers for Past Year With Those for the Year 1929–30

Based Upon Papers Reviewed by the Technical Program Committee

April 30, 1929 to April 30, 1930	No. Papers	Total No. Pages	Avg. Page Length Per Paper	Avg. No. Days Req. for Review, Revision, and Handling[1]	Avg. No. Days Req. for Publication in Pamphlet Copies for Use at Meetings
National Conventions					
Swampscott, June 24–28	144	344	7¾	61.9	40.0
Santa Monica, Sept. 3–6	19	143	7½	27.7	28.2
New York, Jan. 27–31	50	433	8½	67.0	39.2
District Meetings					
Dallas, May 7–9	13	79	6	26.4	22.4
Chicago, Dec. 2–4	18	169	9¼	38.7	37.7
Published in JOURNAL only	6	54		198.2	148.0
Yearly averages	132	1222	8.2	58.4	40.8
Withdrawn and rejected (11 per cent)					

April 30, 1934 to April 30, 1935	No. Papers	Total No. Pages	Avg. Page Length Per Paper	Avg. No. Days Req. for Review, Revision, and Handling[1]	Avg. No. Days Req. for Publication in ELEC. ENGG. for General Circulation
National Conventions					
Hot Springs, Va., June 25–29	30	190½	6¼	30.6	46.8
Salt Lake City, Sept. 3–7	*25	149¼	7½	48.0	59.8
New York, Jan. 22–25	53	345	6½	49.2	56.6
District Meetings					
Worcester, Mass., May 16–18	12	58	4¾	113.0	81.5
Oklahoma City, April 24–26	**7	22¼	4½	137.8	43.0
Published in ELEC. ENGG. only	22	100		78.0	160.4
Yearly averages	142	865	6.1	58.1	72.3
Withdrawn and rejected (28 per cent)					

1. Includes review by committees, revision by authors, and other handling previous to release for publication.
† Includes 18 technical committee reports.
* Includes 5 papers re-presented; 4 from winter convention program and 1 from Worcester meeting.
** Includes 2 papers re-presented from winter convention programs.
(These 3 items not included in vertical column totals.)

Publication Committee

The calendar year 1934 was the peak year in the history of the Institute's publications, first, in the total amount of material published, and, second, in the fact that all this material was distributed to the entire membership of the Institute.

Following the procedure embraced in the unified publication program adopted by the board of directors in August 1933, the Institute's official monthly organ, Electrical Engineering, in its enlarged form now carries to the Institute's membership the full text of all recommended A.I.E.E. papers and the full text of all accepted and recommended discussion of those papers. In addition to this formal technical content there has been retained, in response to widespread membership demand, a proportion of special articles and other features that have been highly popular with the membership since their adoption in January 1931. Further, news of Institute activities has been featured more strongly, and it is recommended that every effort be made to use this effective news distributing facility in order to keep the Institute membership better acquainted with the scope, character, and significance of Institute activities and operating problems.

Beginning with volume 53 (1934) the Transactions has, for reasons of economy and equity in the distribution of the costs involved, been changed to an annual volume in accordance with the provisions of the unified publication program. Inasmuch as the monthly issues of Electrical Engineering convey all material directly and promptly to the membership, the annual Transactions is issued as a supplementary service to those who wish a permanently bound volume for library or reference purposes. Because of the inclusion of an extra quota of 125 pages embracing 19 technical papers to close the gap between the annual volume and the last quarterly Transactions, and because of the 199 pages embracing the special content of the May 1934 fiftieth anniversary issue of Electrical Engineering, the 1934 annual volume was appreciably larger than the average to be expected.

In general, the new publication program may be said to be safely past the principal difficulties incident to the major transition, although of course several minor operating problems now remain to be worked out. The plan has been enthusiastically accepted by the membership in general, and the expected substantial improvement in publication service and reduction in publication costs have become realities.

Standards Committee

As the practice of holding 4 meetings of the standards committee per year has been found satisfactory and the cause of but little delay in the carrying on of routine matters, it was continued during the past year with meetings in May and October 1934 and January and April 1935.

Most of the time of the committee this year was devoted to the consideration of revisions of existing A.I.E.E. and approved American standards as submitted by the technical committees of the Institute, notably the electrical machinery, instruments and measurements, and protective devices committees. These projects thus received and forwarded to the American Standards Association were as follows: air switches, instrument transformers, recording instruments, and lightning arresters. The third of the test code series, the "Test Code for Polyphase Induction Machines," was published in December 1934 and distributed for comment. The "Test Code for Transformers," the first to appear, was forwarded to the American Standards Association and is now before the sectional committee on transformers.

Changes brought about by present industrial conditions necessitated the realignment of the Institute representatives on several sectional committees. In support of its belief in the effectiveness of single sponsorship for sectional committees, the Institute released its joint sponsorship of the sectional committee on radio. This committee will now be under the sole direction of the Institute of Radio Engineers.

Among the many miscellaneous questions coming up for attention were 2 of particular interest, as follows: a suggestion that there be a reclassification of insulation materials, the careful consideration of which resulted in a reaffirming of the present setup; the other question was essentially one of clarification and resulted in the decision that the phrase "limit of temperature rise" should henceforth be "limit of observable temperature rise."

A matter of perhaps great importance chiefly as indicative of the growth of the American Standards Association, but which was called to the attention of the standards committee because of its possible bearing on the work of the electrical standards committee of A.S.A. was the plan now being considered by that organization, which may eventually result in the work of the standards council in fields other than electrical and of the general nature of that now handled by the Electrical Standards Council being delegated to similarly organized committees. The standards committee expressed the informal opinion that the proposal would seem to be a step toward more effective operation of standards council.

U.S. National Committee of the I.E.C.

Meetings of 6 of the advisory committees of the International Electrotechnical Commission were held in Prague in October 1934. Progress was made on the technical work and foundations were laid for the plenary meetings which will be held in The Hague and Brussels, June 18–27, 1935.

Following is a brief résumé of the work accomplished by the advisory committees which met at Prague:

Advisory Committee Number 2, on the Rating of Electrical Machinery. This committee concerned itself with the proposed revision of I.E.C. publication 34, "Rules for Electrical Machinery (including transformers)." The U.S. national committee has prepared its comments on the proposed revision which is now available. The committee also concerned itself with the preparation of an I.E.C. publication covering the measurement by sphere gaps of test voltage at power frequencies in dielectric tests. These comprise essentially the same provisions as A.I.E.E. Standards Number 4. While certain work which is being carried on in this country tends to indicate

errors in the proposed table, the U.S. committee has decided to agree to the publication of the I.E.C. rules and to move for an immediate revision upon the completion of the work on the subject in this country.

Advisory Committee Number 3, on Graphical Symbols. A comprehensive proposal for the standardization of graphical symbols for electric traction which was prepared by the Swiss national committee, the secretariat for this work, was considered in connection with the list of symbols recommended by the international union of railways. A single list of symbols was arrived at and it will be circulated to the national committees for approval before publication as an I.E.C. standard.

Advisory Committee Number 6, on Lamp Bases and Sockets. Recommendations prepared by the international committee of lamp manufacturers and independent experts were adopted with minor modifications. These cover dimensions essential to insure interchangeability of lamp bases and sockets of both the screw and bayonet type. The recommendations cover bases and sockets of both the American and European types. The committee expects to continue the work on gauging.

Advisory Committee Number 8, on Standard Voltages and Currents and High Voltage Insulators. This committee prepared lists of I.E.C. nominal voltages and a series of standard current ratings for electrical apparatus which are now under consideration by the U.S. national committee. Tentative agreement also was reached on a draft of international specifications for the testing of overhead line insulators, and the draft specification is receiving consideration by the U.S. national committee.

Advisory Committee Number 17, on Switchgear. The work of this committee comprises the most important subject before the I.E.C. at the present time. The meeting considered a complete specification for the rating and performance of circuit breakers submitted by the British, and a committee of experts was appointed to meet monthly to prepare recommendations for consideration at the plenary meetings. The U.S. national committee is represented on this committee of experts.

Advisory Committee Number 20, on Electric Cables. Preliminary work was done by this committee looking to the establishment of an I.E.C. specification covering the testing of cables.

At a meeting of the committee of action it was decided to reconstitute the former advisory committee on rules for electrical installation on ships, and to establish new advisory committees covering electronic devices and the rating of rectifiers, and to take the initiative in convening an international conference to standardize, for international purposes, acoustical terms and definitions.

The U.S. National committee at its January meeting elected Dr. A. E. Kennelly, past president A.I.E.E. and professor emeritus of electrical engineering at Harvard University, as its honorary president. Dr. Kennelly has served the U.S. National committee and the I.E.C. with distinction on nomenclature, electric and magnetic magnitudes and units, rating of electrical machinery, and on many other important subjects.

The U.S. national committee has made careful preparations for the plenary meetings to be held at The Hague and Brussels, and at the time of the writing of this report it appears that American electrical industries will be represented by one of the largest and best technically qualified delegations which have been sent abroad in several years.

Co-ordination Committee

The committee followed the established practice of requesting District and Section officers to submit by January 1 applications for the authorization of any national conventions and District meetings desired in their respective Districts during the calendar year 1936. A schedule of 2 national conventions and 2 District meetings was recommended by the committee.

The 1934 annual report of the committee on research, containing recommendations that research be given more prominence in Institute affairs and that this committee be made a general committee, had been referred by the board of directors to the committee on co-ordination of Institute activities. The committee recommended that no change be made in the status of the committee on research, as its activities are not restricted in any manner by the present arrangement, which offers some advantage in unity and in helpfulness to other technical committees.

Certain revisions in the rules governing the award of prizes for papers submitted by the committee on award of Institute prizes were recommended to the board of directors.

The board of directors approved the committee's recommendations on these 3 matters on January 21, 1935.

Committee on Constitution and By-Laws

During the year, the committee approved for presentation to the board of directors several proposed amendments to the by-laws of the Institute, and certain proposed amendments to the constitution, which had been recommended by a special committee, changing the dates in the Institute election procedure to permit the holding of the meeting of the national nominating committee during the winter convention, rather than early in December, thus providing for announcing the nomination of officers at a more appropriate time, and effecting other desirable results. Following approval by the board of directors, these proposed amendments to the constitution were submitted to a vote of the membership.

Committee on Legislation Affecting the Engineering Profession

The following matters were brought to the attention of this committee.

1. Effect of the federal securities bill on the responsibilities of the engineer.
2. Restrictions on the practice of consulting engineering, in the federal law on public utility holding companies.
3. Proposed licensing law in Cuba.
4. Proposed licensing law in Massachusetts.
5. New amendment to the licensing law of New York.

As the first 3 of these are matters which come in the category for which American Engineering Council was set up they were referred to that body and Secretary Feiker took the matters in charge.

The cases of state licensing were referred to the appropriate district executive committees.

No formal action was taken by the committee in any of the cases.

Committee on the Economic Status of the Engineer

The various matters which might otherwise have been acted upon by this committee during the year have seemed to lie definitely within the scopes of activities of American Engineering Council and Engineers' Council for Professional Development. As the chairman of the committee is one of the Institute's representatives upon each of these bodies, and chairman of the delegation to the former, the committee has not acted separately.

Committee on Safety Codes

No meetings of this committee have been called because no matters of importance have demanded consideration which could not be properly given by mail.

Two questions have been given the attention of the membership in this manner:

1. The request of the American Society of Safety Engineers' committee on co-operating with other engineering societies was discussed and, as a result, the Institute committee has recommended that A.I.E.E. co-operate in this movement. It is the purpose of this movement to bring about a closer co-ordination of the efforts of the several professional engineering societies in safety matters, for the benefit of all. The chairman of the committee on safety codes has been designated as the point of contact for effecting such co-operation.

2. The members of the committee have commented on the merits of the "bare neutral" system of interior wiring for the benefit of the chairman in representing A.I.E.E. on the electrical committee of the National Fire Protection Association.

At the meeting of the electrical committee in New York, March 19 to 22, many revisions were voted into the National Electric Code. A.I.E.E. men, several of them members of the committee on safety codes, were active participants in these revisions. It was decided to give the N.E.C. a complete editorial revision to be reported for action in the 1936 meeting. The previous chairman of the committee on safety codes, because of his neutral status, was made chairman of a special technical committee on bare neutral for interior wiring systems in 1932. His report was presented, and his committee was discharged.

The chairman also represents A.I.E.E. on the committee on low voltage hazards of the A.S.S.E., Engineering Section, National Safety Council. This assignment has required no action during the year.

Similarly, the chairman represents A.I.E.E. on the National Fire Waste Council, United States Chamber of Commerce, and attended the annual meeting held in Washington, D. C., on March 29. No matters of vital concern to the committee were discussed in this meeting.

Technical Committees

The technical committees, under the leadership of the technical program committee, have continued their efforts to clarify the definitions of scopes of their activities, in order to make definite provisions for effectively covering all the desired ranges of subjects and to eliminate overlapping among the committees.

They have continued their usual activities in the stimulation of the preparation and presentation of desirable papers in their respective fields and in the review of technical papers submitted.

Membership Committee

The membership committee continued its work with a complete national, District, and Section organization throughout the entire year even including the summer months. The threefold aim of the activities of this group has been to obtain applications for membership, to bring Students into Associate membership, and to urge and help members to reinstatement. In this work it has been aided greatly by the entire membership in their response to appeals to send to the committee the names of those who, they felt, should be invited to join the Institute. This method has been found to be fruitful of results and it is being continued. Membership messages have been carried in all issues of Electrical Engineering and, in addition, the Section organizations have contacted their members in many different ways. Monthly reports to the Section membership committees have served to keep the results in tangible form.

The committee had hoped to be able to report a net increase in members but this has not yet been accomplished. As is seen from table III, there is a reduction in membership from last year. However, there are other factors which give greater promise to the future. From table IV it will be seen that the number of applications received from enrolled Students and from all others has increased and from

Table III—Membership Statistics for the Fiscal Year Ending April 30, 1935

	Honorary	Fellow	Member	Six-Year Associate	Associate	Total
Membership on April 30, 1934	15	714	3694	6149	4659	15,231
Additions						
Transferred		17	180	510		
New members qualified		5	96	12	953	
Former members reinstated		2	26	35	25	
Total	15	738	3996	6706	5637	17,092
Deductions						
Died	3	18	29	32	9	
Resigned		6	49	174	88	
Transferred			13	153	542	
Dropped		23	195	731	775	
Membership on April 30, 1935	12	691	3710	5617	4223	14,253

Table IV—Number of Applications Received From Enrolled Students and From All Others

Year Ending	From Students	From All Others	Total
April 30, 1935	575	715	1,290
April 30, 1934	467	496	963
April 30, 1933	674	305	979
April 30, 1932	779	612	1,391
April 30, 1931	533	964	1,497

Table V—Number of Enrolled Students

April 30, 1935	3806 (1983)
April 30, 1934	3186 (1548)
April 30, 1933	3260 (1494)
April 30, 1932	3700 (1624)
April 30, 1931	3813 (2218)

(Following the number of Students reported for April 30th of each year is indicated within parentheses the number of new applications received during that year; the difference between this number and the reported total, of course, reflects the number of renewals of Student enrollment for the corresponding period.)

Table VI—Number of Members in Section Territory Reinstated

August 1, 1934, to April 30, 1935	697
Year beginning August 1, 1933	741
Year beginning August 1, 1932	277
Year beginning August 1, 1931	327
Year beginning August 1, 1930	375

Table VII—Membership of the Institute, April 30, 1935

Of the 14,253 membership reported for April 30, 1935, 11,496 are fully paid to April 30, 1935. The balance of 2,757 are divided into the following groups:

1. Members owing dues to April 30, 1934.	
Total number of members who have not acted upon resolution of board of directors adopted in January 1935 providing an extension of time for payment of these dues (including 437 members of 6 years' standing or longer who were entitled, upon application, to dues cancellation if unemployed during corresponding fiscal year)	903
Total number of members who obtained dues cancellation to April 30, 1934, because of unemployment, but who have not yet renewed active membership on pro rata basis for current year as provided in resolution of board of directors adopted in January 1935	18
	921
2. Members owing dues to April 30, 1935	1,836

(During the period May 1 to 20, 1935, 312 members have paid dues to April 30, 1935, reducing the total to 1,524.)

Table VIII—Memberships Fully Paid

	Membership as of April 30	Number of Members Fully Paid as of April 30	Per Cent Fully Paid
1935	14,253	11,496	80.6
1934	15,230	11,028	72.4
1927 (year of maximum membership)	18,344	16,247	88.5

table V it will be seen that the number of enrolled Students has increased. Table VI shows that the number of members in Section territory reinstated has increased.

Table VII shows that the number of members being carried whose dues are not fully paid is 2,757, whereas this figure was 4,202 as of April 30, 1934. This represents a decided improvement. Table VIII shows the improved condition as regards membership fully paid.

It is not possible in a short space to picture adequately the great amount of work which the Section membership committee chairmen and their committees continually contribute to the membership activities of the Institute. The fact that applications have been received during the past year from every Section of the Institute, as was also the case last year, shows the universality of the work and the completeness of the extent of the activities. It is due to the work of these groups combined with the efficient work of the headquarters staff in its manifold forms that the membership figures are good.

Deaths

The following deaths have occurred during the year:

Honorary Members: George A. Hamilton, Michael I. Pupin, Frank Julian Sprague.

Fellows: Charles G. Adsit, W. Rawson Collier, Harry A. Currie, George A. Damon, Roy W. Gray, Elwood Grissinger, George H. Harries, Edward M. Hewlett, Edward D. Mathey, Natalis Mazen, William McLellan, Samuel G. McMeen, Charles W. Parkhurst, Leslie L. Perry, Dana Pierce, Calvin W. Rice, Harris J. Ryan, Thomas A. Watson.

Members: William C. Adams, Ray M. Allen, George W. Atkinson, John C. Barclay, C. O. C. Billberg, George F. Brown, Edgar A. Cerf, Jr., Floyd E. Dellinger, Leonard P. Dickinson, John E. Donoghue, Fred D. Emory, G. L. Evans, George S. Gardner, Christopher M. Goddard, Hermann C. Henrici, Rudolph M. Hunter, James M. Kent, Ralph R. Laxton, George M. McCarty, James Milne, Guy K. Mitchell, Warren Partridge, Frederick G. Proutt, Paul W. Ripple, Martin L. Roper, William M. Scott, Paul B. Selden, W. C. Spruance, Charles H. Wilson.

Associates: William E. Ahrens, Donald C. Allison, Herbert A. Barre, Wilfred T. Birdsall, Leon B. Boulavin, Alonzo B. Bradley, Carleton M. Brown, Will G. Cole, George E. Dania, Harry H. Danshoe, Arthur W. Dawson, Thomas J. Drury, Edward M. Duvoisin, Herschel H. Edwards, Burch Foraker, Charles E. Hendricks, Foster D. Keese, Alfred W. Kiddle, Claude King, Charles K. Kneale, Mitchell A. Kreindler, W. Roy McCanne, Fred W. McKown, John A. McManus, Donald P. McNitt, Kikutaro Nogami, Philander Norton, Frank O'Ryan, Henry E. Phelps, Joseph C. Potts, Charles W. Price, Edgar F. Price, Kenneth A. Reed, R. Seshasayee, James F. Sinclair, Torsten F. Son Holmgren, Jerome G. Van Zandt, Harry Von Turffs, Ernest White, Richard L. Wilson, Walter Wood.

Board of Examiners

The board of examiners held 11 meetings during the past year, averaging about $2^1/_4$ hours each, and considered 3,176 cases, divided as shown in table IX.

Table IX—Applications for Admission and Transfer

Applications for Admission		
Recommended for grade of Associate	773	
Re-elected to the grade of Associate	57	
Not recommended	8	838
Recommended for grade of Member	103	
Re-elected to the grade of Member	10	
Not recommended	35	148
Recommended for grade of Fellow	3	
Re-elected to the grade of Fellow	2	
Not recommended	1	6
Applications for Transfer		
Recommended for grade of Member	199	
Not recommended	23	222
Recommended for grade of Fellow	19	
Not recommended	2	21
Students		
Recommended for enrollment as Students		1,941
Total		3,176

Institute Prizes

Four national prizes and 11 District prizes for papers presented in 1934 were awarded to authors. The national prizes were presented at the summer

convention at Hot Springs, and most of the District prizes were presented at various meetings in the respective Districts. The awards were announced in 1934 issues of ELECTRICAL ENGINEERING for June (page 1026), July (pages 1234–5), and September (pages 1327–8).

COMMITTEE ON AWARD OF COLUMBIA UNIVERSITY SCHOLARSHIPS

The committee selected for the award of the scholarship placed at the disposal of the Institute, for the class entering upon graduate study in electrical engineering at Columbia University in the fall of 1934, Robert W. Marshall of station *F*, route 4, Minneapolis, Minn. As usual the availability of these scholarships was announced in the February issue of ELECTRICAL ENGINEERING and in a circular letter to the Counselors of all Student Branches of the Institute.

EDISON MEDAL

The Edison Medal, which is awarded by a committee composed of 24 members of the Institute, was, for 1934, awarded to Dr. Willis R. Whitney "for his contributions to electrical science, his pioneer inventions, and his inspiring leadership in research," and was presented on January 23, 1935, during the winter convention. The medal may be awarded annually "for meritorious achievement in electrical science, electrical engineering, or the electrical arts."

JOHN FRITZ MEDAL

The John Fritz Medal board of award, composed of representatives of the national societies of civil, mining, mechanical, and electrical engineers, awarded the thirty-first medal (for 1935) to Dr. Frank J. Sprague, honorary member and past-president of the Institute, "for distinguished service as inventor and engineer through the application and control of electric power in transportation systems." Dr. Sprague's death occurred on October 25, 1934, only a few days after he had received notification of the award. The medal was presented to his son Robert C. Sprague on January 23, 1935, during the winter convention.

LAMME MEDAL

The Lamme Medal committee awarded the medal for 1934 to Henry E. Warren "for outstanding contributions to the development of electric clocks and means for controlling central station frequencies." Arrangements are being made for the presentation of the medal at the annual summer convention, at Ithaca, N. Y., June 24–28, 1935. The medal may be awarded annually to a member of the A.I.E.E. "who has shown meritorious achievement in the development of electrical apparatus or machinery."

WASHINGTON AWARD

The Washington Award for 1935 was bestowed upon Dr. Ambrose Swasey, honorary member of the Institute, "for his distinguished contributions as a builder of instruments, institutions, and men," and was presented to him on February 20, 1935. This award may be made annually to an engineer by the commission of award composed of 9 representatives of the Western Society of Engineers and 2 each of the A.S.C.E., A.I.M.E., A.S.M.E., and A.I.E.E.

ALFRED NOBLE PRIZE

This prize, established in 1929, consists of a certificate and a cash award of $500 from the income from a fund contributed by engineers and others to perpetuate the name and achievements of Alfred Noble, past-president of the A.S.C.E. and of the Western Society of Engineers. It is made to a member of any of the co-operating societies, A.S.C.E., A.I.M.E., A.S.M.E., A.I.E.E., or W.S.E., for a technical paper of particular merit accepted by the publication committee of any of these societies, provided the author, at the time of such acceptance, is not over 30 years of age. No award was made in 1934.

IWADARE FOUNDATION COMMITTEE

The third lecturer to visit Japan was Dr. Irving Langmuir of the General Electric Company. Doctor Langmuir spent several weeks toward the latter part of 1934 in Japan and addressed many audiences at a number of the leading universities.

The sixth Iwadare Fellow to visit the United States was Mr. Y. Takahashi of the Meidensha Electric Works, Tokyo, and a part-time lecturer at the Imperial University. His visit began in April of last year.

EMPLOYMENT SERVICE

The Institute co-operates with the national societies of civil, mining, and mechanical engineers in operation of the Engineering Societies Employment Service with its main office in the Engineering Societies Building, New York. Offices are operated in Chicago and San Francisco also. In addition to the societies named, others co-operate in certain of the offices as follows: New York—Society of Naval Architects and Marine Engineers; Chicago—Western Society of Engineers; San Francisco—California Section of the American Chemical Society; and the Engineers' Club of San Francisco.

The New York office has co-operated closely with the Professional Engineers Committee on Unemployment which was organized in the fall of 1931 by the local Sections of the A.S.C.E., A.I.M.E., A.S.M.E., and A.I.E.E.

The service is supported by the joint contributions of the societies and their individual members who are benefited. As in the past, it consists principally in acting as a medium for bringing together the employer and the employee. In addition to the publication of the employment service announcements monthly in ELECTRICAL ENGINEERING, weekly subscription bulletins are issued for those seeking positions.

An analysis of this employment service is given in table X.

Table X—Analysis of Employment Service

Month	Men Registered				Men Placed			
	New York	Chicago	San Francisco	Total	New York	Chicago	San Francisco	Total
1934								
May	86	71	55	212	46	19	16	81
June	145	76	66	287	50	9	8	67
July	129	47	46	222	51	18	13	82
August	85	47	45	177	61	22	17	100
September	99	28	34	161	51	12	13	76
October	113	41	58	212	49	40	16	105
November	90	38	37	165	41	23	10	74
December	72	41	31	144	42	12	15	69
1935								
January	102	61	57	220	50	15	17	82
February	101	39	45	185	60	16	13	89
March	79	45	49	173	62	20	13	95
April	109	39	56	204	64	28	12	104
Total	1,210	573	579	2,362	627	234	163	1,024

American Engineering Council

During the past year, American Engineering Council has continued its activity in the wide range of affairs which lie within its objects: "to further the public welfare wherever technical and engineering knowledge and experience are involved, and to consider and act upon matters of common concern to the engineering and allied technical professions," and within the interests of the many national, state, and local engineering societies upon its membership list.

Some of the principal actions taken by the Council at its annual meeting held January 10–12, 1935, provide for:

1. New membership plan under which local societies may pay nominal dues on a flat rate basis.

While formal promotion of the new membership plan has not yet been actively started, Council has already received applications for membership under the new plan from the following organizations:

Engineering Societies of New England
Michigan Engineering Society
Cleveland Engineering Society
Providence Engineering Society
Arkansas Engineers' Club
Engineers' Club of Philadelphia
Engineers' Club of St. Louis
Louisiana Engineering Society
Florida Engineering Society

2. Division of the public affairs committee into subcommittees under the chairmanship of members of the main committee who will co-operate with similar committees of the engineering societies.

3. Organization of a public affairs committee in each state.

4. Continued support of the national mapping program.

5. Efforts to have the facts concerning rural electrification work, scattered among several departments, pooled under the bureau of agricultural engineering, with data already collected by engineering groups throughout the country.

6. Continuance of the holding of a conference of secretaries of engineering societies from time to time.

7. Increase in Council's budget of $^1/_3$ over that of 1934, thus enabling it to render more effective service.

Much of the annual meeting was devoted to symposiums on parts of the federal program connected with construction, planning, and other features involving engineering, with government officials presenting information and leading the discussions. Thus, the members of the governing bodies of the Council received much information which will be helpful in their further deliberations on these subjects.

A conference of secretaries of approximately 40 national, state, and local engineering societies was held in connection with the meeting, and many problems common to engineering societies of various types were discussed. A committee was appointed to study the interrelations of activities of national, state, and local engineering organizations.

At the request of the Council, and with the co-operation of many of the engineering societies, the U.S. Department of Labor is making a survey of the engineering profession, using a list of more than 170,000 engineers, for the purpose of ascertaining facts regarding engineering employment during the past several years, particularly with respect to education, types of work, and compensation.

More detailed information regarding the work of the Council in its broad range of activities may be found from month to month in Electrical Engineering.

United Engineering Trustees, Inc.

During 1934, this organization, as an agency of the founder societies, made many improvements in the facilities of the Engineering Societies Building, changed the arrangements for fire insurance to make reductions in cost, revised the by-laws, and performed other duties necessary to maintain the building and administer the funds in its custody, including those of its departments, The Engineering Foundation and the Engineering Societies Library.

Dr. Alfred D. Flinn resigned as secretary, and John Arms, who had previously been appointed general manager, was elected secretary in addition. Dr. Flinn continues as director of The Engineering Foundation.

The United Engineering Trustees, Inc., and the secretaries of the founder societies made plans for a joint dinner meeting of the officers and boards of the societies and of their joint organizations held on May 20, 1935, for the purpose of establishing a better understanding among these individuals of the many important activities conducted by these jointly operated agencies.

Abstracts of the annual report of the United Engineering Trustees, Inc., were published in the April 1935 issue of Electrical Engineering, page 458.

Engineering Foundation

This department of the United Engineering Trustees, Inc., supplied financial support, during 1934, for many research projects sponsored by the founder societies, notably the following: A.S.C.E.—concrete and reinforced concrete arches, earths and foundations, and plastic properties of concrete; A.I.M.E.—critical review of world's literature on alloy irons and alloy steels since 1890, and barodynamic research; A.S.M.E.—effects of temperature upon properties of

metals, cutting of metals, thermal properties of steam, mechanical springs, riveted joints, and wire rope; A.I.E.E.—welding with pure iron electrodes.

The Foundation also assisted the Engineers' Council for Professional Development, the Personnel Research Federation, and an investigation of the Engineering Index.

The Foundation has authorized the formation of a welding research committee, under the sponsorship of the American Welding Society and the Institute, to make a critical review of welding literature and later to develop a comprehensive program of research.

The Foundation's twentieth anniversary was celebrated at a dinner meeting on October 18, 1934, with Dr. Ambrose Swasey, founder, present as the guest of honor.

An abstract of the annual report of The Engineering Foundation was published in the April 1935 issue of ELECTRICAL ENGINEERING, pages 458–9.

ENGINEERING SOCIETIES LIBRARY

The Engineering Societies Library, which was formed by combining the separate libraries of the 4 national societies of civil, mining and metallurgical, mechanical, and electrical engineers, and the preparation of a composite card catalog, has been expanded as a single engineering library, which probably constitutes the best collection of this type of literature in the country. With its 145,000 volumes, about 1,200 periodicals in many languages received regularly, and its staff thoroughly experienced in rendering all library services required by engineers, by mail, as well as in the library, it has continued, despite drastic reductions in its budget, to afford highly appreciated assistance to increasing numbers of members of the co-operating societies. Special, services rendered include: photoprints, abstracts, translations, bibliographies, searches, book loans by mail, etc.

A more comprehensive statement regarding the library, prepared by Professor W. I. Slichter, national treasurer of the Institute, and chairman of the library board, appeared in the January 1935 issue of ELECTRICAL ENGINEERING, pages 130–31.

ENGINEERS' COUNCIL FOR PROFESSIONAL DEVELOPMENT

This council, which was formally organized in 1932 for the enhancement of the professional status of the engineer, includes 3 representatives of each of the 7 participating organizations: the national societies of chemical, civil, electrical, mechanical, and mining and metallurgical engineers, the Society for the Promotion of Engineering Education, and the National Council of State Boards of Engineering Examiners.

The principal activities of the Council include the guidance of young individuals thinking of entering the engineering field, the accrediting of engineering schools, encouragement and assistance to individuals continuing their engineering and cultural training during several years after graduation, and the establishment of suitable standards for indicating the attainment of the status of an engineer.

Detailed information regarding the recommendations submitted by E.C.P.D. to the participating organizations and other features of its activities were published in ELECTRICAL ENGINEERING for February 1935, page 249, March, page 343, and April, page 452.

REPRESENTATIVES

The Institute has continued its representation upon many joint committees and national bodies, with which it co-operates in a wide range of activities of interest and importance to engineers and others.

FINANCE COMMITTEE

The committee, as usual, recommended a detailed budget to the board of directors, passed upon the expenditures for various purposes, made recommendations regarding delinquent members, and performed the other duties prescribed for it in the constitution and by-laws.

Haskins and Sells, certified public accountants, have audited the books, and their report follows.

Respectfully submitted for the board of directors.

H. H. HENLINE
National Secretary

May 20, 1935

HASKINS & SELLS
CERTIFIED PUBLIC ACCOUNTANTS

22 EAST 40TH STREET
NEW YORK

May 15, 1935.

American Institute of Electrical Engineers,
33 West 39th Street,
New York.

Dear Sirs:

We have made an examination of your statement of financial condition as of April 30, 1935, and of your recorded cash receipts and disbursements for the year ended that date. In connection therewith we examined or tested accounting records of your society and other supporting evidence in relation to the balance sheet and cash receipts and disbursements, but we did not make a detailed audit of the transactions. We present the following financial statements:

Balance Sheet, April 30, 1935 (Exhibit A).
Property and Restricted Funds—Securities, Cash, and Accrued Interest Receivable (Schedule 1).

Statement of Recorded Cash Receipts and Disbursements of General Fund for the Year Ended April 30, 1935 (Exhibit B).

Statement of Recorded Cash Receipts and Disbursements of Property and Restricted Funds for the Year Ended April 30, 1935 (Exhibit C).

In accordance with the terms of our engagement the members and other debtors were not requested to confirm to us the amounts receivable from them at April 30, 1935, and in accordance with the usual practice of the Society, no provision has been made for dues which may prove to be uncollectible.

In our opinion, subject to the foregoing, Exhibit A fairly presents your financial condition at April 30, 1935, and Exhibits B and C set forth your recorded cash receipts and your disbursements of the funds as indicated during the year ended that date.

Yours truly,

HASKINS AND SELLS

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Balance Sheet, April 30, 1935

Exhibit A

ASSETS		
Property Fund Investments:		
One-fourth interest in real estate and other assets of United Engineering Trustees, Inc., exclusive of Trust Funds	$496,948.48	
Equipment:		
Library—Volumes and fixtures	37,296.37	
Office furniture and fixtures (less reserve for depreciation, $22,901.46)	10,043.45	
Works of art, etc.	3,001.35	
Securities—at cost, and cash—Schedule 1	10,065.00	
Total property fund investments		$557,354.65
Restricted Fund Investments—Schedule 1:		
Securities—At cost (less reserve for bonds of doubtful value)	$167,179.02	
Cash	7,267.17	
Accrued interest receivable	223.33	
Total restricted fund investments		174,669.52
Current and Working Assets:		
Cash	$ 54,815.62	
Accounts receivable:		
Members—For dues	23,014.04	
Advertisers	111.00	
Miscellaneous	2,982.01	
Accrued interest on investments	1,840.36	
Inventories:		
QUARTERLY TRANSACTIONS, etc.	2,311.50	
Text and cover paper	1,821.03	
Badges	703.03	
Total current and working assets		87,598.59
Total		$819,622.76

LIABILITIES		
Property Fund Reserve		$557,354.65
Restricted Fund Reserves:		
Reserve Capital Fund	$154,528.25	
Life Membership Fund	9,659.60	
International Electrical Congress of St. Louis Library Fund	4,801.12	
Lamme Medal Fund	4,648.15	
Mailloux Fund	1,032.42	
Total restricted fund reserves		174,669.52
Current Liabilities:		
Accounts payable	$ 4,755.06	
Dues received in advance	3,319.20	
Entrance fees and dues advanced by applicants for membership	621.00	
Subscriptions for QUARTERLY TRANSACTIONS received in advance	48.00	
Total current liabilities		8,743.26
Surplus		78,855.33
Total		$819,622.76

Property and Restricted Funds—Securities, Cash, and Accrued Interest Receivable, April 30, 1935

Exhibit A, Schedule 1

			Restricted Funds					
	Number of Shares of Stock or Face Value of Bonds	Property Fund (Equipment Replacements)	Reserve Capital Fund	Life Membership Fund	International Electrical Congress of St. Louis Library Fund	Lamme Medal Fund	Mailloux Fund	Total
SECURITIES:								
Railroad Bonds:								
Baltimore & Ohio Railroad Company 6% refunding and general mortgage series C, due 1995	$12,000.00		$ 8,940.00			$4,330.00		$ 13,270.00
Central of Georgia Railway Company 5% consolidated mortgage, due 1945	3,000.00		1,477.50					1,477.50
Chicago, Burlington & Quincy Railroad Company 4%, due 1958	5,000.00			$4,868.75				4,868.75
Chicago, Burlington & Quincy Railroad Company 5% first and refunding mortgage series A, due 1971	1,000.00		1,010.00					1,010.00
Chicago & Erie Railroad Company 5% first mortgage, due 1982	1,000.00		1,105.00					1,105.00
Chicago & Northwestern Railway Company 6½%, due 1936	9,000.00		7,202.50					7,202.50
Chicago, Terre Haute & Southeastern Railway Company 5% first and refunding mortgage, due 1960	8,000.00		7,940.00					7,940.00
Florida East Coast Railway Company 5% first and refunding mortgage series A, due 1974 (certificates of deposit)	10,000.00		9,818.75					9,818.75
New York Central Railroad Company 5% refunding and improvement mortgage series C, due 2013	6,000.00		5,742.50					5,742.50
Pennsylvania Railroad Company 4½% general mortgage series A, due 1965	5,000.00		5,130.00					5,130.00
St. Louis-San Francisco Railway Company 5% prior lien mortgage series B, due 1950 (certificates of deposit)	6,000.00		5,497.50					5,497.50
Southern Railway Company 5% first consolidated mortgage, due 1994	1,000.00		980.00					980.00
Western Pacific Railroad Company 5% series A, due 1946	15,000.00		7,225.00					7,225.00
Total railroad bonds—(Forward)			$ 62,068.75	$4,868.75		$4,330.00		$ 71,267.50

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Property and Restricted Funds—Securities, Cash, and Accrued Interest Receivable, April 30, 1935

Exhibit A, Schedule 1

	Number of Shares of Stock or Face Value of Bonds	Property Fund (Equipment Replacements)	Restricted Funds: Reserve Capital Fund	Life Membership Fund	International Electrical Congress of St. Louis Library Fund	Lamme Medal Fund	Mailloux Fund	Total
SECURITIES—Continued								
Total Railroad Bonds—(Forward)			$ 62,068.75	$4,868.75		$4,330.00		$ 71,267.50
Public Utility Bonds:								
Consolidated Gas Company of New York 5½% debentures, due 1945	$ 5,000.00		$ 5,187.50					$ 5,187.50
Duquesne Light Company 4½% first mortgage series A, due 1967	3,000.00		2,970.00					2,970.00
Hydro-Electric Power Commission of Ontario 3½%, due 1952	4,500.00		4,500.00					4,500.00
New York Telephone Company 4½%, due 1939	2,000.00				$ 878.75		$1,000.00	1,878.75
Pacific Gas & Electric Company 5½% first and refunding mortgage series C, due 1952	5,000.00		5,137.50					5,137.50
Philadelphia Company secured 5% series A, due 1967	10,000.00		10,000.00					10,000.00
Shawinigan Water & Power Company 4½% first mortgage and collateral trust sinking fund series A, due 1967	5,000.00		4,581.25					4,581.25
Texas Electric Service Company 5% first mortgage, due 1960	4,000.00		3,910.00					3,910.00
United Light & Power Company 5½% first lien and consolidated mortgage, due 1959	5,000.00		4,975.00					4,975.00
Total public utility bonds			$ 41,261.25		$ 878.75		$1,000.00	$ 43,140.00
Industrial Bonds:								
American Smelting & Refining Company 5% first mortage series A, due 1947	$ 9,000.00		$ 9,085.00					$ 9,085.00
Bethlehem Steel Company 5% purchase money and improvement mortgage sinking fund, due 1936	5,000.00		5,033.75					5,033.75
Cleveland Union Terminals Company 5% sinking fund series B, due 1973	4,000.00	$ 4,010.00						4,010.00
Fidelity Union Title and Mortgage Guaranty Company first mortgage certificates (on property 75–79 Prospect Street, East Orange, N. J.) 6½%, due 1933	14,663.00	977.53	13,685.47					14,663.00
International Match Corporation 5% convertible debentures, due 1941 (certificate of deposit)	3,000.00		2,880.00					2,880.00
New York Steam Corporation 6% first mortgage, due 1947	10,000.00		10,837.50					10,837.50
United States Rubber Company 5% first and refunding mortgage series A, due 1947	2,000.00		1,915.00					1,915.00
Western Electric Company 5% debentures, due 1944	10,000.00		9,818.75					9,818.75
Youngstown Sheet and Tube Company 5% first mortgage sinking fund series A, due 1978	10,000.00		10,137.50					10,137.50
Total industrial bonds		$ 4,987.53	$ 63,392.97					$ 68,380.50
Municipal Bonds:								
New York City 4½% corporate stock, due 1957	2,000.00				$2,204.05			$ 2,204.05
Capital Stocks:								
Commonwealth Edison Company	12 shares		$ 2,892.00					$ 2,892.00
Consolidated Gas Company of New York, $5.00 cumulative preferred	30 "	$ 3,060.00						3,060.00
Public Service Corporation of New Jersey, $5.00 preferred	30 "		2,958.75					2,958.75
United Gas Improvement Company, $5.00 preferred	30 "	1,995.00	997.50					2,992.50
Total capital stocks		$ 5,055.00	$ 6,848.25					$ 11,903.25
Total securities		$10,042.53	$173,571.22	$4,868.75	$3,082.80	$4,330.00	$1,000.00	$196,895.30
Less Reserve for Bonds of Doubtful Value:								
Central of Georgia Railway Company 5% consolidated mortgage, due 1945	$ 3,000.00		$ 1,477.50					$ 1,477.50
Florida East Coast Railway Company 5% first and refunding mortgage series A, due 1974	10,000.00		9,818.75					9,818.75
International Match Corporation 5% convertible debentures, due 1941	3,000.00		2,880.00					2,880.00
St. Louis-San Francisco Railway 5% prior lien mortgage series B, due 1950	6,000.00		5,497.50					5,497.50
Total reserve for bonds of doubtful value			$ 19,673.75					$ 19,673.75
Total securities, less reserve		$10,042.53	$153,897.47	$4,868.75	$3,082.80	$4,330.00	$1,000.00	$177,221.55
Cash		22.47	630.78	4,757.52	1,650.82	218.13	9.92	$ 7,289.64
Accrued Interest Receivable				33.33	67.50	100.00	22.50	$ 223.33
Total property fund securities and cash		$10,065.00						$ 10,065.00
Total restricted fund investments			$154,528.25	$9,659.60	$4,801.12	$4,648.13	$1,032.42	$174,669.52

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Statement of Recorded Cash Receipts and Disbursements of General Fund for the Year Ended April 30, 1935

Exhibit B

Cash on Deposit, May 1, 1934, With the National City Bank of New York		$ 29,834.74
Receipts:		
Dues (including dues allocated to ELECTRICAL ENGINEERING subscriptions)	$166,734.06	
Advertising	25,038.10	
QUARTERLY TRANSACTIONS subscriptions	6,561.18	
ELECTRICAL ENGINEERING subscriptions	12,247.98	
Miscellaneous publications, etc.	6,268.15	
Students' fees	8,736.00	
Entrance fees	5,884.90	
Badges	1,287.15	
Transfer fees	965.00	
Interest on investments and bank balances	7,549.30	
Miscellaneous	50.53	
Total receipts		241,322.35
Total		$271,147.09
Disbursements:		
Publication expenses:		
ELECTRICAL ENGINEERING	$ 74,336.41	
QUARTERLY TRANSACTIONS	4,936.20	
Year book	2,192.50	
Miscellaneous	3,534.95	
Administrative expenses	40,717.61	
Institute Sections	25,464.32	
Institute meetings	10,296.11	
Institute branches	2,343.42	
American Engineering Council	8,000.00	
Forward	$171,811.61	$271,147.09
Total—(Forward)		$271,147.09
Disbursements—(Forward)	$171,811.61	
Traveling expenses:		
Board of Directors	4,301.78	
Branch Counselors	3,061.49	
Geographical districts:		
Executive Committees	604.89	
Vice Presidents	411.45	
National Nominating Committee	1,300.67	
President's Special Appropriation	124.69	
United Engineering Trustees, Inc.:		
Library assessment	8,192.15	
Building assessment	3,938.36	
Standards Committee	5,470.63	
Membership Committee	7,368.07	
Employment service	3,204.16	
American Standards Association	999.99	
Badges	1,291.64	
Retirement salary	2,700.00	
Finance Committee	400.00	
United States Committee of International Commission on Illumination	300.00	
Geographical district prize—Best branch paper	150.50	
John Fritz medal	164.88	
Technical Committees	205.44	
Headquarters Committee	80.75	
Code Committee	60.00	
Edison Medal Committee	188.34	
Total disbursements		216,331.47
Cash on Deposit, April 30, 1935, With the National City Bank of New York		$ 54,815.62

Statement of Recorded Cash Receipts and Disbursements of Property and Restricted Funds for the Year Ended April 30, 1935

Exhibit C

	Total	Property Fund (Equipment Replacements)	Restricted Funds: Reserve Capital Fund	Life Membership Fund	International Electrical Congress of St. Louis Library Fund	Lamme Medal Fund	Mailloux Fund
Cash on Deposit, May 1, 1934, With East River Savings Bank and National City Bank of New York	$7,870.99	$22.47	$630.78	$5,388.29	$1,560.99	$255.78	$12.68
Receipts:							
Interest on bonds	$ 620.00			$ 200.00	$ 135.00	$240.00	$45.00
Interest on bank balances	139.65			139.65			
Miscellaneous	1.10				1.10		
Total receipts	$ 760.75			$ 339.65	$ 136.10	$240.00	$45.00
Total	$8,631.74	$22.47	$630.78	$5,727.94	$1,697.09	$495.78	$57.68
Disbursements:							
Annual withdrawal authorized in by-laws	$ 970.42			$ 970.42			
Bronze and gold replicas of Lamme Medal	277.65					$277.65	
All other disbursements	94.03				$ 46.27		$47.76
Total disbursements	$1,342.10			$ 970.42	$ 46.27	$277.65	$47.76
Cash on Deposit, April 30, 1935, with East River Savings Bank and National City Bank of New York	$7,289.64	$22.47	$630.78	$4,757.52	$1,650.82	$218.13	$ 9.92

Discussions

Of A.I.E.E. Papers—as Recommended for Publication by Technical Committees

ON this and the following 35 pages appear all remaining unpublished discussions of papers presented at the 1935 A.I.E.E. winter convention, New York, N. Y., January 22–25, and of a paper presented at the 1934 North Eastern District meeting, Worcester, Mass., May 16–18. Authors' closures where they have been submitted, will be found at the end of the discussion on their respective papers.

Members anywhere are encouraged to submit written discussion of any paper published in ELECTRICAL ENGINEERING, which discussion will be reviewed by the proper technical committee and considered for possible publication in a subsequent issue. Discussions of papers scheduled for presentation at an A.I.E.E. meeting or convention will be closed 2 weeks after presentation. Discussions should be (1) concise; (2) restricted to the subject of the paper or papers under consideration; and (3) typewritten and submitted in triplicate to C. S. Rich, secretary, technical program committee, A.I.E.E. headquarters, 33 West 39th Street, New York, N. Y.

The M.I.T. Power Factor Bridge and Oil Cell

Discussion and authors' closure of a paper by J. C. Balsbaugh, N. D. Kenney, and Alfred Herzenburg published in the March 1935 issue, pages 272–9, and presented for oral discussion at the selected subjects session of the North Eastern District meeting, Worcester, Mass., May 16, 1934. Other discussion of this paper was published in the May 1935 issue, page 559.

G. M. L. Sommerman (American Steel and Wire Co., Worcester, Mass.): If there is no effect of temperature lag of the various oil test cell parts, the loop power factor-temperature curves obtained on insulating oils as illustrated in figure 7 indicate a lag in one or more of the basic properties of such oils. Before discussing the phenomenon from this viewpoint, it seems pertinent to make some inquiries concerning the temperature variations which obtain within the measuring cell in these experiments.

From the construction of the cell, figure 4, it seems possible that some heat can be imparted to the cell envelope at its center as well as at the outside. If this is so, the temperature-radial distance curve would go through a minimum for the case of temperature increasing, and the temperature of the oil between the active electrodes would be lower than either thermocouple indicates. Likewise it would be higher on the cooling part of the cycle. Such a condition would, of course, explain the loop effect. Even if this condition existed, however, trustworthy results would have been obtained from the average of the thermocouple readings provided the couples were in intimate thermal contact with the active electrodes. A few words from the authors concerning these 2 points, the possibility of heat flow at the center of the cell envelope, and the nature of the contact of the thermocouples, would clear up this question.

Taking the loop effect as truly existing, the following explanation of it is suggested, since none is given in the paper.

The low frequency power factor of an insulating oil may be taken, for the purpose of this discussion, as proportional to the concentration, C_i, and the mobility of the ions in the oil. The mobility of the ions is in turn inversely proportional to the ion radius, r_i, and to the viscosity of the oil, η. Therefore

$$\delta = \frac{KC_i}{\eta r_i}$$

From studies made on insulating oils at The Johns Hopkins University (J. B. White head, A.I.E.E. TRANSACTIONS, volume 52, June 1933, pages 667–81), it was shown that the product of the a-c conductivity and the viscosity of a given oil is essentially independent of temperature. From this and the above equation it follows that C_i/r_i is also practically unaffected by temperature change. Therefore, the principal effect of temperature change on the power factor is that due to the corresponding viscosity change, and it is not necessary to consider velocities of ionic dissociation or of dissociation of neutral molecules attached to ion nuclei. Therefore, if the power factor lags behind the median or steady state curve on rapid temperature change as here reported, it is indicated that the viscosity lags to the same degree. That is, if the temperature of the oil is suddenly raised, the viscosity does not immediately drop to its steady state value at the new temperature, but requires an appreciable time to do so. Since the temperature difference between the median and actual curves for a given power factor is about 8 degrees centigrade for a rate of temperature rise of 20 degrees centigrade per hour, the time for the change is about 24 minutes. Similarly, if the oil temperature is suddenly lowered, the viscosity requires the same time to rise to its new final value. This effect is akin to the supercooling of liquids, but is not so pronounced. Phenomena of this nature have been observed for other substances, notably glycerine. For the case of oils the effect may be entirely internal, i. e., an effect on the motion of only very small particles such as ions, and may not show up in the external characteristics as obtained in a viscometer (G. M. L. Sommerman, Franklin Institute *Journal*, volume 219, 1935, page 433).

J. C. Balsbaugh, N. D. Kenney, and Alfred Herzenberg: W. S. Baird has raised a number of very interesting questions. It is very difficult to see how the loop power factor characteristics as a function of cell temperature shown in figure 6 could be explained by thermal expansion and subsequent cell deformation concurrent with the heat cycle. As the temperature is changed, the capacitance of the cell will change slightly. However, this is relatively small with the type of cell design that is used. This change in capacitance over the complete temperature range has been measured and been found to be materially less than one per cent. The power factor of the cell as measured is, of course, referred to the cell capacitance at the temperature at which it is measured. Any power factor which is a function of cell temperature due to dimensional changes in the cell, could only be accounted for principally by changes in cell length or surface voltage gradients, which would be a second order effect.

Curve *D* of figure 6 represents the results of increasing and decreasing temperatures after heating by induction. That is, after the cell material is thoroughly degassed there is no difference in power factors for increasing or decreasing temperatures. Baird has raised an interesting point relative to the possible explanation of the power factor of air condensers as due to roughened surfaces. Our experience seems to indicate that there is more to the problem than this although this possibly may be one factor of importance. The nickel cylinders in the cells from which these test characteristics were obtained were originally baked out in a hydrogen atmosphere before installing in these cells and also were very highly polished so that it would seem impossible to attribute his suggestion for the cause of these losses. We are at the present time continuing this work and hope to be able in the future to account definitely for these measured losses in an air condenser.

The reason why it may not be desirable to inject an oil sample into a vacuum is that in cases where a test of a service aged oil is desired, the injection of this sample into a vacuum may significantly change those characteristics and therefore the measured power factor of the sample. However, there are cases where the injection of an oil sample into a vacuum would be perfectly appropriate.

With reference to G. M. L. Sommerman's comments, we think he has given an interest-

ing explanation for the cause of the loop temperature-power factor characteristic. Relative to the possibility of heat being imparted to the cell envelope at its center, we made temperature measurements at points other than those indicated in the paper to justify the conclusion that the oil temperature for the measured oil is between the plotted temperatures of figure 7. The center tube of the cell was closed at both ends of the cell, and temperature measurements in this section at the center of the cell showed a lower temperature for increasing temperatures than the lower values of temperature plotted in figure 7 for increasing temperatures.

Ultra-Short Waves in Urban Territory

Discussion and authors' closure of a paper by C. R. Burrows, L. E. Hunt, and Alfred Decino published in the January 1935 issue, pages 115–24, and presented for oral discussion at the communication session of the winter convention, New York, N. Y., January 22, 1935.

J. D. Kraus (nonmember): This interesting paper contributes much to the knowledge of ultra-short wave transmission. The great number of readings made during the survey in the Boston area provides a large amount of valuable data concerning propagation in urban areas.

Of particular interest in this paper is equation 5, in which the field strength is shown to be inversely proportional to the square of the distance. Using this equation for field strength, the radiation from an antenna to produce this field may be shown to be

$$W = \frac{1}{720\,\pi^2}\left[\frac{E\lambda d^2}{h_1 h_2}\right]^2$$

where W is the radiated energy in watts, E the field strength in volts per meter, λ the wave length, d the radial distance from the radiator to the point where E is measured, and h_1 and h_2 the heights of the transmitting and receiving antennas, all measured in meters.

In figure 5, the authors have replotted data from a paper by Henry Muyskens and J. D. Kraus (I.R.E. *Proceedings*, volume 21, Sept. 1933, pages 1302–16) in which it appears that the data may be re-interpreted on the basis of an inverse-square-of-distance variation, as well as by an inverse-distance variation times an exponential attenuation factor. Substituting the field strengths from the inverse-square-of-distance curve in the above energy equation, one finds that the radiated energy from the antenna used by Muyskens and Kraus is within a few decibels of the proper magnitude provided the height of the transmitting antenna is measured from the ground. If the height is measured from the roof of the building on which the antenna was located, the computed power is about 15 decibels high or much in excess of the transmitter input.

In figure 2 of the paper, a distinction is made between 2 curves which are separated by 12 decibels. The lower one is called a "mean curve" and is drawn through the approximate average of the field strengths observed. The upper one is called a "level terrain curve." From the authors' data, it appears that in the case of their fixed location transmitter the "level terrain curve" agrees well with the radiated power if one measures the antenna height above the ground. When, however, the height of the transmitting antenna is measured from the roof, the proper value of radiated power is obtained only by use of field strength values from a curve which lies close to the "mean curve."

The antenna used by Muyskens and Kraus was of the vertical type using 2 half-wave elements excited and oriented so as to increase the radiation parallel to the ground. It was situated above the flat roof of a 4 story building which has closely adjacent a large number of other buildings of approximately the same height. According to Burrows, Hunt, and Decino, such a location should be important in determining the received field strengths. In order to obtain agreement between these data, it appears necessary to assume that the inverse-square-of-distance curve which the authors superimposed on the data of Muyskens and Kraus must correspond to a "level terrain curve." Since the points plotted by Muyskens and Kraus represent individual readings of field strength and those of the authors average values over a given radial distance, this assumption appears to be reasonable. On this basis, it may be said that the effect of the roofs under the transmitting antennas was the same in both cases.

Although it is pointed out that equation 5 has a number of limitations imposed by such things as widely varying antenna heights and ground conditions, it appears to come close to the actual picture under a considerable range of working conditions and should prove helpful in the predetermination of field strengths.

C. R. Burrows, L. E. Hunt, and Alfred Decino: While the authors believe that the method suggested by them for the estimation of the mean field strength to be expected for ultra-short wave transmission in urban territory will not be in error by a large amount in any practical installation, it should not be used indiscriminately. It is our opinion that the situations in the Ann Arbor and in the Boston experiments differed materially in that the building density is much less in the former case. This, together with the fact that the Ann Arbor antenna was located near a corner of the building and only a few yards above it, would make plausible the assumption of Kraus that in this case the height to use in the formula should be more nearly the height above the ground than the height above the roof. The fact that the power radiated in the Ann Arbor experiments could only be inferred from the power input to the transmitter makes a comparison of the 2 experiments on an absolute basis difficult.

The equation used in Kraus's discussion is based upon a doublet antenna. The antenna which he actually employed requires about half as much power to produce the same field.

The authors wish to call attention to an error in expressions 3a and 3b on page 117 of the paper. While this in no way affects the paper itself, the correct expressions are given here in order that any one who may have occasion to use them will not be led to an incorrect result.

$$E_0\left(\frac{4\pi h_1 h_2}{\lambda d}\right)\sqrt{1+\frac{\epsilon^2(h_1+h_2)^2\lambda^2}{(\epsilon-1)\,4\pi^2 h_1^2 h_2^2}} \quad (3a)$$

$$E_0\left(\frac{4\pi h_1 h_2}{\lambda d}\right)\sqrt{1+\frac{(h_1+h_2)^2\lambda^2}{(\epsilon-1)\,4\pi^2 h_1^2 h_2^2}} \quad (3b)$$

The factor 4 was incorrectly omitted from the denominator in each of these expressions in the paper.

Cathode Ray Tubes and Their Application

Discussion of a paper by J. M. Stinchfield published in the December 1934 issue, pages 1608–15, and presented for oral discussion at the electronics symposium of the winter convention, New York, N. Y., January 24, 1935.

C. Francis Harding (Purdue University, Lafayette, Ind.): No discussion of either the Dufour cathode ray tube (figure 3), with variable vacuum, nor the sealed tubes illustrated in figures 4 and 5 of the paper would be complete without mention of the early classic development of both of these types of cathode ray oscillographs by Prof. R. H. George of Purdue University, described in the A.I.E.E. TRANSACTIONS of 1929, which should appear in the bibliography.

Having developed special moving anode focusing devices and vacuum tube initiating circuits for the Dufour type oscillograph he has produced several complete oscillographs for the laboratories of Purdue University and some public utility and manufacturing companies. This special moving anode device permits not only the sharp focusing, from without the oscillograph case, of the electron jet upon either film or screen, but it also permits a wide range of accelerating potentials for all degrees of vacuum and different deflecting potentials. It is therefore a very flexible instrument. The automatic initiating device enables the electron jet to record within $^1/_4$ microsecond and prevents the fogging of the film. It takes advantage of the leading current from the antenna near the high potential line or test circuit resulting from a tuned capacitance and inductance; the potential induced by the rate of change of this current through another small series inductance leading still more the actual recording current. This leading potential neutralizes the bias of the initiating tube thereby recording the entire oscillogram of the steepest front transients.

C. S. Roys (nonmember): The use of the cathode ray oscillograph in its general application has been greatly restricted by the fact that one has not been able to view more than one wave at a time by means of a single tube, since it is apparently unduly complicated and expensive to build tubes with 2 or more electron guns. However,

this limitation has been overcome by a method developed in the school of electrical engineering at Purdue University, whereby 2 or more waves may be shown simultaneously in their correct relative phase positions using the ordinary type of cathode ray tube.

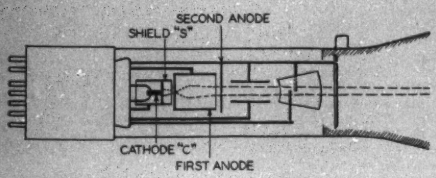


Fig. 1. Schematic diagram of the electron gun and deflecting plates of a cathode ray tube

In the arrangement actually constructed, 2 signals are impressed across the input terminals of 2 separate single stage amplifiers that utilize type 57 pentodes. The sweep circuit is coupled to one of the signal circuits by means of a triode, this method resulting in an amplification of the synchronizing impulse, accompanied by a corresponding attentuation of the distortion in the signal circuit that usually results from the sweep circuit phenomena.

The output to the sweep circuit, in turn, is coupled to the grid circuits of 2 gaseous triodes that are arranged in a manner similar to the simple, single phase inverter. As a result, first one gas triode operates and then the other, causing the screen grid potentials of the 2 pentodes to become alternately positive and negative in succession and thus to block first one amplifier and then the other. Since this switching circuit is locked in with the sweep circuit, and the latter in turn with one of the signals, the final result is that first one of the signals is shown and then the other. In the event that the frequencies of the 2 signals are simple multiples of one another, the 2 waves will appear stationary, and furthermore if the sweep frequency is above 30 cycles per second, the 2 waves will appear to be shown on the screen simultaneously, due to the persistence of vision. It is also possible to extend the general method to the showing of any number of waves simultaneously, special emphasis being placed upon the 3 phase case.

R. H. George (Purdue University, Lafayette, Ind.): I wish to call attention to another type of sealed off cathode ray tube, employing a modification of the electrostatic and gas method of focusing, described in a paper "A New Type of Hot Cathode Oscillograph and Its Application to the Automatic Recording of Lightning and Switching Surges," A.I.E.E. TRANSACTIONS, volume 48, July 1929, pages 884–90.

The sealed off tube was developed at the engineering experiment station, Purdue University, for the purpose of television reception. A schematic diagram of the electron gun and deflecting plates is shown in figure 1 of this discussion.

Regarding auxiliary apparatus, the writer has found an electron tube switching circuit for showing 2 different waves on successive sweeps very useful, both for laboratory and commercial applications. This circuit, which was devised by C. S. Roys and H. F. Mayer, has been further improved by H. J. Heim, G. E. Happell, and the writer until it will operate at sweep frequencies as high as 14,000 cycles per second. With this circuit it is possible to show the proper phase relation between 2 waves at frequencies as high as 70,000 cycles per second.

The "Thyratron" Motor

Discussion and authors' closure of a paper by E. F. W. Alexanderson and A. H. Mittag published in the November 1934 issue, pages 1517–23, and presented for oral discussion at the electronics symposium of the winter convention, New York, N. Y., January 24, 1935.

Philip Sporn (American Gas and Electric Co., New York, N. Y.): In spite of the many known methods for obtaining speed variation of a-c motors, there has been no really satisfactory variable speed motor equal in ease of control and reliability to the d-c shunt motor. In the power industry we have suffered from that, not only because of its retarding effect on the application of electric drive in many cases, but also more directly—in the steam generating station, for example. Thus, for boiler fan drive there have been tried single constant speed motors with damper or vane control on the fan end, one slip ring motor with armature control, 2 slip ring motors each with armature control, each motor covering a portion of the speed range, hydraulic variable ratio couplings, Rossman drive, straight d-c drive, and heaven knows what else. All of these methods have been proved to possess one or more serious disadvantages.

It was with all these thoughts in mind, coupled with the further fact that we have been intensely following electronic applications, and that we are firm believers in the old saying that the way to begin is to commence, that we ordered a 400-hp 2,300-volt, 3-phase 60-cycle "thyratron" motor for induced draft fan service at one of our power plants. This motor has been built and tested but has as yet not been placed in service; it is, therefore, too early to give any operating experience.

The operation of the motor on test, and it was put through very stiff paces, was however very satisfactory. For example, the motor was started with various combinations of tubes out of service, and was even started on single phase power while connected to a load equivalent to the fan load which it is to drive. The motor performed satisfactorily under all of these methods of operation. Undoubtedly the motor will seldom, if ever, be called upon to meet some of these contingencies in actual practice. All of these data it is hoped to present in more complete form in the near future.

The motor itself is simple and rugged; in appearance the only apparently novel feature is a distributor mounted on the shaft for controlling the firing of the tubes. It would seem that the only problem here is to keep the distributor properly enclosed so as to keep out dirt and dust, with the possibility of improper operation from this cause. Two sets of distributor segments are required at present, one set for starting and one for running; it is hoped that further developments will enable one set to be dispensed with, thus simplifying control.

From all the above it is evident that the only unknown in connection with the whole job is the question of tube performance, and particularly tube life. Undoubtedly the tubes available today leave a great deal to be desired, both from the standpoint of life and uniformity, but in fairness to the tube designer, it must be stated that no real progress can be expected until tubes by the hundreds and thousands are put to work in the field and their life histories, including their diseases and complexes, intelligently recorded. This, it must be apparent, is a prerequisite to an intelligent diagnosis and eventual cure. It is here, in the finding of proper tube application, that the utility engineer can do his share in bringing to a realization the promise of advancing the art of generation, distribution, and utilization of electric energy that a full development of the heavy power tubes holds forth.

The cost of this motor is at present higher than that of other variable speed drives, but there is nothing fundamental in this; it will change as tube costs come down, as they surely will, when demands for motors of this type and for other heavy electronic equipment develop. This motor now offers a simple variable speed a-c drive. When the developments mentioned above are realized, it ought to become an inexpensive one also.

L. R. Ludwig (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This motor is made to operate successfully by using circuit means for the suppression of tube faults rather than by eliminating them in the tubes themselves. Although such an arrangement would be satisfactory from a standpoint of operation of the equipment without shutdown, it would seem to be hazardous for the tubes if they are of the thermionic type. The failure known as arcback presents only a small problem in an inverter or commutator tube arrangement, because the fault current is soon reduced to zero by the nature of the circuit, and such a failure would hardly affect the thermionic tube. The type of failure known as loss of grid control, however, may be precipitated by backfire, and even when reactors are used to limit the current to several times normal for a half cycle or so a very unkind blow is given to the cathode of the thermionic tube. If this happens once a day, the life of the tube might be considerably shortened, and I would like to ask if the authors have made life tests to deter-

mine the effect of what might be termed incipient failures, corrected by circuit reactors.

During the development of similar "ignitron" equipment, it was not found necessary to resort to circuit suppression of faults in order to obtain substantial ratings, but schemes for this purpose were devised some time ago, and it might be of interest to mention them since they differ somewhat in principle from the simple introduction of reactance. An inverter can be caused to "ride through" a tube failure, if, when such a failure occurs in one tube, the next tube to carry current is automatically permitted to fire earlier than usual. In this way, the fault current in the tube which failed can be commutated to the next tube. If next the firing point of the successive tubes is gradually retarded to normal, the failure passes by, practically unobserved. With the mercury pool cathode there is, of course, no hazard to the tube.

I would also like to ask the authors if the published performance curves are the results of test or calculation.

The economic practicability of this type of motor seems questionable with tubes in their present state of development. As stated by the authors, their circuit really serves the double purpose of rectification and inversion. Rectifiers are available at a cost comparable to that of a rotating machine converter, and they operate quite satisfactorily although at a power factor poorer than that of a synchronous converter. Inverters, however, will not operate except with the power factor completely corrected, and consequently the inverter tubes cannot be compared in cost with a rotating machine converter, but with the commutator only of that machine. This is very clear from the authors' circuit, in which the commutator simply has been replaced by tubes. At the present time, the tube equipment is considerably more expensive than the commutator, and it would seem that there would be an economic gain if a d-c motor were supplied through a tube rectifier, instead of using a completely commutatorless motor.

P. M. Currier (General Electric Co., Schenectady, N. Y.): In mentioning the characteristics of this motor the authors state that it "operates on an a-c power supply—without any reference to synchronism with the a-c system." Immediately this brings to mind the feature of speed control. I should like to point out another feature which may not be so obvious, i. e., the possibility of its becoming a useful component of an electrical reduction gear.

For example, in propulsion equipment, from the viewpoint of weight, space, and efficiency, it is desired to have the power generating equipment run at as high a speed as possible, while the motor equipment has a fixed maximum speed. If direct current is used for the electrical reduction gear it has the advantage of variable speed but the voltage used must be relatively low and direct current generators are limited in speed to a relatively low value. If alternating current is used it has the advantage of being able to operate at high voltage, but has the disadvantage of not having a variable speed control and of requiring a motor with a large number of poles and a large diameter. A high speed turbine generator of higher than normal frequency feeding a motor of the type described appears to utilize the advantages of both of these schemes without encountering the disadvantages. However, this equipment has not been developed yet to a point where it could be used for large ships.

R. E. Hellmund (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): In the papers by Alexanderson & Mittag and Wagner & Ludwig 2 kinds of arrangements, the work for which was done in 2 different laboratories, are described for adjustable speed motors operated by means of electronic converters. Although work of this character is highly desirable for the reason that something of practical value may eventually result therefrom, it should be pointed out that with the knowledge available at present there seems to be little prospect of a broad general application of these or similar motor arrangements. The situation surrounding these electronic converter motors is somewhat akin to that found in connection with polyphase a-c commutator motors. It will be recalled that a number of years ago and extending over a considerable period of time, many different types of a-c commutator motors were proposed and investigated. However, but few of these types have found any practical application, and the few types that are in practical use have not been applied very extensively. The reason for this is that these commutator motors usually require a larger armature volume (D^2L) than the induction motor and also large commutators and numerous brushes, all of which result in a very high first cost. In addition, these motors are handicapped by the necessity of rather costly brush replacements and commutator maintenance. Furthermore, since the armatures of such

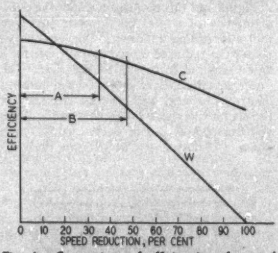


Fig. 1. Comparison of efficiencies of wound secondary and commutator motors

motors must be designed for low voltage, the ohmic drop in brush contacts, together with the brush friction losses, results in a rather low efficiency.

In figure 1 of this discussion, curve W is representative of the efficiency of a wound-secondary motor over the entire speed range and, as is well known, the efficiency drops appreciably with the speed. However, the commutator motor on account of the losses mentioned has a rather low efficiency even at full speed, but the drop in efficiency with reduced speed is somewhat less, as indicated by curve C. If we assume a motor operating somewhat uniformly over the speed range A, it is obvious that over this range a commutator motor will not show any advantage in the way of efficiency. If the maintenance of brushes and commutators and also the amortization of the first cost are taken into account, it is likely that within the speed range B a simple induction motor can be operated as economically as a commutator motor. In other words, economic application of the commutator motor is confined to a few cases where a greater speed range is required and where operation at lower speeds predominates, and to those cases where the steep speed torque characteristic of the induction motor is objectionable.

Unfortunately, the situation does not seem any more promising for the motors described in the papers. As pointed out in the paper on the tube controlled motor, the various motor windings carry current only part of the time, which in turn leads to higher copper losses and consequently necessitates a large armature volume and high motor costs. The addition of electronic devices further increases the first cost. It is also known that, particularly with hot cathode tubes, there will be certain replacements necessary, resulting of course in increased maintenance expense. The efficiency is unfavorably affected by the arc drop of the electronic devices, and in the case of hot cathode tubes by filament losses also. With the arrangement shown by Wagner and Ludwig the motor losses and motor dimensions work out somewhat more favorably and the losses in the hot cathodes are eliminated. However, the particular arrangement shown in the Wagner-Ludwig paper requires a rectifier in addition to the inverter if the primary source of power is alternating current. This means more arc drops and higher first cost than shown in the paper, although neither in excess of that with the Alexanderson-Mittag arrangement. However, the smaller motor dimensions are offset by the necessity of using a transformer with the arrangement shown. There is, of course, the possibility of using "ignitrons" in a scheme similar to that shown for the "thyratron" motor. In this connection it may be pointed out that while the circuit arrangement of the Alexanderson-Mittag paper gives series characteristics with either type of tube, the arrangement described in the Wagner-Ludwig paper give shunt characteristics. As the latter paper deals principally with an inverter, no starting arrangement for the motor has been described but suitable provisions are being developed.

The influence of the arc drop can of course be minimized by using a relatively high voltage, such as 4,000 volts as the motor described by Alexanderson and Mittag. The high voltage is not a great drawback in motor designs for large ratings, and therefore large motors for application in central stations, as mentioned in the discussion by Philip Sporn, may represent one of the more favorable applications for motors of this kind, assuming of course that large speed reductions are necessary for an appreciable part of the time. However, it is believed that even for large motors a good case cannot be made in applications where weight and space limitations are of importance, as, for instance, in railway and ship propulsion work. For the latter application in particular, it seems difficult to find any economies in either first cost or operating costs brought

about by the electronic converter which would more than compensate for the extra cost and losses incident to the use of the inverter. With small motors the arc drop represents an appreciable loss if the motors are designed for low voltages, such as 220 volts, while any attempt to design small motors for high voltages usually leads to very uneconomical designs on account of the poor space factor in the slots. Therefore, with conditions as they can now be foreseen, it appears that these motors with electronic devices will find very little application and only in cases where conditions are particularly favorable.

R. W. Wieseman (General Electric Co., Schenectady, N. Y.): The operation of an a-c motor of this type can be explained by considering a rotating armature machine whose armature winding has 2 independent wye connected circuits as shown by figure 2 of this discussion. The terminals of the 2 windings are connected to 2 segmental slip rings which have 3 segments per pair of poles regardless of the number of armature conductors. For simplicity the neutrals of the windings are connected together and the field circuit is omitted. The field winding may be connected in shunt or in series with the line. The poles and winding represent the motor and the segmental collector rings explain the functions of the tubes and their grid control apparatus including the distributor on the motor shaft.

If direct current is applied to the brushes, current will flow in phases 1 and 2′ as indicated, and the rotor will tend to move clockwise. As the armature rotates, one of the brushes will contact with the next segment and the current will be transferred from phase 1 to phase 3. The sequence of commutation at 60 degree intervals is as follows:

Angular Displacement, Degrees	Current in Phases	Commutation From
0	1 and 2′	
60	3 and 2′	1 to 3
120	3 and 1′	2′ to 1′
180	2 and 1′	3 to 2
240	2 and 3′	1′ to 3′
300	1 and 3′	2 to 1
360	1 and 2′	3′ to 2′

If the currents are traced through the windings in this manner, it will be found that the current in an armature coil never reverses and that a coil conducts current only $^1/_3$ of the time (but during this interval it can carry a higher current than its normal continuous current). The armature copper loss is about twice as much as when the same motor is operated as a conventional synchronous motor with the same output.

To allow sufficient time for the motor counter voltage to commutate the current from one motor phase to another by grid commutation above $^1/_3$ speed, the brushes are advanced as shown in figure 2. This advances the phase position of the motor current wave so the motor draws leading power factor currents whereas the tube circuit draws lagging power factor currents. At starting or at very low speeds within the range of anode commutation, the brushes may be shifted back toward their neutral position and the motor torque substantially increased. Thus by shifting the brushes on the motor distributor the torque per unit current can be made higher at starting and at very low speeds than at full speed. At all speeds the motor torque varies somewhat with the rotor position and the magnitude of the torque variation increases as the brush shift from the neutral position increases. No dead points occur with a suitable arrangement of the grid control circuit.

This type of motor has advantages when large speed variations are required. Its speed is not governed by the supply frequency nor by the limits of pole flux variation nor by commutation difficulties. It can be operated from a constant frequency single phase or polyphase supply at any speed from a few revolutions per minute up to its rated speed by simply moving the

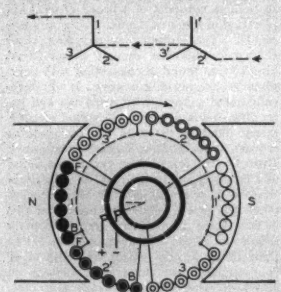


Fig. 2. Diagram illustrating operation of motor

controller. No power is lost in rheostats of any kind in the motor circuit.

Figure 3 of this discussion shows the characteristics of a 400 horsepower, 625 rpm motor for driving a blower. The lower curve shows the required blower horsepower for a speed range of from 625 to 350 rpm. The line kilovoltamperes, power factor, current, controller setting, and over-all efficiency of the set for this speed range are given. From 400 horsepower motor output at 625 rpm down to 75 horsepower at 350 rpm, the over-

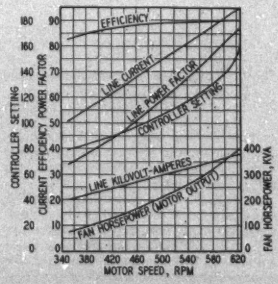


Fig. 3. Characteristics of 400-horsepower 625-rpm 2,300-volt tube-controlled a-c motor for driving a blower

Distributor brush setting 48 degrees advanced

all efficiency drops from 90 to 83 per cent, a decrease of only 7 per cent. The larger the speed range of this type of motor, the greater is its advantage over conventional variable speed motors.

E. F. W. Alexanderson and **A. H. Mittag** (both of General Electric Co., Schenectady, N. Y.): We have had experience with loss of grid control or firing of tubes out of turn. A tube approaches loss of grid control gradually and after a half cycle of such failure it usually operates without failure for a considerable length of time, perhaps a whole day, before there is another failure. Of course, as time goes on these failures become more frequent. The current limiting reactor shown in figure 1 of the paper limits the current for this type of failure as well as for arcbacks and prevents a shutdown of the motor so long as these failures do not occur in too rapid succession. Ample warning is therefore given and at the first opportunity such a tube should be removed.

A tube controlled motor supplied from a d-c source of power can be started from standstill. The commutation of current can be accomplished at standstill and at low speeds with the aid of static condensers.

The performance curves shown in the paper are the results of tests made on our 4,000-volt 400-hp motor.

Industrial Electronic Control Applications

Discussion and authors' closure of a paper by F. H. Gulliksen and R. N. Stoddard published in the January 1935 issue, pages 40–9, and presented for oral discussion at the electronics symposium of the winter convention, New York, N. Y., January 24, 1935.

W. D. Cockrell (nonmember): Gulliksen and Stoddard are to be commended on having written an excellent and instructive article. An interesting point is the large number of copper oxide rectifiers used in the circuits described, which would seem to indicate that the reliability and aging characteristics of these devices have been greatly improved in the last few years.

The diagrams of most of the photoelectric relays include a winding for the light source within the relay enclosing case. There is some question as to whether in general it is preferable to provide a winding for the light source at the relay, since because of the low voltage and high current taken by the light source lamps the drop in the lead may prove excessive. There is also the consideration that if a small transformer is provided at the light source it may be supplied directly from the standard 110 or 220 volt lines which are most convenient to the light source location.

There are, also, a few points in the individual circuits on which the authors' comments are desired. Figures 1, 7, 9, and 11 of the paper show copper oxide rectifiers in the photoelectric tube circuit, although the tube operated by the photoelectric tube has an alternating current supply. Since the speed of operation is determined by the frequency of the alternating power supply,

and since the grid impedance of the vapor discharge tube must be low enough so that for normal lengths of photoelectric tube cable the capacity effect will not be prohibitive, it would seem that the addition of the rectifiers to produce a direct voltage for the phototube is a needless complication of the circuit.

Regarding the lock-in type of controller shown in figure 6, has there been any difficulty from the *KU*-627 tube failing to commutate? Is an auxiliary reactance used in practice to facilitate this action or is the inherent reactance of the circuit sufficient? It would seem that 2 features would tend to cause erratic timing with this particular circuit. The actual instant of pickup of the solenoid would be somewhat dependent on the heating and subsequent resistance of its coil. Also, since the timing contactor can charge up only to the cathode potential of the *RJ*-563 tube, its potential is changing very slowly as it approaches the proper grid potential to energize the solenoid.

It is noted that the electron voltage regulator shown uses a dry battery as the reference voltage. Our practical experience has shown that it is very difficult to have these batteries checked and replaced properly and it has been found best to eliminate batteries from any industrial control equipment in so far as possible.

In the register regulator shown in figure 21 it is seen that a double photo-electric tube bridge is used. Are matched tubes used for this application? If this is not the case, is not the adjustment of the unit very critical and tedious? And is not the adjustment rather critical to the difference in aging in the light sources or in drift in photoelectric tube sensitivities? Are the photoelectric tubes used here of the gas filled or the vacuum type? The voltage characteristics of the gas filled tubes would tend to produce degenerative effects, i. e., the voltage increase across the darkened tube would tend to diminish the expected current change. The vacuum type, of course, is but a fraction as sensitive as the gas filled photo-electric tube.

R. L. Goetzenberger (Minneapolis-Honeywell Regulator Co., Minneapolis, Minn.): Another practical application of electronic control, and incidentally one which has been adopted as a standard of combustion safeguard, is incorporated in a system involving the closing of fuel valves the instant that flame ceases, consequently guarding against explosions of unburned gas which might accumulate in a combustion chamber fired with gas or oil fuel. In functioning it depends upon the fact that a flame is a slightly ionized gas mixture which will conduct a small current. An electrode, either a rod of high temperature alloy or a ceramic sleeve, is projected into the flame. Current is carried by the flame to ground through the burner with which it is in actual contact. An industrial electron tube magnifies this current to close a relay controlling the motor or solenoid operating the fuel valve. If the flame fails to impinge on the electrode the bleeding off of the charge to ground ceases, the tube passes no current, and the relay opens, de-energizing the valve with the result that the flow of fuel to the burner is stopped.

Since this system utilizes the flame itself as a conductor for the current required in operation, it offers certain definite advantages over other types of combustion safeguards, such as:

1. Instantaneous response.
2. Positive response unaffected by light, heat, or radiant energy; affected only by flame. Incandescent refractories or heat absorption cannot cause false operation or delayed response. Works equally well in visible or invisible flames.
3. Independent of size of flame, hence suitable for high-low burners. It is necessary only that the flame electrode extend into some portion of flame present in both high and low operation.
4. Applicable for use with any existing control system where alternating current is available.
5. Closed circuit protects itself against its own failure. Any damage to tube, break in wire, short circuit, or defective connection anywhere in the safety system shuts down the burner immediately.

C. Stansbury (nonmember): I believe that all engineers who have had practical experience in the application of electronic devices in industry will agree with me that the use of such devices accentuates the already pressing need for more competent plant electricians. It is the common experience of control engineers that the average plant electrician does not seem to be capable of understanding the functioning of an ordinary lockout self-starter, and that being the case it may readily be imagined how helpless such men would be when faced with the necessity of intelligent maintenance work on apparatus of the character described in this paper. It is quite common to find men in charge of mechanical apparatus who are skillful and intelligent mechanics, but even a rudimentary knowledge of electrical phenomena does not appear to be a requirement in the selection of the average plant electrician. This constitutes a really serious impediment in the task of the exploitation of industrial electronic apparatus.

It has been mentioned that an electronic device may be made entirely safe by so arranging the circuit that the failure of the tube to conduct shuts down the system and gives a safe condition. This brings up one of the most serious defects of tubes for industrial application in that a tube may either fail to conduct when it should, or fail to block the conduction when called upon to do so. Such a possibility exists in any device used to open and close circuits. In the case of an ordinary magnetic contactor of normally open type, the probability of the contactor failing to open when the coil is de-energized is very slight. The probability of the contactor failing to close when the coil is energized is somewhat greater because of the possibility of a burned out coil, low operating voltage, or defective contacts in the circuit. It is a fundamental principle of ordinary magnetic control practice, therefore, to make the safe condition correspond to de-energized operating coils so that the dependence for reliability as regards safety is placed essentially on gravity or at least a substantial spring.

However, a tube will always ultimately fail to conduct when it wears out in service so that circuits have to be designed to give the safe condition with the tube not conducting. There results the necessity for means for blocking conduction in the tube when not desired which shall be of the same order of reliability as those used with the magnetic device, if equivalent safety is to be attained. No such reliability in this respect can be claimed for tubes at the present time and the result is a serious limitation on their application.

F. H. Gulliksen and **R. N. Stoddard** (both of Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): In reply to Cockrell's remark concerning the location of the light source transformer, it may be of interest to point out that in most installations space is at a premium at the location where the light source is mounted. For this reason it is desirable to make the light source as small as possible, and this can be easily done by omitting the special light source transformer. It is also often desirable to make sure that the photoelectric relay and the light source are excited from the same a-c source in order to prevent independent variations in voltage which might affect the operation of the equipment. The voltage drop in the light source leads is compensated for by the provision of voltage taps on the transformer.

The purpose of the copper oxide rectifiers in figures 1, 7, 9, and 11 is to supply continuous voltage to the photoelectric tube. Alternating voltage of course could have been used, but in that case the length of the tube leads must have been limited to perhaps 15 or 20 feet, owing to the effect of the capacity between the leads. This distributed lead capacity, which would be in parallel with the tube, would produce a phase shift in the tube circuit which would affect the sensitivity and the calibration of the relay. By using a d-c supply this detrimental capacity effect is avoided. The purpose of the continuous voltage is not, as assumed by Cockrell, to increase the operating speed of the relay, which as stated by him is limited by the 60 cycle anode supply voltage.

No difficulty has been experienced with the commutation of the *KU*-627 tube in figure 6. If the resistor in series with the anode is made sufficiently low compared to the condenser charging resistor, the anode-cathode voltage of the tube will drop below the arc drop of the tube and the current through the tube will be interrupted. The effect of temperature variations of the solenoid coil is minimized by the resistor connected in series with the solenoid coil.

The ohmic resistance of this resistor is approximately 10 times the solenoid resistance, and slight changes in solenoid resistance, therefore, will not change the current through the solenoid appreciably. The solenoid is normally energized, and becomes de-energized when the photoelectric controller operates. Because the total de-energizing time of the solenoid is approximately 0.5 cycle, a few per cent variation in de-energizing times does not have any appreciable effect on the operation of the equipment.

The writer agrees with Cockrell that it would be desirable to eliminate the batteries in the voltage regulators. No practical regulator, however, has yet been developed with a sensitivity of $^1/_{10}$ of one per cent without using a battery. The life of a dry cell is between 8 and 12 months, and the replacement of this cell is, therefore, no serious drawback.

Matched tubes are not necessary in the register regulator in figure 21, because a

balancing potentiometer is supplied to compensate for variations in tube characteristic. It is desirable, however, to use tubes as nearly matched as possible. Vacuum tubes must be used in this balanced circuit. Due to the characteristic of the circuit, the over-all sensitivity of the scanner, using 2 vacuum tubes, is the same as the sensitivity of a single photoelectric tube scanner using a gas filled tube; even though the sensitivity of the gas filled tube is 5 times the sensitivity of the vacuum tube. The reason for this is that when the illuminaton of one photoelectric tube is increased, the voltage across this tube is decreased and the voltage across the other photoelectric tube is considerably increased. Because the circuit is designed so that the tubes operate normally above the saturation voltage, it is obvious that a gain in sensitivity is obtained.

Application of Electron Tubes in Industry

Discussion of a paper by D. E. Chambers published in the January 1935 issue, pages 82–92, and presented for oral discussion at the electronics symposium of the winter convention, New York, N. Y., January 24, 1935.

R. L. Goetzenberger: See discussion, page 753.

The "Ignitron" Type of Inverter

Discussion and authors' closure of a paper by C. F. Wagner and L. R. Ludwig published in the October 1934 issue, pages 1384–8, and presented for oral discussion at the electronics symposium of the winter convention, New York, N. Y., January 24, 1935.

R. E. Hellmund: See discussion, pages 751–2.

C. C. Herskind (General Electric Co., Schenectady, N. Y.): The authors point out that in order that a mercury arc rectifier may be capable of operating as an inverter, it is essential that the anodes have a short deionization time. Large size metal tank rectifiers equipped with control grids, and having an estimated deionization time of 250 microseconds or less, have been in operation for a number of years. It can be shown that a deionization time of less than 250 microseconds is not necessary for operation as an inverter at normal frequency.

Expressed in angular units, at 60 cycles, a deionization time of 250 microseconds corresponds to approximately $5^1/_2$ electrical degrees. If it is assumed that the inverter is operating at the commutation limits, it is necessary to advance the grid excitation only about from 2 to $2^1/_2$ degrees in order to obtain sufficient time for deionization, as a small increase in the angle of grid advance causes a considerable reduction in the overlap period. The variation in the angle of overlap with the angle of grid advance for an inverter has been shown on curves given in the paper "Grid Controlled Rectifiers and Inverters," C. C. Herskind, ELECTRICAL ENGINEERING, June 1934, pages 926–35.

When using valves having deionization times of 250 microseconds or less, the accuracy of anode starting is more important than is the length of the deionization period. Experience with a large number of grid equipped rectifier units indicates that there may be a gradual contamination after a long period of operation, and that any foreign matter within the vacuum chamber tends to accumulate in the cathode region and not at the anode. From this we might logically assume that a control device located in the anode region would be more reliable than one in the cathode region. Experience further shows that the grid characteristics become subject to less variance the longer a rectifier has been in operating service. I would like to ask what is the effect upon the ignitor of contamination of the type which might be obtained in normal rectifier operation.

The authors state that the application of the mercury pool cathode inverter has been restricted by the limitations of the grid type of control, due to the grid construction being cumbersome and costly. I wish to point out that over 90 rectifiers equipped with grids suitable for grid control have been sold in this country alone in direct competition with uncontrolled rectifiers for applications not involving use of grid control.

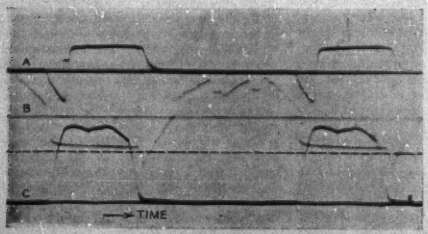
The accompanying reproduction, figure 1, of an oscillogram shows the anode current and voltage wave forms of a 6-phase 1,500-kw 3,000-volt mercury pool rectifier, operating as an inverter at a d-c input of 1,000 amperes and 2,500 volts. This unit was operated at 2,500 volts instead of 3,000 volts, not because of any limitation of the rectifier, but because of the limitations of the available transformer and loading equipment.

The authors state that the control grid is often a source of trouble within the tube since conditions are difficult to avoid under which it will be burned by the arc. I wish to point out that very little trouble has been experienced with rectifiers equipped with grids; and further the danger of burning may be avoided by using grids constructed of graphite, which is practically indestructible as regards burning.

C. F. Wagner and **L. R. Ludwig** (both of Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): We are in agreement with Herskind that a deionization time of less than 250 microseconds is not necessary for the successful operation of an inverter. We cannot see how this can be construed to be inconsistent with the statement that a small deionization time is essential. In conventional rectifiers these small deionization times are obtained by the use of grids and are consequently bought at the expense of higher arc drops. Inherently, a rectifier using the "ignitron" principle can be built with a smaller arc drop.

Herskind also refers to our statements regarding the limitations of grids and the burning of grids in conventional rectifiers. We do not question that it is possible to obtain grid structures which are free from burning or backfire difficulties. However, the presence of these grids necessarily increases the arc drop, and consequently it is of advantage to dispense with the grid if equal or more reliable control is available in another way. It is quite probable that even with "ignitrons" certain applications will require the presence of grids, but even so, the grid structure with the "ignitron" will be smaller than the grid structure for a corresponding conventional grid-controlled rectifier.

From laboratory tests and a large number of rectifier hours in the field we have found that the ordinary cathode contamination collected during normal operation has no appreciable effect upon the ignitor or its starting function.



A. Grid current

B. Anode to cathode voltage (using capacitor in series with potential transformer. Cathode voltage indicated by dotted line)

C. Anode current

Fig. 1. Oscillogram showing anode current and voltage waves on a 6 phase inverter with input of 1,000 amperes, 2,500 volts direct current

Ratings of Industrial Electronic Tubes

Discussion of a paper by O. W. Pike and Dayton Ulrey published in the December 1934 issue, pages 1577–80, and presented for oral discussion at the electronics symposium of the winter convention, New York, N. Y., January 24, 1935.

R. E. Hellmund (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): I wish to indorse heartily the efforts of the authors to bring about standardization of industrial electronic devices and to emphasize in particular the necessity for establishing standard ratings by the "preferred numbers" system as touched upon in the last part of the paper.

Much enthusiasm has been manifested by engineers in the past over the possibilities of

electronic devices for application in the industrial and power fields and the papers presented during this convention present new evidence of such possibilities. Nevertheless the total number of applications for each of the many possible types of devices is so far decidedly disappointing. The reason for this is that the cost of electronic devices for fields other than radio is too high, this high cost of course being brought about by the fact that there are so many types and sizes that quantity production for any one of them is impossible. Therefore, nothing can contribute more toward furthering increased application than standardization. Unfortunately it will be necessary to have many types of tubes to fill the large variety of requirements and therefore it is essential that but few standard ratings for each type be selected if an unduly large total number of standards is to be avoided.

Fortunately the conditions applying to tubes favor the use of but few ratings with large steps between them. Figure 1 indicates in a general way the cost of different

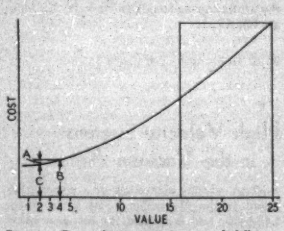


Fig. 1. General variation in cost of different sizes of tubes

sizes of tubes. It will be seen that for the lower ratings this cost curve is very flat, because for these smaller tubes the labor content forms the largest part of the cost, the material being of secondary importance. Let us assume that ratings were established at values 1 and 4, meaning a 300 per cent step between them. If, then, in an application requiring a tube of the value 2, a tube of the value 4 were used, the increased cost of this tube over that of the value 2 tube would be represented by the very small amount *A*. However, very appreciable savings would result through having to carry on less development, keeping fewer stocks, and being able to manufacture the value 4 tube in larger quantities. For the higher ratings, where the material content is of relatively great importance, it may of course be necessary to use somewhat smaller steps, such as the 60 per cent step indicated between the values 16 and 25.

I am thoroughly convinced that little progress will be made in the application of electronic devices unless early and effective standardization is worked out and relatively few ratings chosen along the line just indicated so as to lower costs and improve quality. I wish to support the authors in their recommendation that such ratings be selected from the preferred numbers series, because in such new standardizations these numbers can be used without the usual difficulties arising from interfering with already established standards.

A New Timer for Resistance Welding

Discussion of a paper by R. N. Stoddard published in the October 1934 issue, pages 1366–70, and presented for oral discussion at the electric welding session of the winter convention, New York, N. Y., January 23, 1935.

W. C. Hutchins (nonmember): The author has stated in connection with the use of electron tubes for resistance welding that "welding current always begins at a predetermined point on the voltage wave regardless of time of closure of the initiating switch." Also we know this type of tube stops passing current at the zero point on th current and following the removal of igniter power.

The mere mention of these facts does not convey their importance. True enough they imply that accurate timing can be accomplished using a timer which is not so accurate. In other words the time during which power is supplied to the welder will be the interval from the predetermined point on the voltage wave to a zero point on the current wave. In order to get perfect timing, it is then necessary to have a timer accurate only within approximately a half cycle.

Consistent firing or starting at a predetermined point on the voltage wave is very important for another reason, that of minimizing transient currents which are so common, with the ordinary mechanical or magnetic interrupters. Even though accurate timing is accomplished, if transient currents frequently occur welds made in only 2 or 3 cycles probably will be inconsistent. In one instance, the user of a seam welder equipped with a mechanical nterrupter was getting considerable variation in the quality of his welds and also the welding transformer overheated to a dangerous temperature. To improve the weld quality, a tube control was applied. The result was that rejects were practically eliminated and the welding transformer no longer overheated; in fact it did not reach its rated temperature. The reason for the lower operating temperature was the elimination of the transient currents giving a lower average current in the primary of the welding transformer. From this it may be concluded that with the electron tube control a given design of welder may deliver more power than when ordinary mechanical interrupters are used.

The factors that determine the most effective point on the voltage wave for beginning passage of current are power factor of load, exciting current, and residual flux.

When spot welding, the primary and secondary circuits are opened between each weld. Transients which may occur when making a weld are consequently eliminated before the succeeding weld. The elimination of a possible cumulative action of transients permits considerable variation in the adjustment of the starting point.

When seam welding, the secondary circuit of the welding machine is usually not opened for several hundred impulses of power. Any unbalance remaining from one impulse is added to the succeeding unbalanced impulses. This cumulative action might eventually result in so large a transient as to cause poor welding. Therefore, it is necessary to adjust the point of firing much more accurately with seam than with spot welding, and it is the writer's belief that this can be satisfactorily accomplished only through the use of electron tubes. Mechanical devices for interrupting the welder current directly would naturally wear and require frequent adjustment. Even then it would in all probability be impossible to adjust for the exact starting point.

R. E. Hellmund (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): Spot welding by means of electronic devices has been found particularly advantageous in the welding of thin sheets of stainless steel. Seam welding of materials of high conductivity is another instance where welding by electronic devices has proved of great advantage. In neither of these cases

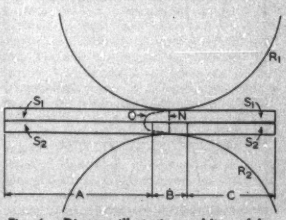
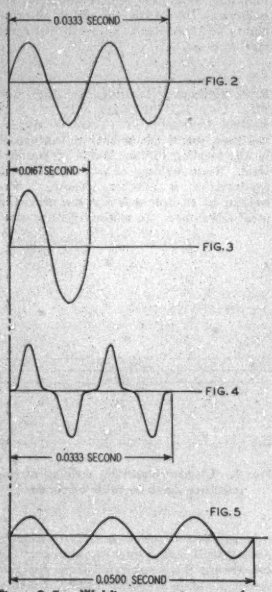


Fig. 1. Diagram illustrating welding of low resistance sheets by roller electrodes

were satisfactory results readily obtainable with mechanical switching devices. In considering the reasons for these superior results, it is usually assumed that the ability of electronic devices to govern exactly the total amount of energy in each weld over a very short period of time is the essential feature. This is probably true in connection with stainless steel, where this feature minimizes deterioration of the material in the welded area, especially on the outer surfaces of the sheets. However, I believe that in seam welding of low resistance materials, correct control of the rate of rise of the welding current is of equal importance if not greater than exact gauging of the energy.

Figure 1 of this discussion shows 2 sheets (S_1 and S_2) of low resistance material to be welded by the roller electrodes R_1 and R_2. It is assumed that the welding of the distance *A* is completed and a welding current is about to be sent through the area *B* to effect the next weld. It may further be assumed that there is in many cases a high resistance oxide film on the surface of the sheets, as indicated by the heavy line over the distances *B* and *C*. If the ohmic resistance alone is considered, it is likely that on account of the low resistivity of the material the current would essentially follow the path *O* instead of the path *N* as desired. If, however, inductance is present in addition to ohmic resistance, the higher inductance of the path *O* will force a greater portion of the current through the path *N*.

It is therefore evident that high inductance, and consequently a higher rate of rise in the welding current, may be essential to accomplish satisfactory seam welding with low resistance materials. Although it may be possible to produce equally satisfactory individual spot welds with currents as shown in figures 2 and 3 of this discussion, as-



Figs. 2–5. Welding current wave forms

suming that the total energy is the same in both cases, the current in figure 3, on account of the greater rate of rise in the welding current, may give much better results than that in figure 2 in the case of seam welding, because as pointed out a greater portion of the total energy will go through the spot to be welded. It is also likely that with even a smaller amount of total energy, the type of current wave shown in figure 4, which as stated in the paper can be readily obtained and exactly controlled by means of an electronic timing device, will give more satisfactory results than the current in figure 2, again for the reason that a greater portion of it is likely to go through the spot to be welded.

The magnetic properties of the material to be welded should also be of importance in connection with these phenomena. If the material to be welded has magnetic properties, it will, other conditions being equal, be much easier to accomplish seam welding without steep wave fronts because the path O will naturally have higher inductance than the path N.

Control of the steepness of the wave front may also be of advantage in controlling the size of the spot weld in the case of high resistance materials. It is well known that with high frequencies there is a so-called "skin" effect, tending to force the current toward the outer layers of the conductor. This is indicated by a number of current paths (N, P, and Q) in figure 6. However, if the material is of high resistance, most of the current will have more of a tendency

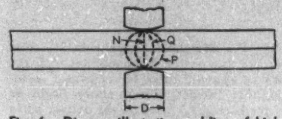


Fig. 6. Diagram illustrating welding of high resistance material

to follow the shortest path N with normal sine waves of standard 60 cycle frequency as indicated in figure 5. With higher frequencies, greater spreading of the current and a larger weld could be effected. Changing the frequency is, however, usually inconvenient, but equivalent results can be obtained with an electronic welder by means of a wave shape as indicated in figure 4. Here again the magnetic quality of the material to be welded may have appreciable influence upon the result because it influences the "skin" effect.

In practice it is customary to find the best adjustment by the cut-and-try method, but appreciation of the importance of the steepness of the current wave, as pointed out in this discussion, may be of assistance in arriving at the proper adjustment more quickly.

H. L. Palmer (nonmember): It is interesting to note that the author describes the use of a mechanical timer to control the power tubes on his line welder control. When using a motor driven interrupter it seems somewhat awkward to change a considerable number of slots in a disk or to put on a new disk. In order to make a large change it may even be necessary to change the gearing between the motor and the disk, and the interrupter must be gear driven in order to maintain synchronism. The welding cycle, or "time on" plus "time off," is confined to a definite number of combinations unless a complicated gear changing mechanism is used. In order to meet the exacting requirements of accurate firing points for the power tubes, this mechanical timer must be a precision device that may require considerable maintenance.

The author under "Description and Rating" states that one of the adjustments in the control box controls the point on the voltage wave at which the weld is initiated. The determination of the correct point of firing the first cycle of a multicycle spot can be determined only by observing the line current by means of an oscillograph. Therefore, the advisability of putting such a control in the hands of an operator seems doubtful unless he is provided with some means of checking his line current transient.

It would seem that such an adjustment which is a function of the particular welding machine and its secondary leads, and not the work, might better be at the main control panel and be changed only by a maintenance man with the necessary instruments. If the operator should get the firing point too far off from that providing minimum line current transient, excessive current surges and saturation of the welding transformer will result. In the case of high duty spot welding this will overheat the welding transformer by excessive exciting current in this saturated condition.

It would be interesting to know just how Stoddard expects the operator to know when this adjustment is correct.

A High Power Welding Rectifier

Discussion of a paper by Daniel Silverman and J. H. Cox published in the October 1934 issue, pages 1380–3, and presented for oral discussion at the electric welding session of the winter convention, New York, N. Y., January 23, 1935.

R. E. Hellmund: See pages 755–6.

High Velocity Streams in the Vacuum Arc

Authors' closing discussion of a paper published in the November 1934 issue, pages 1454–60, and presented for oral discussion at the electric welding session of the winter convention, New York, N. Y., January 23, 1935. Other discussion of this paper was published in the April 1935 issue, page 444.

E. C. Easton, F. B. Lucas, and F. Creedy: L. R. Ludwig has repeated the authors' warning against accepting some of the results of our work without further experimental confirmation.

All tests on the copper arc were conducted at the same time and with the same electrodes. Each point on the curves is the result of one test, but the distribution of successive observations between the 2 curves is quite random. There were, unfortunately, no measurements of arc drop. If this division into 2 curves is not due merely to experimental error, then there must be 2 conditions under which the copper arc may exist. Each of these conditions may be marked by a different velocity of the cathode stream, a different velocity distribution, or, as Ludwig points out, by different masses of the particles which make up the arc stream. The authors have stated in the paper that they themselves are not yet convinced of the existence of this condition of dual stability.

The authors do, however, accept the existence of an anode stream. We have reported the observations which cast doubt on the evidence. The most significant of these concerns the appearance on the vane of cadmium from the shielded electrode. This result, however, can have but little bearing on the tests on the tungsten anode. Here, with a copper cathode, no copper reached the vane. The force on the

vane must, therefore, have been due to the tungsten anode stream. Definite conclusions concerning the variation of velocity with current cannot be drawn from the scanty data at hand.

The occurrence of 2 curves in figure 11 is unexplained. This figure together with the other controversial features of the paper is presented in the hope that other investigators may be inspired to further experiments which will confirm or refute the relations which we have suggested.

Engineering Education Is Meeting the Challenge

H. W. Bibber, October 1934 issue, pages 1356–9

On the Schooling of Engineers

Alex Dow, December 1934 issue, pages 1589–91

Characteristics of a Group of Engineers

Thomas Spooner, December 1934 issue, pages 1571–6

Discussion of a group of papers presented for oral discussion at the session on education at the winter convention, New York, N. Y., January 22, 1935.

P. L. Alger (General Electric Co., Schenectady, N. Y.): In my opinion, these papers form one of the most interesting and thought provoking series ever presented before the Institute. They are encouraging because they show progress is being made in the application of engineering methods to the development of human talents, and they are especially interesting because they reveal the latent possibilities in the development of the social as well as the technical talents of the engineer. The papers constitute an inspiration to all of us to contribute what we can to the further development of engineering education.

An aspect of this subject which interests me particularly is the measurement of the inherent qualities most helpful in attaining engineering success. For success in any field, of course, it is necessary to have energy, courage, and especially initiative, which imply willingness to assume and carry responsibility. Also, the faculty of judgment, or making wise decisions, is essential.

I believe, however, that technical imagination is the one quality which is outstanding in importance for success in engineering as distinguished from other lines. By technical imagination I mean the ability to so observe a particular diagram, object, or machine that its fundamentals, which are invisible to the average person, come to light. Just as the skeleton of a patient is clear in the mind's eye of a surgeon, despite the interposition of clothing, so imagination enables the engineer to see in his mind the lines of flow of the invisible air, or magnetic flux, or electrons, and to truly understand the behavior of the thing observed. This same faculty immediately brings to mind a whole series of pertinent questions whenever any object is critically observed. Anybody seeing a skeleton with half the bones missing would be moved to inquire for them. The unknown principles of any mechanism are equally obvious to the engineering mind.

With such imaginative ability, an urge to immediate action is self-produced, and a foundation for engineering success is made available. I, therefore, believe that some measurement of this faculty of technical imagination, or curiosity, or call it what you will, should be included in every test to select engineering talent.

A second quality, emphasized by Spooner, and which I think has grown much in importance in recent years, is that of co-operative ability, which really means human understanding, or plain sympathy. The tremendous development of science and the growth of large industrial organizations depend upon, and in turn require, increased specialization. In any large project, therefore, numerous individuals must contribute, and the progress made is vitally dependent on the degree of co-operation secured. The question then arises if co-operative ability can be measured.

Co-operation is secured when and only when every individual in a laboratory can draw as often and as deeply on the knowledge of every other member of the staff as he desires, without friction and with the minimum of effort. To co-operate most effectively, it is absolutely necessary that the individuals not merely understand each other, but that they trust each other. Some people have the faculty of appearing to be co-conscious of the ideas and feelings of their fellows, or themselves to receive the emotions and ideas of others with extraordinary facility. Intelligent sympathy of this sort appears to me essential if co-operation is to be secured, and this quality, therefore, is of great importance for success in modern engineering work.

In independent work and in small organizations, the faculty of aggressiveness seems of greater importance, but in larger organizations that of co-operative ability seems predominant, as this ability provides the cement that holds together the numerous human elements in the working group.

I like to think of engineers in industry as separate stones forming a masonry structure. To get the best results, the problem is to build the complete structure with the greatest strength to resist forces applied in any direction. The only cement that can be used is the co-operative ability inherent in the individuals. At best, however, this cement is weak, so that the strongest structure results when a few large stones of interlocking shapes are used, rather than a large number of small round stones. In the same way, it is important to use 2 abilities possessed by a single engineer, rather than to rely on 2 engineers with single abilities. The best engineering organization will result when the ablest individuals are allowed to exercise all their abilities to the fullest degree, and the best co-operators are used as connecting links between groups.

My conclusions are that engineering colleges should, first, select the ablest students they can secure, and then develop their individualities, especially their technical abilities, along the broadest possible lines in the time allowed, including some cultural training. Colleges should make every ability of a student take root and sprout, but should not develop any specific ability very far. After receiving these men, industry should first cultivate the specific abilities most suited to the work to be done, and later the co-operative and administrative abilities that develop with experience. Furthermore, every industry should continually tailor its jobs to fit the growth of the individuals available, rather than try to cut any man down to fit a prescribed job.

Alan Howard (General Electric Co., Schenectady, N. Y.): I have been very much interested in the ideas expressed in these papers and I am glad to see the co-operation and mutual understanding between the schools and industry continue to be increased materially. I am particularly interested in the relation of education to industry since for the last several years part of my work has been in connection with the advanced course in engineering of the General Electric Company. I have thus been in educational work and industry at the same time and so have had an unusual opportunity to see several sides of the picture.

In this work I have seen many exceptionally capable men get their start in industry, and based on this experience there is one important aspect of the training of men to which I would like to call attention. It is an aspect which is implied in nearly all papers on education but it is not pointed out as definitely or as often as is desirable. It is a point which many men coming into industry do not appreciate.

Success in industry is synonymous with accomplishment. Those men get ahead fastest and furthest and are of the most value to society and industry who achieve the most—obtain results—*get things done.* Many graduates have the idea that knowledge, the ability to co-operate, the willingness to work hard are fundamental and that they will be advanced primarily because of qualities of this type. This is not true. These qualities are very desirable, but none of them is basic; advancement is necessarily based almost entirely upon achievement. That is, if a man can make real accomplishments, he will be successful, even though he is materially lacking in many of the factors usually associated with success.

Many engineering graduates have had the habit of studying and working with the primary objective of increasing their store of knowledge for so long that when they arrive in industry they naturally continue in this way. Their prime motive appears to be to gain information and experience rather than to be of service. If questioned directly, they generally state that they believe accomplishment to be fundamental, but their actions and attitudes all too often indicate that they do not realize the importance of *getting things done;* of arriving

at definite and useful results. They do not have the habit of achievement.

The responsibility for the development of this habit of achievement doubtless rests largely with industry, but I believe the colleges can, and that many do, help materially in this respect by continually emphasizing the importance of applying knowledge and ability toward definite ends, and by arranging courses and activities so that students get as much experience in such application as possible.

The specific idea I wish to emphasize is that in addition to being educated in knowledge and co-operation, it is extremely valuable and helpful to the college man to be educated in accomplishment, to have formed the habit of achievement, as well as the habit of study, to be experienced in using his good qualities in addition to merely possessing them. Those graduates who do have the habit of achievement fit more easily into industry and progress more rapidly than those who have to learn this habit after they arrive.

H. W. Bibber (Ohio State University, Columbus): It is most interesting to see that Alex Dow's opinion—that there should be an increased emphasis on the arts of expression, economics, and history in our engineering courses—coincides with that of a fairly large number of Ohio State Engineering College alumni whom we have approached on this question of curriculum content.

Dow's suggestion that a student would do well to go into the field for a couple of years and thereafter come back to school for further work strikes a responsive chord in the heart of every engineering teacher. As a result of the depression there have been many students who have done this at my institution in the last 3 years, with definitely more value to themselves than is often the case with those who take a fifth year immediately following the 4 year program. But in normal times or for those recent graduates who have secured employment, how difficult it will be for them to cut loose from the work in the field where they have been fortunate in securing employment! Many in the course of a year or 2 in the field get married. This makes their return to school more of a problem, but not, of course, impossible. The one thing that would help in this further postgraduate education of junior engineers is to have employers promise re-employment at an increased salary on the conclusion of a satisfactory period of postgraduate study in some university or college. One would think that the self-interest of employers of engineers would lead them to do this. Up to this time I have heard, however, of only a few cases where this apparently promising measure has been taken.

Thomas Spooner in his paper has given the added weight of definite quantitative evidence to the contention set forth in my own paper, that the school should be more a part of real life. Quite as he states, this is not in line with the mass production of engineers, or the effort to improve the "efficiency of instruction" by raising the number of students taught per instructor.

At Ohio State we make use of the Student Branch of the A.I.E.E. to present talks by men from industry to emphasize the importance of personality factors. Each year I make it a practice to have several conferences with men who are failing in their course work, and in the course of these I have discovered several interesting things. To quote just 2 cases which are typical will perhaps show the possibilities of an early study of personality traits. One student who was failing the class work in a-c machinery lacked interest and appeared indifferent and dissatisfied, but the sketches and diagrams of his laboratory reports were excellent. It developed that his real interest was in art, and a transfer to the fine arts department has made him a successful student and revolutionized his attitude, with I think, ultimately far greater promise of professional success. The second case is a student whose work in d-c machine theory was unsatisfactory, and whose ability to grasp technical material was apparently very slight. After considerable questioning the reply came from him that he was taking the electrical engineering course because he wanted to work in a radio station, but not, it developed, in an electrical engineering capacity. He was absolutely in the wrong groove. A transfer to the college of arts where a specially devised curriculum has been laid out for him has turned him from an academic failure to a success, and has worked wonders in altering his mental outlook. One cannot, of course, predict what progress this student will make in actual employment with some radio station, but a fair estimate would place his success much higher there than it ever would have been in professional electrical engineering.

Mention has been made of the fact that the broadening studies included in an engineering curriculum may need to be conceived in a different manner than has been traditional. I quite agree. Psychology, as I view it personally, is a science based upon the more fundamental sciences of life, such as biology, zoology, bacteriology, etc., so that in this sense it is a science dealing directly with factual matter and therefore analogous to the physical sciences. Perhaps I should have spoken of the social studies rather than social sciences, as many engineers and perhaps biologists would not consider the use of the "science" term justified. In economics and business organization there is considerable lack of agreement as to the conclusions to be drawn from data derived from observations of the same phenomena. There is a large amount of opinion carrying a heavy charge of emotionalism. The traditionalists and the verbalists may well confuse engineering students, and social studies taught in the traditional way may contribute but little to the development of the engineering student. I recognize all this, and therefore the newer type of instruction in the social studies is implied in all I have said.

Ernst Weber (Brooklyn Polytechnic Institute, Brooklyn, N. Y.): Bibber tries to incorporate social sciences into the engineering curriculum and a feasible method to do this is described under the heading on "Make-Up of a Modern Engineering Course." It seems evident that the strength of engineering education is the development of problem solving ability. However, this faculty cannot be applied to social sciences. "Problem solving" implies that one knows the problem; but what definite knowledge do we have about a social problem? There are no numerical assumptions possible. It is not even possible to agree upon the proper statement of a social problem. Likewise, whether a solution is correct or not cannot be checked in social science, as the factors in the experiment cannot be controlled. Social leaders must be persons who have long vision, an intuitive grasp of the situation, and ability to think logically; not men trained to solve specific problems. One cannot mix training in engineering and the arts, without weakening either or both. Both curricula appeal to different faculties of the human mind, and only exceptional minds will follow into both fields.

In reference to "real life" it would be necessary first to define what is meant by real life. It does not seem that secondary education is succeeding particularly well in the development of strong personalities. Life in general requires continuous readjustment of the mind. This faculty of adjustment must, therefore, be developed in children, and it is just the lack of well organized training of the mind that makes the freshman the perpetual problem in the college.

It cannot be the aim of any university or college education to prepare men for special jobs. The aim and the indisputable responsibility of the institutes of higher education are to create a large enough reservoir of the nation's most treasured youth to supply any walk of life with "men" and not with "workers." In this connection it is most interesting to note that the proposals in Dow's paper are entirely separated from any specific education for special jobs and emphasize the need for a general fundamental training in preference to any expert training.

The method used by Spooner to study the requirements of research workers to succeed in their special field of choice does not seem applicable in principle. In order to yield proper results, the method must employ large numbers of investigations. How many individuals are represented in a graph? It cannot be permissible to discuss any of the graphs in the manner the author does, as judgment on personality factors is extremely difficult and depends upon the person judging. As a matter of fact, all the graphs look alike and it is very difficult to conceive how discussion could bring out fundamental differences. There is too much tendency on the part of the applied psychologist to consider human beings as more or less mental machines, to be classified, stamped, and numbered. A change in attitude is rapidly approaching and rightly so.

As education is a part of the vast field of social sciences it is evident that no single correct solution for the problem of engineering education can be found. All we can do is join in a concerted effort to attain as high a perfection as is humanly possible of the complex and diversified functions of the institutes of higher education. May I present a few points which seem to me worthy of national consideration:

First, there is a definite need for special preparatory schools for college or university study. At present the first year of college study is usually spent to awaken the student's ability of free and independent thought. Tremendous harm is done by high school

methods to many youthful minds who never can recapture their mental freedom from textbooks.

Second, elementary as well as secondary education should be co-ordinated in a national plan to develop the character of the individual and a broad knowledge of the principles of pure science as well as the social sciences. Present educational conditions lack in general the rather rigid personality training and training of the mind, which can be obtained only by continued exercise in principles and not by memorizing of rules.

Third, instead of the "horizontal" structure of engineering education which Morrow proposed and Bibber again outlined in his paper as 2 parallel branches of engineering training, the "vertical" structure seems preferable. The bachelor's degree should indicate general training with emphasis on particular, broad engineering fields. Expert specialization should take place in additional postgraduate courses so that the master's degree would be an indication of special training.

Fourth, social science courses are in general not yet in such shape that they could be satisfactorily included in an undergraduate engineering program. A beginning may be made but not with the purpose to teach how to administer or do executive work. Particular stress may be laid upon the field of production and consumption economics.

Fifth, the idealistic side of higher education must be stressed; learning in order to know should predominate over learning in order to be worth more in dollars. It is rather detrimental to higher education if it is reduced to a business point of view.

Sixth, in a time when the government goes very far to secure social financial help for the many unemployed men should there not also be more done for social mental promotion and help? A comprehensive plan for national organization of highest education, in co-operation with the existing societies, should prove a fundamental step toward unification and the encouragement of highest standards.

Engineering Education Is Meeting the Challenge

Discussion and author's closure of a paper by H. W. Bibber published in the October 1934 issue, pages 1356–9, and presented for oral discussion at the education session of the winter convention, New York, N. Y., January 22, 1935.

Albrecht Naeter (Oklahoma Agricultural and Mechanical College, Stillwater): In his address at the Hot Springs convention last summer William McClellan emphasized the unity of the engineering profession. He suggested that the great founder societies, among others, should call upon the colleges to start out the graduates of engineering schools with the idea that they belong to one profession by giving them a degree, for example, of bachelor of engineering.

The title of Bibber's paper is highly suggestive and its content admits the possibility of various types of solutions in meeting the challenge of changing society.

A new course in general engineering has been organized at Oklahoma Agricultural and Mechanical College. It will not displace any of the present engineering curricula but is available to provide a broader training than is possible under any of the specialized engineering programs of study.

This new general engineering course of study includes at least $^3/_4$ of the standard courses covered in civil, electrical, industrial, and mechanical engineering, each of which is set up in accordance with the recommendations of the Society for the Promotion of Engineering Education. In effect, it is a composite course of the technical engineering elements of general civil engineering, power electrical engineering, industrial engineering, and general mechanical engineering, set up on the common base of rigorous training in basic physics, chemistry, mathematics, and mechanics. There is the usual amount of English, economics, accounting, etc., and provision is made for a limited number of electives. It is recommended that students choose cultural subjects for electives, even though they may choose scientific or technical subjects. Upon completion of the work, a bachelor of science in engineering degree will be granted.

When he has completed this new course, the graduate can seek employment in a wide range of fields. He will have sufficient training to handle the work that he is likely to be called upon to do. After he has oriented himself in industry, he can complete in one additional year of study the curriculum leading to the standard qualified bachelor of science degree in civil, electrical, industrial, or mechanical engineering.

H. W. Bibber: It is interesting that the Oklahoma Agricultural and Mechanical College has instituted in part the type of program which I was describing. Naeter does not specify the method of administration of the new course, but I assume that it must be well supervised, have high standards, and be not at all a place of last resort or haven for "lame ducks" who want an engineering degree for some reason, but whose intellectual qualifications, in the opinion of most people who come in contact with them, do not warrant it.

P. L. Alger's discussion is most stimulating. What is said by an engineer who is so eminent is very much worth noting. I take it as a postulate that the colleges and universities cannot develop anything in an individual unless a capacity for the talent or skill exists. They can only shape their program and so arrange the execution of their work that the energy, courage, and initiative of the student may be directed in productive avenues of expression. To me this means the necessity of a flexible program and the services of instructors on the staff of the educational institutions who are not dogmatic about hyoptheses or other unproven propositions. One of the disappointments of many college teachers, I suspect, is the lack of ability or even willingness to carry responsibility on the part of most students from ordinary high schools. The type of test to be devised to measure the technical imagination possessed by a student is to me a stimulating problem for research, and I shall be much interested in seeing what can be done to discover this quality at various stages of the careers of our students, preferably as early as possible. Work on experiments and other projects in groups certainly starts a student on the road to co-operative endeavor. Unfortunately, most of the testing of students' qualities which is now carried on in universities consists in measuring his individualistic capacities rather than his co-operative ability. It may very easily come about at the present time that a student with considerable personal mental endowment may secure very high grades on his own performance as an individual and yet be lacking in much of a co-operative gift or spirit. From conversation with representatives of employers who come to our institution, I gather, however, that this is a factor the importance of which they are quite aware, and that they try to estimate the student's capacity in this direction when interviewing him.

Alan Howard's comments lead me to say that the increasing use of the project method should make the graduate of engineering courses in the future more accustomed to definite achievement. Each time a student solves a problem he achieves a goal which has been set for him. It is true that there is a lack of reality to school problems, try as one may to make them vital, because the penalties and rewards of industry are not present in the school situation. Most college teachers would like to incorporate the spirit of reality and achievement in a student's program much more than it exists at present.

While Ernst Weber appears to differ with me in many of the bold statements in my paper, yet it may well be a question of the language or definition of terms alone which gives this appearance. Furthermore, I do not claim that social problems can be solved with the same dispatch or preciseness as physical problems. It is true that numerical measurements in the social science field are at present imperfect or entirely lacking in some parts of this field. To me this indicates that we may now be at an early stage of progress, rather than showing that there never will be any possibility of extensive measurements in the social field. It seems to me that the social sciences are now at the point of relative development at which the physical sciences were a century or 2 ago, but this does not mean that the metrically minded man is not needed in the social science field. Quite the contrary!

To exclude social studies from the undergraduate engineering program because they are not at present as metrical or well organized as the physical sciences is to disregard the type of life which the student will later live.

I agree that a mixture of arts and engineering in one course would be ill advised, but I believe that separate courses in arts and technology may be given to a student in one curriculum during his college years. In actual life situations, an engineer concerns himself with technology from 6 to 8 hours a day, the remainder of his waking hours being largely devoted to problems of social and individual living. I do not claim that many men will become eminent in both engineering and the humanities or arts. I am concerned with an intelligent appreciation or understanding of society, and I believe that an engineer of average intelligence can comprehend significant aspects of this field if reasonably stimulated and guided. K. T. Compton recently remarked, "the increasing necessity for organized co-operation with economic and social controls, whether along the lines of the 'new deal' or some different basis, creates an urgent demand for men with engineering training and a broad conception of relative social values and economic processes. It is desirable to develop a co-operative approach to economic problems by the engineer and the economist, in somewhat the same way as has proved so fruitful in the co-operation of the engineer with the physicist, the mathematician, the chemist, and the biologist."

My references to the newer type of secondary education seem to have been misinterpreted by Weber. It is precisely because of the lack of ability for independent study that efforts are now being made to reform the secondary schools in the United States. As I understand it, the effect of the newer plan is to encourage initiative and self-development on the part of the students and to divorce them from the rigid discipline of a fixed routine of study, substituting therefor a flexible discipline of self-measurement against some objective scale of values. It is precisely because freshmen have no self-discipline that they have been a continuous problem in our engineering schools. At my own institution we have an experimental high school. The new building for this work was completed recently and I was interested to note, carved in stone over an entrance door the words, "Prize the Doubt." From many conversations with the teachers and administrators of this experimental secondary school, I gather that this is characteristic of progressive education. What Weber lists as points 1 and 2 in his suggestions for national consideration are exactly in line with what I understand to be the objectives of present secondary school reform. In his comments as to the "vertical" form of engineering training, I agree that the master's degree may often indicate specialization. My suggestion of "honors courses" is based on the possibility of recognizing and taking advantage of individual differences in students. In other words, a gifted student may master and be able to use effectively in 4 years as many engineering principles as a less well endowed student in 5 years or more.

Characteristics of a Group of Engineers

Author's closing discussion of a paper published in the December 1934 issue, pages 1571–6, and presented for oral discussion at the education session of the winter convention, New York, N. Y., January 22, 1935.

Thomas Spooner (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): "Technical imagination," as defined by P. L. Alger, is undoubtedly a very valuable trait and one which could well have been included in figure 2 of my paper. He states that it "should be included in every test to select engineering talent." I hope that some time he will amplify this suggestion and tell how best to determine to what extent this trait is present in an individual.

I am glad to note that he emphasizes the desirability of co-operative ability, especially in a large organization. In this connection it is interesting to point out, as shown by figures 1 and 3 of the paper, that lack of co-operative ability appeared as 13 per cent for those men released and was zero for those retained.

Alan Howard's expression "habit of achievement" is a particularly happy one. However, for the young engineer, it needs, perhaps, a little clarification. To the student, achievement may mean simply a correct solution of an assigned problem. To the design engineer, it may often mean much the same thing. To the development and particularly the research engineer, it usually means much more than this. Unless the solution was urgently desired by some designer or commercial department, the research man is faced with the necessity of selling his idea so effectively that it will result in manufacturing and sales activity. This may require his most persuasive efforts and will bring into play his social and personality traits. He cannot simply say of his development: "Here it is. It is good. Take it or leave it." He may have to work for months or years to convince others that it is worth while, and without this effort there will be little real achievement and no chance to acquire the habit of achievement. Even the designer, who has been set a specific problem, must convince others that his solution is the best one, since most design is largely a matter of compromise.

Howard is quite right. It is an engineer's record of accomplishment rather than his reputation for knowledge which counts most with his superiors.

Ernst Weber states that the graphs of my paper "look alike and it is very difficult to conceive how discussion could bring out fundamental differences." They do look alike, of course, but quantitatively, they are quite different. Figures 1 and 3 only can be compared directly. An analysis shows that the faults of those retained amount to only 46.5 per cent of those released. This seems like a significant difference. Individual items are even more important as, for instance, the one of co-operative ability mentioned above, where this lack is 13 per cent for one group and zero for the other.

Weber intimates that valid conclusions cannot be drawn from the graphs because "judgment on personality factors is extremely difficult and depends upon the person judging." We grant the difficulty and variability, but an executive's or personnel expert's opinion must be reasonably reliable for it is chiefly on the basis of such judgment that successful organizations are built up. I believe that Weber must grant that after a group of men has been associated together closely for years, each man has a fairly accurate knowledge of the strong and weak points of his individual co-workers, with respect to both technical and temperamental traits. The difficulty lies rather in balancing the strong points against the weaknesses and deciding on a man's value on the basis of all of his qualities when it comes to a question of promotion or release.

I wish to comment on Weber's statement in the next to last paragraph of his discussion; namely, that "the idealistic side of higher education must be stressed; learning in order to know should predominate over learning in order to be worth more in dollars." It is quite right and eminently desirable that a certain number of able scientists should be seeking knowledge for its own sake without any ulterior motive, but the number should of necessity be rather limited. We are discussing engineering and not scientific education. Most students study engineering because they believe that for them it will lead to the pleasantest method of earning a living. If they are tempermentally and mentally suited to become engineers, this aim is a reasonable and just one. I believe that the primary aim of an engineering education is to teach one to earn a living in a manner which will be useful to society and to accomplish this with a reasonable degree of success requires much more than the mere acquisition of technical knowledge. Human relationships are quite as important as technical ability.

On the Schooling of Engineers

Discussion of a paper by Alex Dow published in the December 1934 issue, pages 1589–91, and presented for oral discussion at the education session of the winter convention, New York, N. Y., January 22, 1935.

H. D. James (Westinghouse Elec. and Mfg. Co., Detroit, Mich.): I read this paper with considerable interest, particularly as I know the author's background, which makes his statements of unusual value to me.

We are apt to consider our graduation from college as the end of systematic study; we hope that we are well equipped for our life work. If we did conscientious work at college we have laid a valuable foundation, but have acquired only a limited knowledge and training. We instinctively study the problems presented by our immediate job, and for a time they may absorb most of our energy. After we have mastered them we should plan for broader study.

The occasional reading of magazine articles on a wide variety of subjects gives us a smattering of information that is useful in conversation but adds little to our real education. We should select one or two definite subjects and study them in a systematic manner, selecting other subjects only after we have acquired a good understanding of the first ones. Each year we should try to add something definite to our education.

Only part of our studies should be on engineering subjects; we should try to improve our own efficiency in writing and speaking and business methods, in the preparation and presentation of reports, and in learning how to intelligently enjoy ourselves. One or 2 hobbies will help us to relax.

Some of our efforts should help us to understand the "human machines" with whom we must co-operate and whom we may later have to lead. As the author points out, this is not an exact science, but we can understand persons through history which tells us how people have acted in the past; psychology gives us some idea of their mental processes, and economics helps us to think more clearly on business problems. We cannot get all of these things in 4 short years at college, and, besides, information on these subjects is increasing each year so that we must continue to study them. Knowledge is "dynamic," not "static."

As we grow older, the things that count most are character, judgment, a human attitude toward and understanding of others, and that subtle quality that we call personality. To develop these we must acquire a broad knowledge of human nature and of spiritual values. We must develop a philosophy of life that is sane and that will help us through our difficulties and give us bal-

ance when we are successful. These things do not fit into an exact science nor can they be expressed by a mathematical formula. They come from systematic study and careful thinking.

Dow says that men do not carry nameplate ratings; he knows that each person has a different individuality. If we are to be successful in leadership we must understand each individual that we direct or work with; this knowledge is a composite of our own training and experience. We cannot hope to inspire a higher performance in others than that which we are capable of rendering ourselves. The real leader is the one who sets an example.

Low Pressure Gaseous Discharge Lamps

Discussion of a paper by Saul Dushman published in the August 1934 issue, pages 1204–12, and in the September 1934 issue, pages 1283–96, and presented for oral discussion at the illumination session of the winter convention, New York, N. Y., January 23, 1935.

A. C. Downes (nonmember): There are given in table I of the paper luminous efficiencies of various sources of light. In this table appear some data on a white flaming arc. It is not stated whether this arc is on direct or alternating current, and against the data for this arc is the following notation, "assuming that most of the light is due to the carbon crater, the temperature of which corresponds to that of a black body at from 4,000 degrees to 5,000 degrees Kelvin." In flame arcs the craters on the electrodes are sources of only a very small part of the energy emitted and the major portion of the light comes from the luminous flame between the carbons.

In this table the white flaming arc is shown to have an optimum luminous efficiency, L_0, of 220 lumens per watt. We have calculated this value from measurements on a white flame arc burning at 40 amperes and 37.5 volts (Bowditch, Joy, and Downes, Society of Motion Picture Engineers *Journal*, volume 22, page 58) and find the value of L_0 to be approximately 216 lumens per watt, a very close agreement with the value in Dushman's table.

The specific luminous efficiency L_s for this white flame arc is shown to be from 27 to 45 lumens per watt in the same table. Actual measurements in our laboratory have shown that a white flame arc operating under the above conditions, that is, 40 amperes and 37.5 volts, has a specific luminous efficiency of 79 lumens per arc watt.

In the table this arc is shown to have an energy utilization ratio 100η of from 12 to 20. Actual energy distribution curves of such an arc have shown that 36.6 per cent of its energy lies in the visible portion of the spectrum, between 4,000 and 7,000 Ångström units, and the value calculated from $L_0 = 216$ lumens per watt gives this same value for the energy utilization ratio.

Operating the same type carbons on an alternating current circuit with a number of arcs in series or a single arc operated on a transformer under the same current and voltage conditions will show a specific luminous efficiency of 70 to 75 lumens per watt and approximately the same energy utilization ratio.

Induction Motor Locked Saturation Curves

Discussion of a paper by H. M. Norman published in the April 1934 issue, pages 536–41, and presented for oral discussion at the induction motor session of the winter convention, New York, N. Y., January 24, 1935.

S. F. Henderson (nonmember): This paper is of considerable value to the motor designer, and when its merits are fully appreciated will receive wide use. The corrections given here have been applied to a number of designs and the calculated starting currents checked test results within 5 per cent.

The most outstanding example involved an English design of a wound rotor motor having a small air gap and overhanging teeth of light section. The results were:

	Starting Current, Amperes	Max. Torque Per Cent
Calculation without correction	160	145
Test values	260	225
Calculation with correction	248	215

The importance of making corrections for saturation is evident in a design of this type and it is interesting to note that the formulas in this paper gave results with good accuracy.

Since the corrections are in the form of reductions in slot and zigzag reactances, I believe the author could include to advantage formulas for the various reactances of a motor. Each design engineer has his own set of formulas and a paper dealing with motor reactance calculations should be of considerable interest and result in much interesting discussion.

Efficiency Tests of Induction Machines

Discussion and authors' closure of a paper by C. C. Leader and F. D. Phillips published in the December 1934 issue, pages 1628–32, and presented for oral discussion at the induction motor session of the winter convention, New York, N. Y., January 24, 1935.

S. L. Henderson (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper shows how much more difficult it is to determine by test the load losses of an induction motor than the load losses of a synchronous machine. The paper is confined to a discussion of 3 different types of test, i. e.: (1) test by dynamometer, (2) test by loading on a duplicate machine, and (3) segregated loss method. The first 2 tests are primarily input-output tests and as in any such test are subject to the same difficulties and large expense attendant on obtaining reasonably accurate results. This point is well brought out in the paper. These tests, at least at present, can be made only on motors of not over 200 horsepower because of the limitations of equipment. This leaves then only the third method, the segregated loss method, for the larger motors. There is a fourth method, the calorimetric method mentioned but not discussed by the authors, which has possibilities at least in some cases.

The segregated loss method for determining the efficiency is attractive because the cost of the tests is less and the component losses can be obtained with greater accuracy. The only element in doubt at present is the accuracy with which the load loss may be obtained. On synchronous machines the load loss is obtained by driving the machine excited with direct current and with its terminals short-circuited. The load loss is found by subtracting the friction windage, driving motor losses, and the stator copper loss from the driving motor input. The accuracy of this test has been demonstrated by input-output tests and by calorimetric tests.

It is proposed in the induction motor test code, now being drawn up, to use this same test for induction machines. However certain difficulties arise when attempting to apply this method to induction motors, and further there has not been a sufficient number of confirming tests made to check the accuracy of the method when applied to induction machines.

The application of the method presents no difficulties on wound rotor motors and the test is conducted in the same manner as on a synchronous machine; one member is excited with direct current, the other member is short-circuited and the rotor driven at synchronous speed. The difficulty arises when applying the method to a squirrel cage motor. In this case the stator must be excited by direct current, but the rotor resistance and current cannot be measured to permit the calculation of the copper loss in the rotor.

A number of suggestions have been made to overcome this difficulty. The one in the paper is to obtain the rotor loss from a brake test at standstill and it would be interesting to know what the authors think about the accuracy of this test. A second method proposed by E. H. Linckle is to drive the motor at various speeds at constant excitation and plot loss against speed. The intersection of this curve with the ordinate through zero speed would give the rotor copper loss. The copper loss found in this manner is too low and the load loss too high. A third method would be to measure the slip at some load and from the slip calculate the rotor I^2R loss for this load. The copper loss at any other load will be proportional to the ratio of the square of the stator currents corrected for the magnetizing current. Fortunately it will probably always be possible to get a slip reading on load on a squirrel cage motor as seldom do these motors exceed 1,000 horsepower.

As for the accuracy of this short-circuit method for determining load loss, only a small amount of data and that only on small

machines has been presented. Linckle found in his work that on a wound rotor motor only half of the loss so measured equaled the load loss and on squirrel cage motors all the loss found on the short-circuit tests was equal to the load loss. The Westinghouse company has checked this method on one large motor.

A 200-horsepower, 700-rpm squirrel cage motor was found to have a load loss of 1.15 per cent from the short-circuit test but only 0.70 per cent from the dynamometer test. This dynamometer test was made according to modification of method *a* given in the paper. In other words, this one test shows the loss as obtained by the dynamometer as 60 per cent of the loss from the short-circuit test.

Short-circuit tests have been taken on 6 other motors ranging in size from 200 to 1,250 horsepower, both squirrel cage and wound rotor. The load loss varied from 0.9 to 2.5 per cent. There was not time, however, to check these motors by either a dynamometer or pump back test.

What is needed in order to approve the proposed test code on induction motors is more evidence as to the accuracy of the short-circuit test.

F. E. Harrell (Reliance Electric and Engineering Co., Cleveland, Ohio): The authors of this paper have indeed performed a service in pointing out the particular considerations in connection with the 5 methods of measuring efficiency of induction machines.

Table V in this paper, showing a comparison of results of the tests of various motors by the 3 methods most recommended, is of particular interest. Noting that the variations among the different methods of testing the same motor give results from checking exactly up to a variation of one per cent is a very much more favorable picture, certainly, than could be anticipated from the average testing laboratory, not to mention the average commercial test floor. These results are a tribute to the state of perfection and degree of training of the personnel conducting these tests and should give us all a worthy goal.

In connection with the proposed test code for polyphase induction machines, there are 2 items which, in the light of experience with inspectors from various governmental departments, bear emphasizing. First, in the so-called separation of loss method, the temperature of reference for stator and rotor I^2R loss is taken as 25 degrees centigrade plus the actual temperature rise, or not to exceed 65 degrees centigrade on an open motor as compared with 75 degrees centigrade previously established in the A.S.A. and A.I.E.E. existing standards. This is certainly a step in the right direction and should bear sufficient emphasis to register with these inspection departments.

Second, the matter of insulation resistance in the test code is covered by the conventionally accepted formula which makes acceptable less than half a megohm for a 440 volt induction motor. Where, from the standpoint of danger of breakdown, one megohm would seem to be a reasonable figure, there are repeatedly instances where inspection departments are insistent on maintaining values after abnormal tests of from 10 to 20 megohms, thus introducing needless cost and difficulty. It might be of interest to note in this connection that one large industrial plant whose surrounding conditions are extremely unfavorable to the average standard motor insulation regularly employs the megger to determine the condition of the motor insulation. The regular routine inspections are conducted at stated intervals, noting the insulation resistance. Motors are permitted to remain in service without unusual attention or further inspection beyond these regular periodic visits, until the insulation resistance drops below 50,000 ohms on 220 volt motors. The exact value below 50,000 ohms determines whether or not a motor is permitted to remain in service until the following week end or whether it is to be slated for immediate replacement.

C. E. Peck (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The calorimeter method of obtaining the load losses of an induction motor has the following advantages:

1. The total losses are measured directly instead of being determined by the difference of 2 large quantities as in the dynamometer method.
2. The accuracy of determination depends on relatively few quantities compared to the other methods, namely: (a) measurement of temperature rise of the air directly as a difference between ingoing and outgoing air; (b) measurement of speed; (c) measurement of power input. All 3 of the quantities can be measured with commonly used test equipment. From the writer's experience the total losses of the motor can be measured with accuracy within $1^1/_2$ per cent.
3. The motor may be tested directly with the equipment it is intended to drive.
4. The method is more adaptable to all sizes of motors.

The method of carrying out the test involves the following:

1. The total no load losses of the motor are obtained in the conventional way.
2. A temperature run is performed on the motor under no load conditions. A stack is built around the motor in such a way that the temperature rise of the air passing through the motor can be measured accurately by means of thermocouples connected in differential series. Figure 1 of this discussion shows a motor under test with stack in place. From these data the volume of air passing through the motor can be found. The volume will be a constant for subsequent load conditions, and depends only upon the speed at which the motor is operated. The purpose of the no load run is to obtain a calibration of the air volume at a given speed.
3. A temperature run is performed under load and the temperature rise of the air is again measured, together with motor input. The total loss under the load condition can be determined from the air temperature under the load and the air volume obtained from the no load run.

T. H. Morgan and **V. Siegfried** (Worcester Polytechnic Institute, Worcester, Mass.): The importance of including the stray load loss in the determination of induction machine efficiencies is rapidly being recognized, as is also the need for more reliable methods of measuring this loss. The tests described in this paper indicate an improvement in the technique of segregating losses as measured by input-output methods under actual conditions of loading. The stray load loss, however, still appears only as a residual after subtraction of the output and known losses from the input. The measurement with d-c excitation is made under conditions quite different from those actually existing under load and consequently is at best only an indication rather than an accurate measurement of the stray load loss. The results of the tests by the authors would seem to bear out this contention. In the tabulated values, good agreement in the determined stray load loss is shown by the input-output test results, but there is a

Fig. 1. Motor under test surrounded by stack for measuring air temperature rise

considerable difference between these values and the stray load loss determined by the "direct method."

The pump back methods used with similar machines furnish the surest means of determining this loss under actual conditions of load, but distinction must be made between tests in which the machines are directly coupled mechanically and those in which the electrical supply is common to both machines. Where the rotors are directly coupled, the excitation of each machine is at a different frequency, and measurements of input and output must be made separately. The determination of the stray load loss in this case results from the subtraction of one relatively large quantity from another of similar magnitude, involving the inaccuracies common to all input-output tests. However, when the machines are excited from the same electrical source and the rotors operated at different speeds to accomplish the loading, the total input from the source is only that represented by the losses. This type of measurement allows much greater accuracy to be obtained in the segregation of losses and the determination of the stray load loss.

A series of tests recently completed at Worcester Polytechnic Institute were made to compare the various methods of determining stray load loss and particularly to validate the belted load back method. ("Stray Load Loss Test on Induction Machines," T. H. Morgan and P. M. Narbutovskih, Elec. Engg. (A.I.E.E. Trans.), v. 53, Feb. 1934, p. 286–90.) These tests were made on identical motors rated 10 horsepower, 1,800 rpm, 3 phase, 60 cycles, 550 volts.

As a standard of reference for the other tests, a modification of the belted load back

test was used to measure the stray load loss in the most direct manner possible under actual load conditions. The rotors of the induction machines were coupled to calibrated d-c machines which were themselves loaded back on each other. With the induction machines at no load (slightly negative slip) and power circulating between the 2 d-c machines, the d-c input was adjusted to include all of the losses of the d-c machines and the no load losses of the induction machines. The a-c input was then zero. With the induction machines loaded, the currents in the d-c machines were kept at exactly the same values as initially, with the result that the d-c source still supplied the no load losses of the induction machines, and the a-c source supplied the losses due only to the change in load current. These losses are entirely I^2R and stray load losses. After all corrections had been made for minor changes, such as change in speed, the stray load loss determined in this way was found to be 2.9 per cent of full load output.

Tests made on the same machines when loaded back through a belt showed a stray load loss of 2.5 per cent. In connection with this method, it might be well to call attention to the manner of determining the belt slip loss described in the paper previously referred to. The belt slip should be determined from the actual pulley ratio and from the actual speed of the 2 machines as determined by mechanical or electrical stroboscopes. The belt slip loss is then the belt power or motor output times the ratio of belt slip to motor speed.

Tests made by exciting the stator of the machine with direct current showed that the stray load loss determined in this way is not the same function of equivalent a-c stator current as the actual stray load loss, but for these particular machines it compares favorably with the other results, giving a value at full load of 2.6 per cent. Loading of the induction motors on calibrated d-c generators was found to give a resulting stray load loss of 2.0 per cent, but as pointed out above, this is merely an input-output test and cannot be expected to be of comparable accuracy.

These tests demonstrate the worth of the load back method when both machines are excited from the same source, and the writers believe this method preferable to any other when identical machines are available. The fact that the test is made under actual load conditions and does not involve the inaccuracies of input-output measurements and that a minimum of testing equipment is required is much in its favor.

C. P. Potter (Wagner Electrical Corp., St. Louis, Mo.): The authors have presented a very concise yet complete description of the various methods recommended by the A.I.E.E. and N.E.M.A. committees for the testing of induction machines, and have made recommendations which are extremely practical. We agree that for motors up to 100 horsepower the dynamometer method is the most convenient and should, therefore, be the preferred method. While the separate loss method recommended for larger machines may not exactly duplicate actual load conditions, it at least provides a measuring stick which will be used by all those interested in determining the efficiencies of large machines.

At the present time motor manufacturers are accustomed to specify conventional efficiencies for most induction motors in the integral sizes. The adoption of the test methods described in this paper and covered by the test code recommended by the committees of N.E.M.A. and A.I.E.E., will make it necessary to revise the efficiency guarantees for integral size motors. This will entail a large amount of work and it will be some time before such a change can be completed.

The situation may be compared with the one which confronted the transformer manufacturers several years ago, when transformer efficiencies were based on measured core losses and copper losses calculated from resistance measurements taken at 25 degrees centigrade. It was generally recognized that the efficiencies calculated in such a way were incorrect, and it was therefore decided to change the rules and base transformer efficiencies on copper losses measured by wattmeter at 75 degrees. In this case it was a simple matter to measure the stray losses and comparatively easy to predetermine them before the transformers were built. In the case of induction motors, it is difficult both to predetermine the stray load losses and to measure them in a finished machine.

In spite of the difficulties involved, we believe that the adoption of the test code and the consequent change in the A.I.E.E. rules are steps in the right direction which should be taken in the near future.

R. E. Hellmund (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The authors, while making brief reference to the calorimetric method, have not included it as part of their study. The usual calorimetric method, which consists of carefully measuring the amount of air flowing through a motor and determining the losses from the temperature increase of the air, will not be of great practical value or importance in the case of small motors. However, a similar method recently reported on by Roth to a subcommittee during the International Electrotechnical Commission conference at Prague seems to have considerable merit in connection with small and medium sized motors. In this test the entire motor is enclosed in a duct, as indicated in figure 2 of this discussion. The temperature rise of the air is measured by means of temperature indicators, G_1 and G_2, while the motor is loaded. Subsequently the motor is run at light load with increased voltage and the core and other no load losses are adjusted in such a manner that the temperature rise of the air is the same as during the load test. This then means that the losses at full load are the same as those that are measured with over-voltages at no load. If it is impossible to obtain sufficient losses at no load in the motor, extra known losses in resistors R can be added.

This method has the great advantage over the usual calorimetric method that no measurements of the amount of air are necessary and that all of the difficulties usually encountered in such measurements are avoided. The test is a purely comparative test, and if the temperature conditions of the inflowing air and of the walls of the duct are kept reasonably uniform, very satisfactory results should be obtained without an undue amount of care in the measuring, as is necessary with a number of other test methods. It is conceivable that whenever the wall temperatures of the duct cannot be kept reasonably uniform, some discrepancies might occur as the result of the radiation of heat from the motor to the walls of the duct; however, such variations probably can be kept to a negligible amount by supplying heat reflecting barriers K made of such material as bright aluminum sheet, for instance.

The equipment for such tests is quite simple and inexpensive and the method should therefore prove to be of practical value for any size of motor which it is feasible to enclose in a duct.

The authors make reference to a method proposed for testing stray losses which consists in exciting the stator of a squirrel cage motor with direct current and driving the rotor by an external force. The accuracy of this method seems questionable and in fact the method hardly seems to warrant any serious consideration because the magnetic flux and eddy current condi-

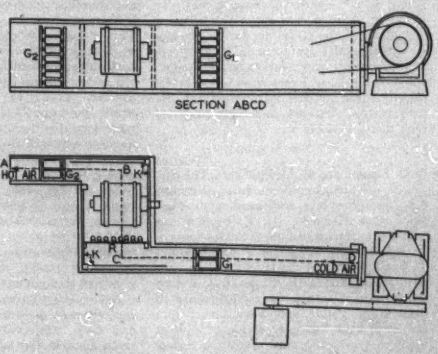


Fig. 2. Schematic diagram of duct arrangement for determination of load losses

Duct is constructed of fir boards with asbestos sheeting on all external faces for heat insulation

tions in a squirrel cage motor during such tests are so different from those obtained under actual load conditions. This is especially true in small and medium sized squirrel cage motors, for which a number of other and superior methods are available.

O. E. Stamm (New York Edison Co., New York, N. Y.): The methods presented in this paper are eminently suitable for test floor work when the degree of accuracy obtainable with them is required. The difficulties involved in using the various methods are clearly brought out. However, until it is realized that the need for determining the performance of induction motors in the field is frequently met with, the seriousness of these difficulties is not fully appreciated. In field testing, it is practically always necessary to test the motor in position, which may be ceiling mounted, supported on brackets, mounted on columns, or directly connected to some machine, in many cases in closely confined spaces. Therefore, the impracticability of utilizing dynamometer equipment, aside from any consideration of the range of ratings of such equipment which might be necessary to meet the testing needs, is evident. Similar machines, as required by the pump back test, are not available. In the direct method of determining the stray loss, it is necessary to use a driving motor. In field testing, this is generally impracticable. It seems to the writer that the present standards of the A.I.E.E. and the proposed American standards for rotating electrical machinery would, without any modification, permit the use of methods *a* and modified *a* and method *b* under paragraph 9–301 (*a*). Where these methods are not practicable, the conventional efficiency, the equivalent circuit, or the circle diagram must, of necessity, be used, and should be recognized in the standards. The data given on stray loss in this paper on the 30 horsepower motor on which detailed figures are given would indicate that it is of the order of one per cent. It would be of interest to know the order of magnitude of the stray loss for the motors on which results are given in table V. A more thorough appreciation of the importance of the stray losses would also be obtained if for purpose of comparison the conventional efficiency had been given for each motor in table V.

C. C. Leader and **F. D. Phillips:** The discussion has brought out a number of important questions and additional methods of measuring efficiency. O. E. Stamm has asked as to the magnitude of the load losses. In general, they are larger in small motors and smaller in larger machines. They vary with design and with the amount of care taken in manufacture. A good design of 10 horsepower motor will have about $2^1/_2$ per cent load loss. A motor of several hundred horsepower may have a loss as low as 0.6 per cent while a 5 horsepower motor with the high value of 7 per cent load loss has been tested.

Several speakers have inquired as to the accuracy of the various methods and their comparative accuracy. For the general accuracy to be expected, we would refer to an article by A. A. Emmerling, "Modern Equipment for the Precise Testing of Motors," in the *General Electric Review*, volume 37, page 471. We have had excellent results with the alternative dynamometer method suggested by Leader and find that it checks closely with the dynamometer method and the pump-back method with which we have compared it.

The calorimetric method of determining efficiencies as presented by R. E. Hellmund gives promise of both usefulness and accuracy. We have not had experience with this method but it seems to be worthy of continued study as recommended by the I.E.C. subcommittee.

The belted pump-back methods proposed by T. H. Morgan and V. Siegfried have some advantages and we are glad to learn that they are continuing their work on this and similar methods. A suggestion has been made that this method does not account for the losses in torque from internal friction in the belt as contrasted with belt slip losses but these are probably of small magnitude. We find, however, that a majority of the motors which we have been required to test for true efficiency are high speed machines, 1,800 or 3,600 rpm, which are too large for belting.

Power Losses in Induction Machines

Discussion and authors' closure of a paper by P. M. Narbutovskih published in the November 1934 issue, pages 1466–71, and presented for oral discussion at the induction motor session of the winter convention, New York, N. Y., January 24, 1935.

A. Van Niekerk (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper is of merit because it emphasizes the importance of a detailed research into the nature of the stray load losses. Its closing paragraph, however, might give the impression that up to the present hardly any work relating to this subject has been done. This impression would be far from the truth; in fact, many interesting papers dealing with the stray load losses in induction machines have appeared in European technical literature during the last 10 years. As it would be impossible to review all these papers in this discussion, I should like to mention a few of the earlier ones.

An important paper dealing with the experimental side of the problem was published by Rogowski and Vieweg: "Additional Losses in Small Induction Motors" (*Archiv für Elektrotechnik*, 1925, v. 14, p. 574). Although it relates primarily to small and medium motors, its conclusions are broad enough to warrant the short review of its contents which now follows.

About 100 3 phase motors, of both the squirrel cage and the wound rotor types, had been subjected to highly accurate brake tests in the laboratories of the German government; in addition, the conventional test data (no load and locked test readings, d-c resistance of stator winding, and full load slip reading) had been determined with great care, so that the conventional losses by the indirect method (stator copper loss, core and friction losses, and rotor loss) could be computed readily. The sum of these conventional losses, called by the authors the "measurable" losses, was found to be always smaller than the actual losses determined by brake test, i. e., the difference of the latter minus the former, called the "additional" losses, was always positive. A list of 25 50-cycle motors from 0.33 to 20 horsepower, and their measurable and brake test losses, contained in the paper, reveals that at full-load the actual efficiencies are from 0.7 to 4.8 per cent (average 2 per cent) lower than the efficiencies determined by the indirect method. Of even more interest are the experimental rules indicating how the stray load losses vary with the load. It was found that:

a. The additional losses, in watts, plotted against the square of the stator current, follow practically a straight line.

b. The straight line mentioned under *a* remains practically unchanged when the line voltage varies while the line frequency remains constant.

c. The additional losses change with the line frequency (the line voltage remaining constant). In general, they were found to increase faster than the first, and slower than the second power of the frequency.

After presenting the experimental results, the authors discuss the possible causes and seats of the additional losses. They found in the first place that losses in solid stationary parts (brackets, etc.) attributable to stray fluxes set up by the end windings are practically zero. Calculations showed that the increase in stator copper loss from skin effect cannot amount to more than a few tenths of one per cent (in large motors the situation may be different, of course). It was further known that the friction and windage losses are practically independent of the load. From these facts the conclusion could be drawn that the main seat of the additional losses is in the core, where they increase the iron losses (fundamental, surface, and tooth pulsation losses) already present at no load. The surface and tooth pulsation losses at no load are mainly "reluctance" losses, caused by the variations in air gap reluctance by the slotting of the cores. Under load, however, there is another source of surface and tooth pulsation losses: the periodic changes in the relative spatial ampere-conductor distributions of the 2 members, which set up "saw tooth fields" that would be absent if said distributions would be continuous and sinusoidal all around the air gap. These fields pulsate at high frequencies and, as their intensities increase with the load, cause core losses that increase with the load. By winding test coils around the crowns of some of the stator teeth, the flux pulsations in these teeth could be recorded; the records clearly show that the amplitudes of these pulsations increase with the load. These tooth pulsations do not, however, induce any electromotive forces in the phase winding on the primary, and therefore the tooth pulsation losses are not covered by the primary circuit like the fundamental core losses. In fact, both the tooth pulsation and surface losses are consequences of the rotation of the secondary, and therefore are covered mechanically by the rotor (and not electrically by the rotor winding); this explains why these reluctance and saw tooth field losses are not included in the rotor losses computed from slip and power transmitted through the air gap. But as the reluctance losses are already included in the no load losses, only the saw tooth field

losses are neglected when efficiencies are calculated by the indirect method.

The behavior of a squirrel cage motor is essentially different from that of a wound rotor motor in so far as in the former the flux pulsations will induce high-frequency damping currents in the cage bars, thus causing an increase in rotor copper loss that is not included in the slip losses either. Oscillograms taken by the authors clearly reveal these higher harmonic currents in the cage bars, and show that their amplitudes increase with the load. The additional rotor copper loss could be estimated from the oscillograms and was found to be relatively small, amounting in one case to $^1/_8$, and in another to $^1/_5$ of the total additional loss. In motors with phase wound rotors, this additional rotor copper loss will be practically zero, but, as the damping influence of higher harmonic currents on the flux pulsations will be absent, the additional losses very probably will be higher in a wound rotor motor than in a squirrel cage motor of corresponding design.

The material contained in the paper was also presented by one of the authors at a meeting at Berlin (*Elektrotechnische Zeitschrift*, 1924, p. 988) which was followed by a discussion (*Elektrotechnische Zeitschrift*, 1925, p. 1011). On that occasion Ruedenberg stated that, in his opinion, the pulsation losses depend mainly on the ratio of air gap to tooth pitch. No additional losses occur if the air gap is longer than half the tooth pitch; with decreasing air gap these losses increase, first slowly, and then rapidly, it being well known that turning of the rotor of a given motor will decrease the stray load losses considerably. In addition, he claimed that the pulsation losses will be higher in silicon cores because, the skin effect being less pronounced due to the higher resistivity of silicon steel, the damping influence on pulsations inside of the core will not be as strong as in cores of ordinary sheet steel.

A paper more specifically devoted to a discussion of test methods suitable for making routine tests, "Test Methods for Determining the Stray Load Losses in Induction Machines," appeared in the *Siemens Zeitschrift*, 1927, page 223. A short account of the 4 test methods discussed follows here:

A. Brake test, or input-output method. Advantage: stray load losses directly found from operation under load (as the difference between the measured total loss and the sum of the individual losses computed by the indirect method). Disadvantages: not very accurate unless carried out with the utmost care; unsuited for large machines.

B. Circulating load test. Two identical machines belted together; pulley ratio (1–2 times full load slip); stators connected to a line supplying the losses; slip of each machine measured in order to determine belt losses. Stray load losses of the 2 machines equal to the difference between the total measured loss and the sum of individual losses (by the indirect method) plus belt losses; can be split up proportionally to the squares of the 2 stator currents. Advantage: same as under *A*. Disadvantages: inaccuracy in measuring the power supplied by the line on account of the very low power factor; unsuited for large machines.

C. Machine running as a synchronous motor carrying wattless load. Machine running idle with stator connected to line; rotor over- (or under-) excited by direct current until stator carries the desired load current; stator input measured. The method has several disadvantages: power is supplied to the stator at a very low power factor and therefore cannot be measured accurately; when the machine is underexcited, it has a tendency to pull out of step; the main flux density, which must be known in order to find from an ordinary no load test the no load losses to be subtracted, together with the stator copper losses, from the measured stator input, cannot be determined with great accuracy; at higher current values (near full load current) the losses increase much faster than the current squared, and are then positively too high. Hence method not suitable for determining the stray load losses in induction motors.

D. Short-circuit method. Machine driven at normal speed by a calibrated d-c motor; stator short-circuited; rotor excited until stator carries the desired load current. Stray load losses put equal to the difference between the power input (shaft) and the sum of friction and stator copper losses. For commercial purposes, the machine can be driven at synchronism and the rotor excited by direct current. In the author's opinion (based on a comparison of results obtained by methods *A* and *D*) the assumption that the losses thus found are identical with the actual stray load losses in the loaded machine is sufficiently accurate for technical purposes, although in the rotor the d-c belt distribution under actual load conditions. He has checked this point by making additional tests with the rotor excited by low frequency 3 phase currents supplied by an a-c exciter, and found that the discrepancies in results for the 2 methods of exciting the rotor are relatively small.

The author found that with the exception of method *C* at higher current values all methods give good results which come close to the straight line loss characteristic previously mentioned; he states that method *D*, the easiest one for routine tests, will give the best results, adding, however, that this method cannot be applied to squirrel cage motors, which should be tested by method *A* or method *B*.

A quite elaborate report on the possibilities of test *D* was published by E. H. Linckh: "On the Determination of Stray Load Losses in Induction Motors" (*Archiv für Elektrotechnik*, 1929, v. 23, p. 19). Of interest is the statement that the losses found by test *D* are always higher than the actual stray load losses by brake test; the explanation given is that the 2 tests are carried out under entirely different conditions of magnetization. In connection herewith the author proposes to use certain correction factors in connection with method *D*. He further states that method *D* is also applicable to squirrel cage motors, and that different correction factors must be used for wound rotor, squirrel cage, and double deck motors.

The first serious attempt to establish a complete theory of high frequency core losses, including those constituting the greater part of the stray load losses, has been made, to my knowledge, by L. Dreyfus: "Theory of Additional Core Losses in Polyphase Induction Motors" (*Archiv für Elektrotechnik*, 1928, v. 20, p. 37, p. 188, p. 273). This highly theoretical paper has been supplemented by L. Dreyfus and S. E. Eriksson: "Additional Losses in Induction Motors" (*Elektrotechnik und Maschinenbau*, 1927, p. 737, p. 756, p. 881, p. 904), a paper which presents the subject to the practical engineer and gives an account of research work done in support of the Dreyfus theory.

This theory deals with the high frequency core losses occurring in wound rotor induction motors at the air gap surfaces (tooth crowns), in the teeth, and in the cores just back of the teeth, in the form of eddy current and hysteresis losses. A method is presented for computing the eddy current losses with a reasonable degree of accuracy, taking into account, where necessary, the influence of skin effects. The discussion of the hysteresis losses is more of a qualitative nature, although a few formulas are given by means of which the additional hysteresis losses in tooth crowns and tooth bodies (those in the cores back of the teeth can be neglected) can be estimated. Dreyfus proves that the reluctance and the saw tooth field losses can be calculated separately and then added, without introducing an appreciable error (the former hardly change when load is applied to the machine; the latter, practically negligible at no load, increase rapidly with the load).

A few statements made by Dreyfus in his *Elektrotechnik und Maschinenbau* article concerning the test methods for determining the stray load losses are also of interest, but cannot be repeated here in an abridged form.

Although it cannot be said that the Dreyfus method is something final and readily applicable by the designer of commercial apparatus, it constitutes, in my opinion, a very important step in the right direction and should not be left unconsidered by those who, on the basis of theoretical investigations and experiments, must develop practical methods or short cuts for computing or estimating the stray load losses in induction machines.

T. H. Morgan and **V. Siegfried** (Worcester Polytechnic Institute, Worcester, Mass.): The division of the core loss between the fundamental and rotor-tooth frequency components can be determined experimentally at no load by a simple measurement involving the use of a rated d-c motor directly coupled to the induction machine. This motor should be so chosen that the no load losses of the induction machine are a substantial portion of its rating, and a careful determination of its losses should be made. If the rotor of the induction machine be driven at synchronous speed, as indicated by a stroboscope, the fundamental frequency iron losses and stator I^2R losses will be supplied by the a-c source, and the rotor tooth frequency iron losses will be indicated by an increase in the d-c input over the power required to drive the unexcited a-c machine. Due to the presence of a torque on the rotor caused by hysteresis of the rotor iron, these measurements must be made with the rotor revolving with an exceedingly small slip, first above then below synchronous speed. The average of these 2 readings cancels out the hysteresis torque power, which changes sign as the slip is reversed. If, then, the rotor be driven above synchronous speed until the a-c input is only that required for stator copper loss, the increase of d-c input over the unexcited power will be the entire core loss, both at fundamental and rotor-tooth frequencies. Rotor copper loss is negligible in both cases.

Measurement of these quantities on a typical machine showed the major portion of the core loss to be at fundamental frequency. A 10-horsepower 1800-rpm 3-phase 60-cycle 550-volt machine was driven by a 1 horsepower rated d-c motor. At synchronous speed the average a-c power, representing the fundamental frequency core loss, was 206 watts, while the increase in d-c power, required to supply the rotor tooth frequency core loss, was 52 watts. Driving the rotor ahead to supply all of the

core losses through the d-c machine showed them to be 258 watts. The hysteresis torque power was found to have a value of 38 watts.

With this information at hand, the correctness of assigning all of the core losses to the secondary portion of the equivalent circuit (as proposed in various testing methods) might be questioned.

P. M. Narbutovskih: A. Van Niekerk gives a fine résumé of practically all (to the author's knowledge) that was written on the subject of the stray load loss in induction machines. At the time of publishing the paper the author was not aware of the existence of this literature, and discovered it only some time later.

Since the article by Rogowski and Vieweg is mentioned by Van Niekerk, it might be of interest to call attention here to an effect of load upon the high frequency

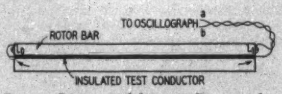


Fig. 1. Device used for recording rotor bar currents

eddy currents in the bars of a squirrel-cage motor. The effect was observed in the course of an experimental study of the sources of stray load loss in induction motors. As a result of this observation the statement made in Rogowski and Vieweg's article concerning the negligibly small value of the eddy current loss in the rotor bar can be questioned.

A few preliminary statements will help to explain the situation. The device used by Rogowski and Vieweg for recording the squirrel cage bar currents is shown in figure 1 of this discussion. It can be shown that if no current flows in the test conductor, the instantaneous value of voltage produced between leads a and b is given by the integral

$$e = \int_{l_0}^{l_1} \rho\delta \cdot dl = \int_{l_0}^{l_1} \rho\delta \cos\gamma \, dl$$

Where

ρ = resistivity of the material of the bar

δ = current density at any point in the bar along the test conductor

γ = angle between the direction of the test conductor and the direction of the current flow at any point along the conductor. Since the direction of current flow is coincident with the direction of the test conductor for the greater part of the path, $\cos\gamma = 1$, except at the very ends of the bar.

In other words, the voltage appearing between conductors a and b equals the voltage drop between points l_0 and l_1, due to the current within the bar flowing in the immediate neighborhood of the test conductor. Unless the current density within the bar cross section is uniform, test conductors placed in various parts of the bar must obviously give different records, a fact which was, apparently, overlooked by Rogowski and Vieweg. This gives a possibility of experimentally investigating the current density distribution within the bar cross section.

Tests performed according to this scheme show that along the outer and side surfaces of the bar heavy high frequency currents flow, due to the stator teeth. The amplitude of these currents varies with the air gap flux density, i. e., at the slip frequency of the rotor, from nearly zero, for zero value of induction, to over 10 times the amplitude of the fundamental useful current at full load. The amplitude decreases rapidly with the distance from the surface of the bar. Roughly, the amplitude reduces to $^1/_{10}$ of its value on the surface at a distance $^1/_3$ of the depth of bar down, and $^1/_4$ of the width from one side. Machine used is rated at 10 horsepower, with rotor bars $^3/_4$ inch wide, $^1/_2$ inch deep, and 8 inches long.

The effect of load is to increase considerably the amplitude of the eddy currents in the region of the outer trailing corner of the bar, and to reduce it in the region of the outer leading corner (outer meaning the one farthest from the axis of rotation). It was supposed that the phenomenon was caused by the saturation of the rotor tooth shoulders (semiclosed slots) due to the rotor leakage fluxes. As a check, the machine was run as an induction generator, which gave a complete confirmation of the hypothesis; with load pulsations increased in the leading corner and decreased in the trailing one. A glance at figure 2 of this discussion will explain the mechanism of the phenomenon. The trailing and leading tooth shoulders operate at different values of magnetic induction, which is a result of

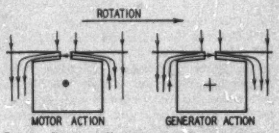


Fig. 2. Diagram illustrating amplitude of eddy currents

superposition of the fundamental and leakage fluxes, and therefore at different values of permeability. Hence, the shoulders offer a different degree of magnetic shielding of the bar from the high frequency components of flux due both to the stator reluctance and magnetomotive force distribution. In other words, the effect of the rotor leakage fluxes upon saturation of the tooth shoulders is equivalent to a variable effective width of the slot opening.

The actual oscillographic records of bar currents obtained in the laboratory are quite complicated, and therefore a detailed discussion of the information contained therein is omitted here.

The information submitted by T. H. Morgan and V. Siegfried is of an undoubted practical value. It would be of interest to compare similar measurements made on various motors, especially in view of the statement made by other investigators that the measured iron loss in induction motors is greater (and in some cases several times greater) than the computed iron loss. The increase has been attributed primarily to the tooth pulsation loss, which supposition is not supported by Morgan and Siegfried's measurements.

Transient Voltages on Bonded Cable Sheaths

Authors' closing discussion of a paper published in the January 1935 issue, pages 73–82, and presented for oral discussion at the cables session of the winter convention, New York, N. Y., January 24, 1935. Other discussion of this paper was published in the April 1935 issue, page 436.

Herman Halperin, J. E. Clem, and K. W. Miller: When the switching operations on high voltage cables with specially bonded sheaths are confined to windings of the power transformers other than those to which the high voltage cables are connected, as in the case mentioned by E. R. Thomas, then it seems likely that the transient sheath voltages would be considerably smaller than when switching is done at the line voltage.

A correction for table VII of the paper is as follows:

Under the heading "Sheath Surge, Case (2)" the values of e_{RB}/I and e_{1B}/I should read xse'/D and $(xse'/D)-se''/2$, respectively.

In line with the remarks made by G. B. Shanklin and D. M. Simmons after the presentation of this paper at the convention, it should be noted that the use of insulating sleeves to eliminate sheath losses on single conductor cables has been highly satisfactory from a technical standpoint as well as from economic considerations. Experience subsequent to the preparation of the paper has again demonstrated that there are no technical difficulties in developing sheath bonding transformers to successfully withstand transient sheath voltages. These latter transformers were purchased with a specification requirement that the insulation withstand an impulse test of 16 kv, which value was considerably above the maximum transient voltage found imposed on the sheath bonding transformers in Chicago.

Dielectric Properties of Cellulose Paper

Authors' closing discussion of a paper published in the October 1934 issue, pages 1389–96, and in the November 1934 issue, pages 1498–1503, and presented for oral discussion at the cables session of the winter convention, New York, N. Y., January 24, 1935. Other discussions of this paper were published in the March 1935 issue, pages 322–4, and in the April 1935 issue, pages 431–4.

J. B. Whitehead and E. W. Greenfield: The figures for per cent moisture content as indicated in the title of table II, and in connection with the formula upon which the computations are based, are the minimum amounts of moisture necessary to account for the variation in properties as observed. Wherever elsewhere in the paper reference is made to the amounts of moisture these minimum values are to be understood.

These minimum values are computed on the assumption that all of the moisture in

the paper exists in solid layers or films parallel to the electric field. If, on the contrary, all of the moisture be assumed to be in layers normal to the field, we may compute the maximum amount of moisture consistent with the experimental observations. The formula for the maximum moisture content in per cent of total volume would be as follows:

$$M = \frac{K_w(C_w - C_0)}{C_0 K_w(K_w - 1)} \cdot 100$$

G. M. L. Sommerman's formula for the same quantity is in agreement. The corresponding maximum possible amounts in per cent of total volume would be 0.43, 0.6, 0.77, 1.02, 1.47, and 2.14, for the 6 pressures beginning with 0.25 millimeters of mercury and ending with 765 millimeters of mercury, respectively, as given in table II. Obviously neither of these pictured extreme distributions of moisture exists in any actual case. The true values for each pressure are probably approximately the mean of the minimum and maximum values as given.

Louis Meyerhoff and Sommerman call attention to the uncertainty of the value of the dielectric constant of water as related to the degree of dryness. To this view we subscribe. However, the possible range of values, and particularly the average condition as between the series and parallel relation of the water layers of the direction of the field make it probable that there would be little change in the approximate values of moisture content as given.

We are particularly interested to see the suggestion of J. A. Duncan that the Freundlich equation for adsorption isotherms may explain the simple relation we have found between moisture content and pressure. The connection indicated seems to us highly probable and we are happy in the added support thus given to the validity of our method and conclusions.

R. W. Atkinson and F. W. Godsey, Jr., raise the question of the influence on dielectric loss of the presence of impurities other than water in cellulose paper. Their comments are in line with our own, described at the opening of the paper, on the general properties of paper for insulation purposes. Our figure 12 in fact suggests the possibility of a very small value of loss at zero moisture content. Certainly, however, no other impurity has anything approaching the influence that water, with its high dissociating properties, has on conductivity, phase difference, and loss in high quality dielectrics. This long-known result is borne out by our own experiments, as indicated particularly in figures 8 and 12. There appears to be no reason to speculate here as to whether pure cellulose or pure rosin could be shown to have electrical conductivity or loss not due to admixed moisture. This question has, in fact, no important bearing on the conclusions of our paper. It arises only in connection with the deductions from figure 8, and here only indirectly. The important matter is that all of the quantities studied decrease markedly with decreasing moisture and in accordance with apparently regular laws. The conclusions of the paper are based on these definite experimental relationships to moisture content and to temperature, and assume the influences of other impurities to be negligible, or rather to play no part in variations which are clearly due to removable moisture.

Atkinson and Herman Halperin have presented figures on temperature changes of capacitance in cables of various dimensions. The figures range from a very small fraction of 1 per cent all the way up to 4 per cent or 5 per cent. It is stated that diametral changes alone in these cables would not account for the higher ranges of observed values. To this we agree. No explanation of the observed increases is offered. Note, however, that some of Halperin's figures are sufficiently low to be accounted for by just this type of change. Observed increases in our samples are completely accounted for by simple thermal expansion. It appears to us not improbable that if longitudinal expansion and possible internal deformation, as the result of sheath stretching or other cause, be taken into account, it may well be found that the entire observed increases in cables may be due to dimensional changes rather than to inherent properties of the dielectric. The only apparent alternative is the presence in the cable of so much gas that the thermal expansion of the impregnated material may cause a reduction of gas volume in favor of dielectric, sufficient to account for the observed changes in capacitance. We believe that few cable engineers will accept this explanation.

Meyerhoff raises a question as to the accuracy of our figures on the thermal expansion of the brass tube, and the consequent changes observed in dimensions. We agree that the figures are abnormal as for brass, and we have devoted considerable study to this question. In view of its importance, as related to our conclusions, we have repeated the measurements using other observers, but under similar conditions of experiment, and the figures as given in the paper are closely confirmed. Two possible explanations suggest themselves. One is the chemical constitution of the material of the tube. Certain alloys involving large proportions of tin, for example, have thermal expansion coefficients close to the average values observed by us. We believe a more probable explanation, however, is to be found in a state of strain which is sometimes set up in the manufacture of seamless drawn brass tubing. It is known that under such conditions, abnormal values of expansion coefficients may result.

Meyerhoff also suggests that our values of capacitance as observed might be accounted for by changes in density due to compression of the dielectric, rather than to the change in electrode dimensions as reported. We agree with his figures on density changes as far as they go. However, in addition to compression by the electrode, the paper is also stretched circumferentially and longitudinally, owing to the change in the dimensions of the brass. The estimated values of these somewhat uncertain factors are just about sufficient to offset the figure for increased density given by him. We note with interest his suggestion that the variation of dielectric constant of water with temperature might be made the basis of an extension of our method of studying the effect of moisture content on electrical properties.

A. M. Myers has made a very pertinent comment on an essential difference between our method of drying and measuring and his own. It undoubtedly accounts for the differences in power factor as between his measurements and ours. As a consequence it also means that the amounts of moisture remaining in our specimens are substantially less than in his and therefore it seems to us a quite adequate explanation of the fact that our computed values of the moisture content are substantially lower than any he has observed. Incidentally this appears to mean that in the factory drying of cables, the amounts of moisture remaining in the paper may be substantially greater even than any of our computed values. This raises the question as to the influence of such residual moisture on the final impregnated insulation.

R. J. Wiseman seems to find in our results evidence of the sufficiency of the drying methods used in the manufacture of cables. I do not feel, however, that we can go all the way with him in this. He speaks of drying pressures within the range of from 4 to 5 millimeters. The results for the moisture content indicate values of residual moisture of from 0.4 to 0.5 per cent by volume. Until the questions as to what this moisture does after the paper is impregnated and as to what effect it has on oil stability and life are answered, I do not think it is safe to conclude that we need not seek further for improvements in our drying processes. Incidentally, we note an error in figure 11 of the paper as published. The decimal points in the scale of ordinates, i. e., power factor, should be moved one place to the left. This means that our low values are about the same, or slightly lower than the extreme values quoted by Wiseman.

Dielectric Strength of Mineral Oils

Author's closing discussion of a paper published in the January 1935 issue, pages 50–5, and presented for oral discussion at the cables session of the winter convention, New York, N. Y., January 24, 1935. Other discussions of this paper were published in the March 1935 issue, pages 326–7.

F. M. Clark: In my discussion of the comments submitted by C. S. Sprague, J. B. Whitehead, F. W. Godsey, Jr., and Preston Robinson, I am confining my remarks to Whitehead's severely critical analysis.

His opinions in the field of dielectric phenomena are usually well-founded and reflect serious consideration, and with them I hestitate to disagree. His position in this instance, however, appears untenable. He suggests that the correlation of mineral oil breakdown and gas phenomena cannot be supported because of "much other evidence" as for example (*a*) difficulty of repetition, (*b*) wide variations between dielectric strength and pressure, (*c*) importance of impurities, and (*d*) conditions at the electrode surface. It is difficult to answer such unsupported contentions. Perhaps we may expect a contribution by him in which he will show that the dielectric strength of oil is not affected by the increasing gas content or, better still, that the dielectric strength falls with increasing gas pressure applied under testing conditions similar to those of the present paper.

At this time I can only assure him that there is no evidence among the extensive data which I have collected in my own laboratory or which have come to my attention in the literature which would show a wide variation in the effect of gas pressure on the dielectric strength of mineral oil. With increasing gas pressure, increasing dielectric strength always results. The behavior is not difficult of repetition. With proper attention to testing technique, the dielectric strength of mineral oil is easily reproducible within the limits normally expected in dielectric phenomena. A recent article by E. Scheu (*Archiv. für Elektrotechnik*, volume 29, page 192), discusses the testing procedure capable of reproducing dielectric strength values with an expected scattering of not more than from 5 to 7 per cent from the average. Procedure such as outlined, with adequate "rest" periods covering several hours, has invariably been followed in obtaining the author's results outlined in the paper.

As concerns impurities and conditions at the electrode, one would be foolhardy to suggest a constancy of physical behavior under all possible testing conditions of contamination or otherwise. No such claim has been made. The article concerns mineral oil as representative of liquid dielectrics tested under normal voltage application procedure. It makes no attempt to consider contaminated liquids although in a previous article it is stated that "the dissolved gas (in oil) is considered as the major impurity. Secondary impurities which act only in their effect on the dissolved gas characteristics are dust particles, fibers, and other insoluble or partially soluble foreign materials." (Franklin Institute *Journal*, 1933, volume 216, number 4, page 431.) The experience of the author has been that although such impurities may affect the absolute value of dielectric strength, within normally occurring limits of contamination, the response of dielectric strength to gas pressure change is in accordance with the expected behavior.

Whitehead next claims that the impulse breakdown of an oil is independent of pressure and within wide limits of the dissolved impurities. With this the author has no disagreement. The impulse type of electrical breakdown was considered as beyond the scope of the present paper which confines itself entirely to the normal 60 cycle type of oil breakdown test. The author has already discussed the impulse behavior in a previous paper in which the broader aspects of the problem were treated. I quote from the section entitled "The Time Factor" which appears on page 453 of the *Journal* of the Franklin Institute for 1933, volume 216, number 4: "Gaseous breakdown involves a time factor of exceedingly short duration. Since the breakdown of 'impure' (gas containing) liquids involves secondary factors affecting gas elimination in addition to gaseous ionization, the time to break down should be of longer duration. This is true. The shorter the time interval, the more nearly the breakdown approaches that characteristic of the same liquid under impulse voltage, and, as has been shown also, the less the difference between the 'pure' (degassed) and the 'impure' (gas containing) classification." Or again quoting from the same article, "with decreased time, the impulse breakdown is gradually approached and the gassing type of electrical breakdown merges into the impulse or (oil) molecular ionization type." The information in parenthesis is inserted for clarity.

I see no basis for the contention that a relation should exist between conduction phenomena and the dielectric breakdown of mineral oil. Gas-containing oil breakdown differs from gaseous breakdown in that it involves a complexity of substances (liquid and gas) and that it occurs in normally good oil with unexpected rapidity and "explosiveness." Should the rupture of air saturated oil involve the separation of a gas bubble, and this possibility is not denied, the conduction characteristics of the oil before the gas separation would not be expected to show relation to the rapid sequence of events occurring when such a gas bubble is discharged into a field of high intensity, far above the gas ionization potential. Experience fails to show any relation between the type or degree of conduction in dielectric liquid and the dielectric strength. Air saturated liquids widely varying in molecular make-up or mineral oils differing widely in physical characteristics all respond with increased dielectric strength when tested under increased gaseous pressure.

In the first 2 paragraphs of the article under discussion, reference is made to 2 previous articles describing the dielectric behavior of insulating liquids in the light of gas solution phenomena. I again suggest reference to these previous publications for further data which were considered as "beyond the scope of the present paper," which limited itself only to a discussion of mineral oil containing dissolved air and tested in accordance with the usual procedure of voltage application. These previous publications may alleviate the regret "that the author has not presented more experimental data."

Whitehead next objects to the reference made to the work of Kock. Referring to this work he says, "Moreover, his (Kock's) oils were free of gas." Reference to Kock's work reveals no such condition. Kock used an arrangement for his pressure application involving a hydraulic pump and gas pressure tanks of air and carbon dioxide. It is apparent from the object of his researches (the use of gas under high pressure in transformer design) as well as the precautions taken to prevent gas bubble entrapment during the preparation of his samples for test that Kock's liquids contained dissolved gas. The reference to Kock was made merely to illustrate the behavior of oil at pressures higher than 8 atmospheres, the limit of pressure investigated by the author. Other illustrations might have been used with equal force.

And, finally, Whitehead suggests an alternative hypothesis to explain the behavior saying ". . . the experiments quoted do indicate the type of correlation proposed by Clark." The suggestion says (*a*) the ionization involves a loosely bound electron of the oil atom, (*b*) these loosely bound electrons are chemically active and are involved in oil oxidation, and (*c*) increased air in the oil merely ties down or restrains loosely bound electrons and thus diminishes secondary ionization. He suggests experiments involving gases other than air. With his hypothesis I have little sympathy. It is obviously a manifestation of his desire to explain electrical breakdown of oil in terms of conduction phenomena. The reversibility of the dielectric strength-pressure relation, the normal response of the dielectric strength of oxidized oil to pressure change, the similarity in the behavior of widely varying chemical types of insulating liquids, the similarity in the pressure-dielectric strength relation for dielectric liquids irrespective of the type of gas used to obtain pressure change, and the high dielectric strength obtained when the gas content of the oil is reduced to a value corresponding to a few microns of gas pressure are all factors which cast doubt on the validity of any such type of speculation. Specifically, in answer to his suggestion concerning the use of different gases, I refer him again to the previously mentioned article (page 39, volume 215 of the *Journal* of the Franklin Institute for 1933) in which experimental data concerning the dielectric strength of oil as a function of its gas content is described. The gases used are hydrogen, air, and carbon dioxide. The increased dielectric strength of oil under increased nitrogen gas pressure is usually recognized. The type of gas used to produce increased oil dissolved gas content is not of major importance. The controlling factor is the changing quantity of oil dissolved gas, a factor which has been expressed in the present paper as the oil-dissolved gas density. The use of such terminology reflects the attempt to correlate the breakdown of gas-containing dielectric liquids and the breakdown of gases, modified "as is necessary by the affinity of the molecules of the solute (gas) for the molecules of the solvent (oil)."

Cable System Neutral Grounding Impedance

Author's closing discussion of a paper published in the January 1935 issue, pages 30–40, and presented for oral discussion at the cables session of the winter convention, New York, N. Y., January 24, 1935. Other discussions of this paper were published in the March 1935 issue, page 324, and in the April 1935 issue, pages 434–6.

J. E. Clem: Most of the discussion of this paper questions the soundness of the original theory (presented by Doctor Petersen) on which it is based. The author wishes to emphasize the fact that he holds no brief for any particular theory and that if and when a better analysis of the arcing ground phenomena appears than that used by him as the basis of the development in the paper, he hopes to be among the first to accept it. Inasmuch as there seems to be such a fixed difference of opinion as to whether arcing ground overvoltages actually exist and if they do, how they develop, the author feels that nothing will be added by continuing the discussion.

The statement that the proposal to limit the calculated arcing ground voltages to 3 times normal had been "tentatively . . . accepted by the operators" was made in good faith, but it appears to have been based on misinformation. It is regrettable that this mistake was not called to the author's attention in the approval stage.

Heat Flow in Turbine Generator Rotors

Author's closing discussion of a paper published in the October 1934 issue, pages 1359–65, and presented for oral discussion at the electrical machinery session of the winter convention, New York, N. Y., January 22, 1935. Other discussions of this paper were published in the May 1935 issue, pages 555–7.

C. E. Peck (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The writer appreciates the thorough study made by Snell in applying the calculation to a large turbine generator rotor. His study emphasizes especially the desirability and in many cases the necessity of separately studying the different sections of the rotor which do not have similar cooling conditions and arriving at a temperature rise constant for the rotor body which is a weighted average of the temperature rise constants obtained from calculating the different sections separately. This extension of the analysis is important in long rotors in which the axial and radial velocities of the cooling medium vary greatly from the end to the center of the rotor body, in which case the use of a single average value for each of the various heat transfer coefficients is not accurate enough. This point was not mentioned in the paper and the writer considers Snell's study an important addition to the paper. The satisfactory agreement between calculated and test values indicates that Snell has paid particular attention to the importance of having available a reliable and representative set of physical constants to apply to the calculation method.

Comments upon the choice of constants have been given by Mortenson. The importance of air pockets in the insulation cannot be underestimated and average values of the equivalent air film can be obtained only by carefully conducted tests, preferably on a model coil. In the rotor the effect of the air pockets on the accuracy of the calculation is not as critical as in the stator because the thermal drop across the insulation is not as large a proportion of the total thermal drop as in the stator, particularly on the higher voltage machines. When constants are determined by test methods, it is very desirable to make more fundamental studies of a developmental nature, preferably on elements in the form of models because many variables can be studied and more comprehensive and fundamental relations can be derived from the tests. The results thus obtained may be applied successfully to a wide range of sizes.

The analytical methods outlined in the paper enable one to predetermine the effect of various schemes for increasing the rotor output. In many cases an investigation of this type shows that what looks to be a promising scheme does not give enough gain to justify the cost of adopting a new type of rotor construction.

The methods of calculation shown in the paper could be adapted to estimate the gain from the use of the ventilating scheme illustrated in figure 6 of Mortenson's discussion. Test data would be needed on the velocities of air in the vent ducts, but such velocities have been determined by model tests. The calculation could then be used to determine whether or not the scheme could be used to advantage on a full size rotor. The calculations are useful for analyzing test results as well as studying the effects of changes to obtain more output.

In conclusion, the writer wishes to point out that the present paper is a direct application to the rotor of the equivalent thermal circuits which have been previously worked out by C. R. Soderberg in his paper "Steady Flow of Heat in Large Turbine Generators," A.I.E.E. TRANSACTIONS, volume 50, June 1931, pages 782–98. His work justified the use of the equivalent thermal circuit of the form shown in the paper for solution of 2-dimensional heat flow problems because he compared the results obtained, using the circuit with an independent fundamental mathematical treatment of the 2-dimensional steady heat flow problem applied to the slot region of an electrical machine. His work made possible the reasonably complete application given in this paper and shows how valuable a tool the equivalent thermal circuit is for solution of heat flow problems in electrical machines.

Transients in Magnetic Systems

Author's closing discussion of a paper published in the March 1934 issue, pages 418–25, and presented for oral discussion at the electrical machinery session of the winter convention, New York, N. Y., January 22, 1935. Other discussion of this paper was published in the May 1935 issue, page 557.

C. F. Wagner (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): Weber raises the question that for small air gaps the assumption of uniform flux density in the air gap cannot be correct. With this I quite agree. Neither is the assumption of equal radial distribution in the iron and air gap correct. Actuality lies somewhere between these 2 assumptions. The particular value of my paper in the realm of small air gaps is that it provides a second limiting value within which the actual solution must lie. Without this analysis there would always have been some speculation as to the accuracy of the assumptions of previous investigators. Perhaps this point was not stressed sufficiently in the paper. Figure 1 of this discussion shows the calculated difference for the 2 assumptions. The constants chosen are marginal for a large synchronous machine.

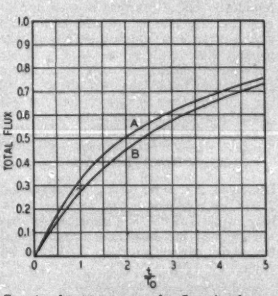


Fig. 1. Limiting curves for flux distribution
A. Assuming uniform flux density in air gap
B. Assuming radial distribution of flux density same in air gap and solid part of iron
$\frac{T_s}{T_o} = 4.0 \quad n = 0.5$

In this connection I could have calculated and plotted the curves of figure 3 of the paper using different parameters. Thus a family of curves with $\frac{\theta}{T_o} = n \frac{T_s}{T_o}$ constant might have been determined for different values of n. The difference between the curve for which $n = 1$ and any other curve would then give the difference between the solutions for the 2 assumptions under discussion.

Impulse and 60 Cycle Strength of Air

Discussion and authors' closure of a paper by P. L. Bellaschi and W. L. Teague published in the December 1934 issue, pages 1638–45, and presented for oral discussion at the transformer symposium of the winter convention, New York, N. Y., January 22, 1935.

C. M. Foust (General Electric Co., Schenectady, N. Y.): The authors have summarized some very interesting data in their paper. While they have applied humidity and air density sparkover corrections in some cases, still it is apparent that more precise information on these is required. As work on the strength of air proceeds, this matter of corrections becomes more difficult to take care of. Corrections for humidity and air density appear to vary with wave shape and polarity of the applied voltage, electrode shape, field configuration, and voltage level. For the present, an established procedure of carefully recording all test conditions will undoubtedly prove helpful.

The curves and tables presented again call attention to the great influence of polarity on sparkover when dissimilar electrodes are used. The authors conclude that "the flashover voltage is lowest when the positive polarity is applied to the electrode where the electric field is most intense." In connection with the rod-plate tests described, a slight extension above the plate resulted in sparkovers occurring consistently to the extension when it was positive in polarity. With the extension negative in polarity sparkovers took place partly to the rod extension and partly to the adjacent surface of the plate. The protective cone of the positive extension therefore includes the entire plate and is decidedly greater than that of the negative extension. This phenomenon was pointed out by Lewis and Foust in the *General Electric Review*, August 1931, in connection with the polarity of lightning currents in transmission line tower structures. Since that time additional data on these currents have been accumulated. Tower currents resulting from lightning strokes are almost

exclusively negative in polarity, that is, the tower top is negative relative to the tower base. This suggests a negative cloud with the tower acting as an extension above the positive ground and serving as a terminal for all negative cloud strokes within a wide area. The laboratory tests described by Bellaschi and Teague again bear this out.

J. C. Dowell (General Electric Co., Pittsfield, Mass.): The authors have used a humidity correction factor of 3 per cent per grain per cubic foot for their rod gap and rod to plate gap 60 cycle sparkover data. Similar 60 cycle data obtained in Pittsfield during the past several years indicates that this correction factor for the rod gap is not a straight line, but is a curve. The correction factor of 3 per cent is a fairly good average and close enough for general use over the range of humidities below 6.5 grains per cubic foot, but for humidities above 6.5 grains the curve departs appreciably from the average value of 3 per cent. For example, in correcting 8.5 grains down to the standard value of 6.5 grains per cubic foot, Pittsfield data indicates a correction factor of only 1.7 grains per cubic foot. While the deviations mentioned are not appreciable for the range of humidities over which the data presented were taken, it does indicate a possibility for further refinement along this line.

It is noted that the impulse time-lag curves given on the different type gaps stop at 2 microseconds. It would seem that from the standpoint of the design engineer the most valuable time lag data exists in the range of time lags below 2 microseconds. The writer would like to ask if this time is the limit of the recording equipment.

The time lag data presented in figures 11 and 12 indicate that the positive and negative sparkover curves given in figure 13 are not for a constant time to breakdown but probably vary over quite a range. It would seem that these curves in figure 13 would be of more value if plotted for a constant time-lag condition for the different gap spacings.

W. L. Lloyd (General Electric Co., Pittsfield, Mass.): The results given in this paper are of considerable theoretical interest. That these results are in agreement with previously published data will be of general satisfaction. There is close agreement between the data on the rod gap and the data in "Flashover Voltages of Insulators and Gaps," ELECTRICAL ENGINEERING, June 1934, pages 882–6, and "Impulse Flashover of Suspension Insulators and Rod Gaps," *General Electric Review*, December 1934; and, as mentioned in the paper, the sparkover data for the point-to-plane and sphere-to-plane gaps are in good agreement with those of Goodlet, Edwards, and Perry published in 1931.

Not mentioned by the authors and presumably overlooked by them is the remarkable agreement between their conclusions and those of earlier investigators. As early as 1915, for example, it was pointed out that the effect of polarity on the impulse sparkover of air gaps varied with the degree of dissymmetry of the electrodes. Thus, "for dissimilar electrodes, impulse sparkover takes place at the lowest voltage when the electrode in the densest field is positive. For uniform and fairly uniform fields a difference between + and − rupturing voltages cannot be detected" from a 1915 paper ("The Effect of Transient Voltages on Dielectrics," F. W. Peek, Jr., A.I.E.E. TRANSACTIONS, volume 34, 1915, part II, pages 1857–1909) is almost identical with the main conclusion of the 1935 paper by Bellaschi and Teague. This conclusion is the one having chief practical importance. It is, however, 20 years old.

P. L. Bellaschi and W. L. Teague: Referring to J. C. Dowell's discussion, his comments on humidity corrections are in line with our experience.

The characteristics of rod and sphere gaps on very short impulses have been published. (Refer to "Factors Influencing the Insulation Coördination of Transformers—II," P. L. Bellaschi and F. J. Vogel, ELECTRICAL ENGINEERING, June 1934, pages 870–6, and "Sphere Gap Characteristics on Very Short Impulses," P. L. Bellaschi and W. L. Teague, *Electric Journal*, March 1935, pages 120–3.) The technique of measurement has been developed in the past few years to a degree that these very short impulses can be recorded with good engineering accuracy.

The curves in figure 13 are for minimum flashover voltages. A family of constant time-lag curves could readily be drawn from figures 11 and 12.

The recent impulse data are obtained using the refined methods of measurement developed in the past few years. Furthermore, the effects of air density and humidity can now be accounted for. Hence, good checks have lately been possible between the different laboratories.

Particular mention is made of the early published data in the second paragraph of the paper and in references 13 and 19. To be sure, these early data are of qualitative interest but are obviously inadequate for the present design requirements. It is for these reasons that investigators have given so much attention in the past 5 years in an effort to establish reliable impulse data. These recent data are, therefore, of great practical usefulness as they relate to impulse waves of practical interest and to gap openings that correspond to the full practical range of transmission line voltage levels.

Recommended Transformer Standards

Discussion of a paper by H. V. Putman and J. E. Clem published in the December 1934 issue, pages 1594–7, and presented for oral discussion at the transformer symposium of the winter convention, New York, N. Y., January 22, 1935.

I. W. Gross (American Gas and Electric Co., New York, N. Y.): One objective of the committee, stated as "attempting to set up reasonable insulation levels for the design of transformers," is a worthy one, but since the transformer is only one link in the chain of insulation on a system, the question of whether the transformer impulse level here proposed by the committee will fit in with the broad problem of establishing insulation levels (a problem the joint N.E.M.A.-E.E.I. insulation co-ordination committee is now working on) should be carefully examined. Establishing insulation levels requires the co-ordinating of the various links of the insulation chain, and it does not seem obvious why the transformer is the starting point. On the contrary, it does seem reasonable that the transformer insulation strength, after system insulation levels have been set up, can be arrived at on the basis of the magnitude and characteristics of impulses which can reach the transformer, taking into account the type of protection used, that is, lightning arresters for both grounded and ungrounded systems, rod gaps, or even no protection whatsoever. This consideration logically leads to the conclusion that transformers in a given voltage class will require more than one voltage level.

The conclusion has been drawn by the authors that the 2 year experience on factory impulse testing on large power transformers "has demonstrated the practicability of commercial impulse tests." If the statement implies that all transformers tested have successfully withstood the impulse tests, and are giving satisfactory service in the field, supporting data will be most welcome to bear out this contention. In fact, it would be most desirable if the authors could give us, first, a summary of the number and kilovolt and kilovolt-ampere ratings of all transformers which have been impulse tested during the past 2 years, second, advise whether any of these transformers failed or showed distress during the test, third, inform us whether any failures of the transformers so tested have taken place after they have been placed in service, and, fourth, how long they have been in service under lightning conditions. An unspotted record over a sufficiently long period of time, showing that the transformers tested had successfully passed tests and had given perfect service in the field, would give considerable assurance that the present impulse test proposal is headed in the right direction.

The commercial impulse testing of transformers, which some 5 years ago was considered impractical by some closely connected with transformer designs, has now been established, but there is still a great deal to be done before we have the same assurance with regard to the impulse strength of transformers that we have on their 60 cycle strength. The commercial test work already done lays a foundation for extending the test procedure to give an indication of the insulation strength of a completely assembled transformer under more severe conditions than produced by minimum $1^1/_2 \times 40$ microsecond positive waves.

Regarding the revised impulse dielectric strength tests, it is suggested that a test be applied with "a wave having a crest at least 10 per cent greater than the minimum flashover voltage of the test gap." This statement in its present form is rather confusing and should be clarified.

Another point in connection with the test code relates to the polarity of the test wave. Assuming, as we have been told, that the insulation strength of the trans-

former is the same on both positive and negative impulses, the application of either polarity wave would indicate the strength of the transformer. However, data have been published showing that for a given rod gap some 15 per cent higher impulse voltage is required to break down the gap if the wave is negative than if it is of positive polarity. This means that the co-ordinating gap, so called, if used in service with the transformer would have to be set for approximately 85 per cent of the test gap to give the same protection against negative impulses of the same general shape as the test wave. With this consideration in mind I would like to ask the authors the interpretation which is to be placed on the gap spacings listed as "co-ordinating gap" in table I. It seems that a clear definition of "co-ordinating gap" would clarify the situation and would show just where this gap fits in the picture of insulation levels and co-ordination.

Again, if we are later to test transformers with negative impulses, since the test gap has some 15 per cent higher flashover for negative waves than for positive waves, the present proposed test gap spacings would have to be altered accordingly. The more consideration one gives to the gap as a standard of co-ordination the more it appears unsuited as an insulation level reference. Its value as a testing device is not questioned. This brings up again the question of establishing a standard for designating and measuring the impulse strength not only of transformers but also of other insulation.

It was pointed out as far back as 1930, at the time the lightning and insulator subcommittee of the power transmission and distribution committee was working to set up a standard of preferred test waves, that lightning strength should be expressed in terms "definitely expressive of lightning conditions," and that is in terms of volts and time and not in terms of gaps, insulators, or some other secondary standard.

One has only to refer to table III of the paper to see the difference between an expressed insulation strength in kilovolts and inches of rod gap spacing. The kilovolt values are definite, and can be co-ordinated with other insulation and other links in the insulation chain. Little can be said for the rod gap except that it is necessary to refer back to published curves or tabulated data to get the kilovolt value of each rod gap to co-ordinate its flashover value with other apparatus. It is believed that the sooner we can talk of impulse values of insulation in definite voltage values, the quicker we will put the entire insulation co-ordination, in its broadest aspect, on a firm foundation for solution.

It appears from table III that the proposed impulse flashovers for bushings are approximately 5 per cent higher than the test gap voltages for transformers. In other words, the proposal seems to set up a situation where the bushing is stronger than the safe limit of the transformer; that is, we are faced with a situation where the transformer is definitely not self-protecting in any sense of the word, unless it is proposed to use the factor of safety between the transformer tested strength and its ultimate strength to render the transformer self-protecting. I wish to ask the authors on what basis of co-ordination these proposed impulse flashovers for transformer bushings were arrived at, and how this basis compares with the situation which has existed for years on transformers which are now in service.

L. C. Nichols (Allis-Chalmers Mfg. Co., Milwaukee, Wis.): This paper shows that considerable progress has been made in establishing insulation levels. The last recommendation for impulse testing should be adopted instead of the first one proposed, as it can be determined better from the oscillograph records whether there has been a failure or not if the last impulse test is made with a full wave instead of with a chopped wave.

Table I referring to co-ordination gaps should be omitted, as we are standardizing tests and test gaps only.

There is a reasonably definite relation between the test gap and the low frequency dielectric tests. There also should be a fixed ratio between the impulse strength of the test gap and the impulse strength of the bushings. Bushings should have a 5 per cent greater impulse strength than the gap. These values should be the same for both power and distribution transformers.

If, on account of the size and importance of a transformer, it is desired to have larger bushings, then insulation of the next higher class should be used and the corresponding test gap, bushing, and low frequency test used.

If operating conditions are bad, severe lightning encountered, or if transformer protection requires the use of lightning arresters of larger size than normal as a result of overvoltage conditions prevailing, then insulation of the next higher class should be used.

If good operating conditions exist with good lightning protection provided and the neutral solidly grounded, then the next lower insulation class could be used.

Whatever insulation class is selected determines the test gap, bushing, and low frequency test. In other words, 3 standards of insulation are available. Bushings on transformers when shipped should always be provided with gaps of the same impulse strength as the test gap.

C. M. Foust (General Electric Co., Schenectady, N. Y.): In connection with this paper I would like to say something about impulse testing recommendations from the standpoint of the laboratory engineer who is called upon occasionally to make such tests. I will have to insist that the recommendations I have tried to follow in the past in performing tests have not been sufficiently clear to avoid possible incorrect procedure on the following points:

1. Is the test gap connected when the impulse is applied and does it spark over or not? This should be made clear for each impulse application. I do not believe that the phrase "minimum wave permitted by the test gap" as in test 1 of the proposed tests will be clear to all concerned. Just how a test gap permits or does not permit certain waves is left entirely to the imagination. In test 2 a wave is called for which is "just sufficient to flash over the specified test gap," and in test 3 "a wave having a crest at least 10 per cent greater than the minimum flashover of the test gap." Unless the sentence in the following paragraph reading "the test gap is connected directly to the ground" is taken as an instruction that the test gap shall be set at the specified gap of table I and connected in the circuit for tests 1, 2, and 3 these phrases are not specific. Probably the next paragraph beginning "without the test gap the transformers, etc.," does add to the clarity of what comes before. If so, my difficulty had already been recognized, and a way of overcoming it devised. A similar paragraph at the beginning reading "with the test gap connected and the spacing adjusted as per table I the transformer shall, etc.," would make the picture clearer from the beginning.

2. Is the impulse always applied to one high voltage terminal with the other terminal grounded? This should be made clear, so that there will be no temptation where both terminals are insulated to apply the impulse to both high voltage terminals.

3. When is power voltage to be applied? In test 5 I read as follows: "A wave as high as in test 3 or 4 but with means for maintaining the excitation voltage across all parts of the winding." The paragraph immediately following states: "All 5 of these tests are to be made with the transformer under full power voltage excitation and with impulse synchronized, etc." I am still at a loss to know just when to hold power voltage on the transformer. In this connection I would urge that some definite statement as to the important reason or reasons for holding power voltage on be incorporated in the recommendations. Such a statement would assist engineers in other fields to decide for themselves whether they required power voltage or not during impulse tests.

I note that the committee is hard at work on changes in the present test code. I would be happy to see the new recommendations very specific on points such as referred to above. I realize that the present paper is not supposed to be a standard in itself and that therefore my criticisms as applied to it may be little justified. However, it gives me the opportunity to call attention to uncertainties I have encountered in the present recommendations.

Overloading of Power Transformers

Discussion and authors' closure of a paper by V. M. Montsinger and W. M. Dann published in the October 1934 issue, pages 1353–5, and presented for oral discussion at the transformer symposium of the winter convention, New York, N. Y., January 22, 1935.

Herman Halperin (Commonwealth Edison Co., Chicago, Ill.): In considering the permissible short-time loads for transformers given in table I, it should be noted that, in those cases where the transformers feed into underground lines the relation of the short-time to the full-load ratings for cable may be quite different from the relations shown in the table.

In the A.I.E.E. rule for maximum allowable copper temperature for underground cable, there is no provision for high temperatures for short periods of time as there is elsewhere for some other insulations such as in transformers. Therefore, the establishment of short-time loads for cables has to be done either (1) at the expense of reducing the maximum allowable temperature for continuous loading and using the difference between this temperature and the maximum permissible by the A.I.E.E. rule to provide for special overloads, or (2) by permitting temperatures on the cable insulation in excess of those specified in the A.I.E.E. rule.

In the Commonwealth Edison Company the first procedure is being followed for 66 kv cables of the ordinary type, the maximum allowable temperature for steady load

being a few degrees below the maximum of 60 degrees centigrade set by the rule. As a result, as indicated, for example, in the accompanying table for the line out of State Line station the one hour overload rating for the cable for recurrent loads is 5 per cent larger than the same rating for the transformer, while for emergency loads that may occur every few years the transformer rating is considerably larger than the cable rating for one hour overloads.

Ratings of 100,000-Kva 66-Kv Transmission Apparatus in Chicago in Summer

	Apparatus Ratings in Kva	
	Transformer	Cable
Full load	100,000	96,000
One hour overload,		
Recurrent	105,000	110,000
Emergency	140,000	110,000

For about 10 per cent additional cost, oil filled cable may be used instead of 66 kv cable of the ordinary type covered by the table, and in such case the one hour emergency rating for use in Chicago conduits would be about 180,000 kva, which is more than the transformer rating. It is doubtful for the example given whether we could or would try to feed 140,000 kva or 180,000 kva into the 66 kv system even if the cable could safely stand the load. For most of our system, however, the transformers feed into a bus and the 66 kv lines come off the same bus, so that in rare instances some advantage may be taken of the high emergency ratings of such transformers. Normally these transformers operate appreciably below their full load rating, with the result that the copper temperatures at the time of daily system peak are, roughly, from 15 to 60 degrees centigrade or more below the permissible maximum of 105 degrees.

By decreasing the magnitude of the overloads on its distribution transformers, so that in general the transformers operate over a period of only a few months at about full-load rating or 10 to 20 per cent over full-load rating, the company has practically eliminated failures in these transformers from overloads and high temperatures.

Our operating engineers indicated a few years ago that from their standpoint the most efficient way of rating cables was to establish full-load ratings in such a way that the lines would have ample carrying capacity for normal conditions when all lines and equipment are in service, and establish overload ratings to take care of those occasional situations when a line or piece of equipment is out of service. This arrangement has proved quite satisfactory.

For 3-conductor 12-kv cables, we have established, for one special group of lines, an emergency rating for 2 hours following full load of about 10 per cent over full-load rating in contrast to the 25 per cent excess permitted in table I of the paper for emergency loads on transformers for 2 hours.

There are a number of factors not covered by A.I.E.E. rules or in the A.E.I.C. cable specifications, such as cable movement, sheath stretching, void formation, and maximum allowable copper temperature for short periods, which must be taken into account in the establishment of special ratings for cables.

For 66 kv cables of the ordinary type, we have found some lots which have been in service for a number of years and removed for various reasons to have suffered no appreciable deterioration even after operating at about the maximum allowable temperature permitted by the A.I.E.E. rule. In contrast with this, we have the implication in the article by the authors and in the report of experimental data in the paper by L. C. Nichols that, when transformer insulation is operated at the maximum allowable temperature for continuous operation and at excess temperatures for short periods of time, the insulation would have a relatively short life. Nichols gives a life of only $1^1/_2$ years for transformer insulation operated at 105 degrees centigrade. This temperature is 20 degrees and 30 degrees, respectively, above the maximum allowable temperatures for low voltage impregnated paper insulation and varnished cambric insulation when in cables according to the A.I.E.E. rules. For higher voltages, the differences are larger. Even after allowing for the differences in the duty on these similar fibrous materials used in transformers and in cables, apparently there is a smaller factor of safety in the allowable temperature limits and allowable overloads established for transformer insulation than for cable insulation and, when considering the transmission units consisting of transformers and underground lines, utility engineers should keep this point in mind.

L. C. Nichols (Allis-Chalmers Mfg. Co., Milwaukee, Wis.): This paper gives some valuable information regarding the overloading of power transformers. It is interesting to note that the emergency overloads use up $^1/_4$ of one per cent of the life for each overload and the recurrent overloads use up 1/1,000 of one per cent of the life for each load.

It might be well to reconsider the allowable overload of one per cent for each degree that the ambient temperature is below 30 degrees centigrade. If a transformer will carry 100 per cent load in a 40 degree ambient, it can carry more than 100 per cent load when the ambient is below 40 degrees but above 30 degrees without exceeding 105 degrees at a hot spot. The present rules should be changed to allow one per cent overload for each degree the ambient is below 40 degrees. Another way of expressing permissible load would be to set up a tabulation showing permissible load and time of load according to actual oil temperature without the temperature of the windings exceeding a hot spot temperature of 105 degrees. The tabulation should show permissible loads following full load and following no load. The tabulation would be approximately as given in table I of this discussion.

The oil temperature should not be allowed to exceed 90 degrees centigrade under any conditions, and when full load is carried on the transformer, the oil temperature should be limited to 80 degrees. When the oil temperature is below 80 degrees increased loads can be carried as shown in the tabulation.

The allowable loads can better be determined from oil temperature than from ambient temperature.

Basil Lanphier* (American Gas and Electric Co., New York, N. Y.): Although I am a member of the transformer subcommittee, my first acquaintance with the matter contained in this paper, which is presented in the name of the transformer subcommittee, was through the pages of ELECTRICAL ENGINEERING. I want, therefore, to dissociate myself completely from any official connection or any official sponsoring of the matter contained therein.

The statement in the first paragraph that "the sole purpose of these standards is to establish a standardization of design and test" may express the designer's and manu-

* Deceased; see page 801.

Table I—Permissible Load on Transformers With Hot Spot Temperature of 105° C.

Following Full Load	Oil Temperature, Degrees Centigrade										Per Cent Loss in Life
	80	75	70	65	60	55	50	45	40	35	
Per cent load, 1 minute	100	160	200	235	265	290	315	338	360	380	0.0002
Per cent load, 2 minutes	100	136	165	190	210	229	247	263	278	293	0.0004
Per cent load, 3 minutes	100	127	151	171	190	206	220	233	246	258	0.0006
Per cent load, 4 minutes	100	122	144	161	177	191	205	218	230	241	0.0008
Per cent load, 5 minutes	100	120	139	155	170	183	196	207	218	228	0.0010
Per cent load, 10 minutes	100	117	132	145	157	168	180	189	199	208	0.002
Per cent load, 20 minutes	100	114	128	140	152	162	173	182	191	200	0.004
Per cent load, continuous	100	114	128	140	152	162	173	182	191	200	

Following No Load	Oil Temperature, Degrees Centigrade										Per Cent Loss in Life
	80	75	70	65	60	55	50	45	40	35	
Per cent load, 1 minute	230	244	272	300	322	345	366	387	410		0.0002
Per cent load, 2 minutes	160	185	206	225	242	260	276	291	305	319	0.0004
Per cent load, 3 minutes	137	157	177	194	210	225	239	251	263	274	0.0006
Per cent load, 4 minutes	124	144	161	177	192	206	218	230	240	261	0.0008
Per cent load, 5 minutes	117	136	153	168	181	194	206	217	228	237	0.0010
Per cent load, 10 minutes	104	121	135	148	159	170	181	191	200	209	0.0020
Per cent load, 20 minutes	100	114	128	140	152	163	173	182	191	200	0.004
Per cent load, continuous	100	114	128	140	152	163	173	182	191	200	

Oil temperatures must not be exceeded. Per cent loss in life is the per cent loss for each time transformer is loaded. Twenty minute interval should elapse between each overload.

facturer's viewpoint. In the eyes of the operator and purchaser, however, the standards are looked upon as a guide toward obtaining transformers that will operate with a minimum amount of trouble when carrying their rated load continuously for an indefinite number of years.

In support of the foregoing thought, I quote paragraph 121 of A.I.E.E. Standards No. 13—"continuous duty is a requirement of *service* that demands *operation* at substantially constant load for an *unlimited period*." Further, paragraph 150 defines rating as "a rating of a machine, apparatus, or device is an arbitrary designation of an *operating* limit."

A second point in the authors' paper that should be amplified and supported by the details of their laboratory tests is the statement that "the rate of mechanical deterioration of fibrous insulating material doubles approximately for each 8 degree centigrade increase of temperature." In support of this conclusion, reference is made to V. M. Montsinger's paper "Loading Transformers by Temperature," A.I.E.E. TRANSACTIONS, volume 49, April 1930, pages 776–90.

From a careful review of this 1930 paper, we find that tests were made on black and yellow varnished cloths for a period of 68 weeks to determine the decrease in tensile strength when subjected to temperatures of from 90 to 100 or 105 degrees centigrade in both air and oil.

It is our thought that varnished cloths constitute a very small part in transformer insulation and that further research should be conducted, particularly upon oil which is relied upon for the larger portion of the insulation, and upon the solid materials, such as "herkolite," which are used for the coil forms and other major insulation.

Decrease in tensile strength of materials in a stationary device such as a transformer winding we do not believe should be made the major factor in determining the rate of aging of the entire transformer. As long as the machine is undisturbed, the only requirement of the fibrous insulation on the turns is to give spacing and separation. Oil in good condition will supply the required insulation.

The useful life of power transformers can best be determined, we believe, by an analysis of failures in actual service. A survey of the records of our companies discloses that during the past 10 years about a dozen failures have taken place in large power transformers, and with one exception, these failures have been definitely diagnosed as caused by lightning.

The one exception mentioned above resulted from a failure of the protective devices to isolate a transformer that was supplying energy to a solid short circuit.

By proper application of the lightning arresters that are now available, together with the co-ordination of line insulation, installation of ground wires, etc., we believe that we have definitely corrected these conditions and eliminated lightning as the major cause of continued failures on our large power transformers.

It seems to me that the authors are definitely admitting that for years they have been selling equipment under definite guarantees and are now beginning to have doubts as to whether those guarantees should be taken as seriously as most purchasers have taken them. Disregarding many of the questions of business responsibility and business ethics that this attitude raises, it would seem to me that it is imperative not only that the manufacturers do something to improve the present insulating materials to withstand the present A.I.E.E. standard temperature limits, but that an effort be made to raise the present operating temperature limit of 95 degrees so that the cost of transformers may be substantially reduced. Whether this takes the form of new insulating materials to replace varnished cambric, paper, and other solid insulating materials used in transformers, new liquid dielectrics, or new methods of cooling, is a manufacturer's research problem. There is one thing, however, that the manufacturers and their engineers may be certain of—the need for lower cost equipment is imperative. It remains to be seen whether the manufacturers with the most experience in this field will rise to this demand.

E. A. Church (Edison Electric Illuminating Company of Boston, Mass.): It might be stated that the 2-hour overload capacities for recurrent loads listed in table I check very closely the results we have obtained for 24-hour period load cycles. It might be well to define more clearly the term "recurrent loads" before this standard is adopted by the A.I.E.E. for loading of transformers. Does recurrent mean repeated daily, weekly, or what period? The results we have obtained indicate that they might be repeated daily without decreasing the life of the transformer to any appreciable extent.

V. M. Montsinger (General Electric Co., Pittsfield, Mass.) and **W. M. Dann** (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): Lanphier questions the validity of the 8 degree rule on the basis that it was based only on tests on varnished cloths as reported in the 1930 paper on "Loading Transformers by Temperature" by V. M. Montsinger. Figure 8 in this report gives the results of tests made at the Massachusetts Institute of Technology on cable paper. This shows that the 8 degree rule holds for cable paper as well as for varnished cloth. Cable paper is used quite extensively for turn insulation in transformers.

Lanphier further states that his company has had no failures from deterioration but presents no data to show that any of the transformers involved were operated at long periods at temperatures approaching 105 degrees centigrade hot spot. If he has data of this sort it would be valuable to have it presented before the Institute.

The Institute standard prescribing a temperature rise of 55 degrees centigrade at full load was established many years ago to define the size of a transformer having a given rating, and we find in Standard No. 1 the statement, in capital letters, that this temperature rise was established *for the purpose of assigning a rating*. It was coupled—rightly or wrongly—with a *maximum* ambient temperature of 40 degrees and the whole plan constituted "an *arbitrary* designation of an operating limit," to quote from Lanphier's remarks with just a little change in the emphasis. This scheme of rating is quite a different matter from a specification that the transformer will operate continuously in a 40 degree ambient for a long period of time with no measurable deterioration of the insulation. However, experience has shown that this standard of rating has been satisfactory for usual operating conditions and that trouble has been encountered only in relatively few cases with unusual conditions. The differences between standards for rating and operating practice are on the whole rather generally appreciated.

Lanphier states that he does not consider the tensile strength of the insulation a good measure of the deterioration in a transformer. There are, broadly speaking, 2 forms of deterioration in oil immersed transformers; the first being deterioration of the solid insulations, and the second being deterioration of the oil. Either of these, if carried to extremes, will ruin a perfectly good transformer. It has been found from careful laboratory investigations that tensile and bending tests are the most satisfactory measures of deterioration in the solid materials. Dielectric tests are practically useless for this purpose since the dielectric strength remains practically constant until the insulation is completely ruined when the puncture strength falls off suddenly to practically nothing. In large transformers in particular it is important that the mechanical strength of the insulations be maintained to prevent disruption and electrical failure as a result of magnetic forces.

Nichols suggests that the present A.I.E.E. rules on operating recommendations be changed to allow one per cent overload for each degree the ambient is below 40 degrees instead of one per cent for each degree that the ambient is below 30 degrees. It seems to us that he is not consistent in advocating this change. For instance, he states in his paper on "Effect of Overload on Transformer Life" that if the transformer is operated at rated load continuously in a 40 degree ambient, the life will be very much below that normally expected of a transformer. Everyone knows, of course, that transformers seldom operate continuously under these extreme conditions and it is for this reason that transformers under average operating conditions have given satisfactory service. Now Nichols is proposing that the rules be changed to permit sufficient overload in low ambients to simulate the condition of a transformer operating at rated load continuously in a 40 degree ambient. As a matter of fact, by permitting the one per cent rule to start at 40 degrees it would be possible and much more likely to result in continuous operation at 105 degrees hot spot than it is possible to maintain 105 degrees under rated load conditions in a 40 degree ambient. For this reason we are somewhat surprised to see that Nichols proposes to start the one per cent per degree overload at 40 degrees instead of 30 degrees.

Halperin in comparing the overload capacities of cables and transformers shows the transformer at a disadvantage on recurrent overloads but in doing so states that his full-load rating of the cable was arbitrarily reduced before making the comparison. According to his own statements, the transformer would have a 5 per cent, one-hour recurrent overload rating, whereas the cable would have a zero overload rating

and must, therefore, be underrated for the normal application. A still greater advantage for the transformer would be shown if it also were underrated for normal load. The mere fact that it is necessary to underrate a cable and not a transformer shows the advantage of the cooling by oil circulation that is used in transformer designs.

Church raises the point as to the precise definition of a recurrent load. The definition of a recurrent load given in the paper states that it is one regarded as an occasional occurrence with steady state temperature conditions restored before repetition. This would permit the loads to be repeated at least once a day as this will give time enough for the temperature to be restored to the value preceding the overload.

Effect of Overloads on Transformer Life

Discussion and author's closure of a paper by L. C. Nichols published in the December 1934 issue, pages 1616–21, and presented for oral discussion at the transformer symposium of the winter convention, New York, N. Y., January 22, 1935.

W. M. Dann (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The 8 degree rule, which is the foundation of Nichols's ideas about the life of transformer insulation, seems to have enough authority behind it to justify using it in the way that he has done. If we can accept it as a fact that it holds true over a range of temperatures corresponding to time periods from a few seconds to a number of years, then with the relation between deterioration and temperature definitely fixed, all that is necessary in order to create a complete schedule of transformer life under all temperature conditions is to be sure that we select the proper starting point as the basis of deterioration and temperature.

As I understand it, Nichols has selected for his starting point a life of 5 years for insulation under oil at 90 degrees centigrade. Based on this starting point, the life of a transformer operating continuously at 55 degrees rise above an ambient temperature of 40 degrees works out to be $1^1/_2$ years. I suspect that among those who have done research work with transformer insulation there will be a number of different opinions about the validity of this starting point and of the results that come from it.

I should like to point out the importance of this starting point. When we make temperature runs on transformers, it is sometimes difficult to duplicate temperatures on identical tests within 2 or 3 degrees. Suppose that instead of the starting point of 90 degrees centigrade we were to adopt a temperature only a couple of degrees higher. Then all the curves and tabulations shown in this paper would be wrong to the extent of 25 per cent, and immediately 4 months would be added to the $1^1/_2$ years which is given as the life of a transformer operating continuously at 55 degrees rise above 40 degrees. I mention this simply to point out that a very small difference in the temperature of the starting point makes a large difference in all the calculated results.

My idea of this paper is that the author has contributed a *method* which is ingenious and which has a lot of merit. Nevertheless, I am afraid that it is not at all clear that we can accept his conclusions as a definite and precise guide for overloading transformers in service.

J. E. Clem (General Electric Co., Schenectady, N. Y.): The subject of overloading of transformers has received a great deal of attention by the transformer subcommittee during the past 3 or 4 years. When this subject was first introduced into the subcommittee by the publication of 2 articles entitled "Loading Transformers by Temperature," by V. M. Montsinger, and "Operating Transformers by Temperature," by W. M. Dann and presented at the A.I.E.E. winter convention in January 1930, the subcommittee considered 2 general methods of overloading transformers. One method was to base the magnitude and duration of overloads on the mechanical deterioration of the insulation. The other method was to assign definite overloads in terms of the rating for different durations of time.

At the time the subcommittee undertook this work it had available a large amount of data on the effect of temperature on the aging of insulation (given in Montsinger's paper). The suggested method as now proposed by Nichols was carefully considered but it was not felt to be either a safe or practical method to use in setting up standards.

The subcommittee finally decided to recommend conservative overloads in terms of the name-plate rating for various durations of time as given in the subcommittee's report by Montsinger and Dann.

Now that Nichols has suggested the method of governing overloads by the deterioration of insulation, it becomes necessary to point out some of the principal reasons why the transformer subcommittee did not recommend this method. Up to the present time we have had very little experience in operating transformers under heavy overload conditions. In fact, until about 1925 the A.I.E.E. rules stated that "the name-plate rating of a transformer must not be exceeded whatever be the ambient." Although A.I.E.E. Standards No. 100 has permitted for some 3 or 4 years 30 per cent continuous overload for self-cooled transformers and 25 per cent continuous overload for water-cooled transformers coupled with low ambient temperatures, the final temperatures have not exceeded about 85 to 95 degree centigrade. Consequently, we really have had no experience in overloads that produced high temperatures for definite periods of time. During short circuit the duration of the time is very indefinite. The same can be said of grounding transformers which are expected to stand 160 degrees for one minute.

Even under conservative methods of loading transformers, experience has shown that some transformers have extremely long lives while others operating under severe conditions have relatively short lives. The reasons for this very large difference are the many factors which enter into the life of a transformer such as mechanical vibration, variation in quality of insulating materials, formation of sludge on the windings, effect of temperature in decreasing the dielectric strength momentarily—all these in addition to the mechanical deterioration of the insulation during the duration of the high temperature. It should be recognized that one cannot impose severe overloads on a transformer and expect it to have the length of life of a transformer that is not called upon to carry severe overloads.

The question, of course, is an economic one and in some cases the operator may be willing to sacrifice some of the life of the transformer in order to carry him over an emergency condition. However, if one expects a transformer to last from 20 to 30 years, which is not unusual, it cannot be expected to carry extremely heavy overloads at frequent intervals. When the transformer subcommittee was considering this method, calculations soon indicated that extremely heavy overloads could be carried for short periods with a very small amount of mechanical deterioration of the insulation. Having had no experience along this line it was not felt safe to recommend a method which indicated that such heavy overloads could safely be carried. It was recognized, however, that under emergency conditions one would be justified in permitting overloads considerably in excess of recurrent overloads; that is, overloads which are deliberately imposed on the transformer at frequent intervals. For this reason the subcommittee recommended permitting higher overloads for emergency conditions than for recurrent conditions.

In the final analysis it comes down to the fact that one cannot get something for nothing. If you impose heavy overloads on transformers you must expect a shortened life and if conservatism is not used the life may be very much shorter than that indicated by adding up the per cent deterioration of the insulation alone.

It was principally for these reasons that the transformer subcommittee abandoned the method now suggested by Nichols and recommended the method given in the companion paper. I strongly recommend that for the present we give the more conservative method a trial. Later, after we have obtained more experience, it may be possible to increase the loads above the values recommended by the subcommittee.

W. H. Cooney (General Electric Co., Pittsfield, Mass.): The author has approached the problem of transformer overloading by an interesting and ingenious method, but I cannot agree with his paper in 2 aspects: first, the data which he presents; and second, the dependability of aging of insulation as a sole basis for determining permissible transformer overloads.

The subject of aging, and its application to transformer loading, was covered quite fully in V. M. Montsinger's "Loading Transformers by Temperature" (A.I.E.E. TRANSACTIONS, volume 49, April 1930, pages 776–90), in which he presented for the first time the so-called 8 degree centigrade rule. This rule is to the effect that for each 8 degree increase in temperature, the rate of deterioration of insulation is doubled, and it is interesting to note that figure 1 of Nichols shows the same change of rate of deterioration as Montsinger's figure 11. A wide discrepancy is evident in the life at 105 degrees, the previous paper showing 7 years, this one $1^1/_2$ years. This is a ratio of over 5 to 1, holding

throughout the curve. Other than to state that after 5 years in oil at 90 degrees insulation is "exceedingly brittle," Nichols does not describe the type of mechanical test on which his curve is based. Montsinger used both tensile and folding, and if Nichols used some other form of test, this may explain part of the wide difference.

The value of the varying safety factor of figure 1 is doubtful, for at 250 degrees centigrade the 5 to 1 discrepancy I mentioned becomes 50 to 1. From another viewpoint, at 250 degrees the calculated life is based 10 per cent on data and 90 per cent on an arbitrary factor. If some safety factor is considered necessary it should be uniform, or preferably the safety factor should be applied to the temperature calculations.

Figure 1 also shows the danger of extrapolating data of this sort. A life of 100 years at 55 degrees centigrade and especially of 1,000 years at 30 degrees seems to be extrapolating to an unreasonable extent.

Whether the aging of insulation alone is a dependable guide for operating transformers is a question open to discussion. In Montsinger's paper he stated "It is doubtful if the actual life of a transformer can ever be determined, even by the most carefully conducted laboratory test, due to the lack of a proper criterion by which to judge whether an insulation has reached an unsafe degree of deterioration."

I have called attention to the wide difference between the 2 sets of data. In addition there is a large variation of "life" among the various transformer insulating materials and also with the treatment applied to a given material, although in general the 8 degree rule is followed. Since a transformer is a complex combination of materials, any general aging rule is bound to be a very crude approximation.

The question of dielectric strength cannot be ignored. It seems to have been proved that even exceedingly brittle insulation has practically its original dielectric strength provided it is not disturbed. (That is, aging is primarily a loss of mechanical strength.) However, the dielectric strength of insulation decreases with increasing temperature, and tests have shown that with an elevation in temperature of 100 degrees centigrade untreated insulation suffers a loss of 50 per cent of its dielectric strength. Although the original dielectric strength is regained after cooling, it is evident that a transformer is quite vulnerable to overvoltage during a heavy overload.

Insulation aging is not the only factor which may shorten the life of a transformer. At prolonged high temperatures the oil, especially in open transformers, may become oxidized long before serious aging of the insulation occurs. There is also oil within the windings and a thin film of oil in contact with the surface of windings which may have a temperature equal to or approaching that of the copper during severe overloads. Undoubtedly these local oil temperatures will have a deleterious effect on the life of the oil. Nichols does not even consider these factors.

One of the principle fallacies in using insulation aging as a basis for loading is the premise that all the life may be used; that, for instance, a load which uses 10 per cent of the life may be applied 10 times. This ignores the progressive mechanical weakening. That is, when 50 per cent of the life is gone, it should be considered that the transformer insulation is only one half as strong as when new and it may fail under the mechanical stresses of a short circuit which it could easily have withstood in its original condition. A simple analogy is that of a rope, used to lift a given load, which becomes half worn through in a year. It cannot be assumed that it will last another year, for it may break the next time it is used.

Moreover, the amount of aging which a transformer can experience and still withstand short circuits varies greatly with the type of conductor, turn insulation, treatment, general winding design, etc. These factors will influence through a wide range the degree to which the loss of original life may be carried before transformer failure.

Still another factor is the type of overload which may be applied. Aging data may indicate a given life for a transformer with (a) sustained overloads not greatly exceeding rated load in value or (b) a large number of heavy overloads, each of comparatively short duration. The transformer which is never subjected to appreciable overloads may approach the theoretical life before failure occurs; the transformer which is subjected to severe overloads will probably fail much sooner because the vibration and stresses of heavy overloads will tend to hasten mechanical failure of the insulation between various parts of the windings.

Manufacturers and operators know of cases of extremely short and extremely long transformer lives. Some transformers have operated for over 30 years. Others under very severe conditions have lasted only a few. That is, the extremes of life have been observed, with the obvious conclusion that the more a transformer is overloaded, the shorter is its life. Considering the wide variation of data and the many factors which must be considered, aging alone does not appear to be a reliable guide for loading. Rather, it seems desirable to follow recommendations based on general service experience, such as those proposed by Montsinger and Dann for the transformer subcommittee ("Recommended Transformer Standards," ELECTRICAL ENGINEERING, October 1934, pages 1594–7).

However, the paper by Nichols is of value in promoting at this time a full and frank discussion of a subject of interest to every transformer designing and operating engineer.

Philip Sporn (American Gas and Electric Co., New York, N. Y.): I wish to comment upon conclusion 4 of this most interesting and, in some respects, astonishing paper. This conclusion states, "If a transformer is loaded at a constant load 24 hours a day in a 40-degree ambient temperature, then a transformer rated $^1/_3$ larger than the load should be used." The natural corollary to this conclusion is, of course, that it is *not safe* to operate transformers of present American design and manufacture at a temperature maintained continuously at 95 degrees centigrade.

Further, where such operating conditions have been called for and a transformer rated only up to the load was purchased, then the presumption is that a transformer too small for the load has been purchased.

Contrasted to this conclusion, I would like to quote a statement made by E. T. Norris, chief designer of Ferranti, Ltd., England, in his paper presented before the A.I.E.E. in June 1929, entitled, "Safe Loading of Oil-Immersed Transformers" (A.I.E.E. TRANSACTIONS, volume 48, Oct. 1929, pages 1206–12). He stated, "It has become general practice for operating engineers to consider the standard rating as being the maximum safe rating under normal working conditions. Transformers larger than is necessary are, therefore, installed." These are 2 views of the chief designers of 2 outstanding manufacturers, which most certainly do not agree at any point.

There is another most vital point that needs to be considered. A.I.E.E. Standards No. 13 specify as usual service conditions that the temperature of the cooling medium shall not exceed 40 degrees centigrade, and that a temperature rise of 55 degrees for continuous loading shall not be exceeded. The summation of these 2 limiting conditions results in a total temperature of 95 degrees. I am sure that I express the opinion of most designing and operating engineers when I state that they have all for many decades been specifying, buying, and installing transformers on the basis that if the transformers were operated at full load at those temperatures their life would not only be comparative with that of other electrical equipment, but considerably longer, in view of the static nature of the device. Our own experience would indicate that we have had considerable justification for that belief.

If it is the intent of Nichols in presenting this particular viewpoint to scare a great many users into replacing transformer equipment, or if his intent is more subtle, I for one must admit not being able to penetrate the subtlety of the intent. Certainly from a standpoint of guarantee contained in A.I.E.E. Standards there is no warrant for an attitude implied in the paper, although there may be ample warrant for a belief that insulation does not last indefinitely and that its life is affected by the extent to which it is subjected to high temperatures. Further, I do not believe that the author's experience with his own transformers, with the performance of some of which we are acquainted, is such as to warrant an opinion on his part that they are subject to the hazards of life indicated by his data. I do believe, too, that where such situations do exist it is imperative that the designers concerned do something toward correcting these conditions and seeing that the equipment is brought up to the point where it will meet A.I.E.E. standard guarantees under the conditions prescribed and allowed for by these guarantees.

H. V. Putman (Westinghouse Elec. and Mfg. Co., Sharon, Pa.): I have been very much interested in reading this paper, which deals with a subject which those of us engaged in transformer work have had to consider. He arrives at a practical answer to a number of practical questions, but there are one or 2 questions which I think may well be raised before accepting completely his conclusions:

First, I would like to ask whether the curves shown in figure 1, which show the life of insulation in oil at various temperatures, are based completely on experimental data or whether they are drawn by assuming the validity of the so-called "8 degree law," and determining the constants to be used in this formula in order to make it check 1 or 2 experimental points. Was there sufficient experimental data obtained to support the validity of the 8 degree law, which in previous experiments has been found to be approximately correct?

Second, I would like to point out that the deterioration as indicated by figure 1 is largely an oxidation process, at least up to temperatures of the order of 150 degrees centigrade, so that the rates of deterioration may be greatly affected by the conditions under which the experiment is performed. Some years ago we made tests on transformer insulation at the research laboratory in an inert air atmosphere such as is present in an "inertaire" transformer. Over a period of 2 years, at a temperature in excess of 105 degrees, there was no measurable deterioration of the insulation, mechanical strength and brittleness of the insulation being the characteristics examined for deterioration. I am therefore not prepared to accept the author's fourth conclusion to the effect that a transformer cannot carry its full load at 40 degrees ambient temperature with a 55 degree rise. I am certain that a transformer in an inert atmosphere cannot only carry this load continuously but can carry it without measurable deterioration.

The next question I would like to raise has to do with the life of the insulation. When is the life completely used up? I think there is room for consideradle speculation on this point. Recently we made a distribution transformer experimentally without gum treatment for tests at high temperatures. As a final test we operated it at 175 degrees copper temperature for approximately 2 days. According to curve 1 of the paper, the life of the insulation at this temperature would have been about one day. At the end of 2 days there were no external signs of distress or deterioration and the transformer was given its regular dielectric test a second time and was then tested to destruction with impulse voltages. Its impulse strength was found to be normal, so that the insulation appeared to be as good as ever from a dielectric strength standpoint. We then sawed a large section out of the winding and opened it in the middle to expose the innermost layers. Considerable roasting of the insulation in the middle of the winding was immediately apparent and the discoloration extended from the center to within an inch or so of the outer edges. Physically the insulation was intact, but it had lost much of its mechanical strength because one could scrape off with the finger nail the cambric and paper insulation exposing the bare copper. Should we say that the life of the insulation in this transformer was completely used up? My own personal opinion is that it might still have delivered the full life of useful service in spite of the fact that it had been operated approximately twice as long as Nichols' curves would indicate. My point is that insulation deterioration at best is very intangible and indefinite, and when we proceed to define the life of insulation in terms of days, hours, and minutes as Nichols has done, we should keep this in mind.

My next point has to do with the practical application of permissible short-time overloads. Power transformers as a rule are provided with hot spot temperature indicating equipment and the amount of load can in many cases be adjusted by the load dispatcher, so that given a knowledge of the permissible short-time overloads it is physically practicable to use this information in the operation of the transformers. When we come to distribution transformers the problem is different. It isn't the load dispatcher, but it is Mrs. Jones or Mrs. Brown or somebody else who determines how much load the distribution transformer shall carry, so that the problem of operating distribution transformers by temperature becomes one of utilizing a protective device in the circuit which can be made to follow the temperature characteristics of the transformer winding. This is a problem in which I have personally been very much interested, and as many of you may know, the circuit breaker which we utilize in our "CSP" transformer is so arranged that it will function to trip the transformer from the line; not at any particular overload, not at any particular oil temperature, but at some particularly dangerous copper temperature.

Originally we thought the maximum copper temperature should be between 105 and 110 degrees and our breakers were adjusted to limit the copper temperature to this value under all conditions. However, we soon found that it was perfectly possible to so design the thermal elements of the breaker and to so make the adjustment that higher copper temperatures would be permitted for relatively short times. For example, data of Nichols and our own experiments show that it is quite all right for a transformer to withstand for a few minutes a copper temperature as high as 175 or 200 degrees, whereas if the overload is to endure for an hour the maximum copper temperature should be 25 or 30 degrees lower. We have found that it is practicable to adjust breakers on this basis, permitting a very high temperature for very short times and lower temperatures for correspondingly longer periods. We are thus able to make a practical application in distribution transformers of the important conclusion of the paper that transformers can withstand for short periods of time surprisingly high copper temperatures without appreciable loss in life.

V. M. Montsinger (General Electric Co., Pittsfield, Mass.): The curves in figure 1 indicate that the life of insulation at 105 degrees centigrade is $1^1/_2$ years. The curve given in figure 11 of my paper "Loading Transformers by Temperature" (A.I.E.E. TRANSACTIONS, volume 49, April 1930, pages 776–90) indicates a life of 7 years at 105 degrees.

In reading Nichols's paper I gather that his tests were made by immersing single layers of insulation in oil in such a way that both sides of the insulation were exposed to the oil. I found that there is a considerable difference in the life of insulation depending on whether each side is exposed to the oil or whether the sheets are on the inside of a packet, more or less protected from the oil. I am wondering if this large difference in our results cannot be accounted for by the difference in the methods of making the aging tests.

As a matter of fact, most insulations in a transformer, except the outside layers, are protected from the oil to a certain extent. For this reason I believe Nichols' curves are too pessimistic when used in determining the actual life of a transformer.

I would like to ask the author if he has any data to support the 8 degree rule, which was given and supported by data in my 1930 paper. If the author has such data it would be interesting to know how closely it supports this rule.

Lynn Wetherill (General Electric Co., Pittsfield, Mass.): The writer does not share the author's belief that overheating transformers involves no danger except embrittlement of insulation, but these comments are limited to assumptions used in calculation of loss of life from short time overloads, as shown in table I of the paper.

It appears that the rise of hot spot over average winding temperature, which is 10 degrees centigrade at continuous full load, is assumed to increase in proportion to average winding rise over oil. This accords with usual practice.

It further appears that in calculating the amount of life used in short time overloads Nichols has assumed the temperature to rise instantly to the maximum value when the load is applied, and to return instantly to normal when the load is removed. This may be substantiated by checking the values in table I, and is illustrated by the fact that the loss of life shown for 24 hour overloads is independent of the preceding load. Thus 125 per cent load for 24 hours in a 40 degree centigrated ambient is said to use 6 per cent of the life regardless of the initial temperature.

Consider 2,000 per cent load for 5 seconds after full load in a 20 degree centigrade ambient, for which Nichols obtains 26.5 per cent loss of life. The copper reaches maximum temperature in 5 seconds, but requires 20 minutes to cool, with the result that practically all of the aging occurs after the overload has been removed. Assuming, with Nichols, that the maximum temperature is 250 degrees, the loss of life during the overload is less than 1 per cent, but approximately 40 per cent is lost after the overload has been removed.

Nichols states that the resistance is assumed constant at the 75 degree centigrade value. The magnitude of the error involved in neglect of change in resistance can be best appreciated by considering the accompanying table I, which shows the components of the ultimate rise for 150 per cent load in 40 degrees ambient.

Calculation is based upon the same transformer characteristics used in the paper. If resistance change is neglected a hot-spot temperature of 164 degrees centigrade is obtained, which checks Nichols' results fairly closely. If resistance change is considered, 193 degrees is obtained; this is 29 degrees higher.

In table I Nichols indicates that a transformer would operate 24 hours at 150 per cent load in 40 degree centigrade ambient, despite having a hot-spot temperature near 190 degrees most of the 24 hours.

Consider the effect of resistance change on temperatures resulting from very short time overloads. In figure 9 Nichols shows 120 degrees winding temperature rise over oil for 1,000 per cent load maintained 23 seconds. Assuming an initial temperature of 75 degrees centigrade, and 10 per cent eddy loss at 75 degrees, a proper allowance for resistance change indicates a winding rise over oil of 161.5 degrees instead of 120 degrees.

The method of calculation which Nichols uses is subject to large errors when applied to the rise of winding over oil for overloads lasting 5 minutes or less, even though resistance change is considered. For such overloads a calculation based upon the fraction of the ultimate rise appearing at a certain time is not only inaccurate but is physically absurd when the fictitious ultimate rise is on the order of 1,500 degrees centigrade. For overloads of this nature, the calculations should be based on the current density and the eddy loss (the formula is given in A.I.E.E. Standards No. 13).

Consider the case of 200 per cent load for 30 minutes following full load in a 40 degrees centigrade ambient. For this condition Nichols' curves indicate the following temperature (degrees centigrade) and resultant loss of life:

Ambient temperature	40
Oil temperature rise over ambient	52
Average temperature winding rise over oil	60
Hot-spot temperature rise over average winding	40
Total temperature rise	192

The resultant loss of life is indicated by

$$\frac{4.8 \times 30}{600} 100 = 24 \text{ per cent}$$

Nichols gives 3 per cent loss of life in table I. Perhaps he failed to include the 12 degree centigrade increase in oil temperature.

However, if resistance change is considered, the following results (degrees centigrade) are obtained:

Ambient temperature	40
Oil temperature rise over ambient	52
Average temperature winding rise over oil	78
Hot-spot temperature rise over average winding	52
Total temperature rise	222

The calculation of the loss of life is

$$\frac{7.2 \times 30}{50} 100 = 430 \text{ per cent}$$

It is readily seen that the correct allowance for the change in resistance with increasing temperature makes a tremendous difference in the indicated loss of life.

Despite the foregoing calculation showing 430 per cent loss of life when 200 per cent load is applied for 30 minutes, most of us will agree that a transformer will probably carry 200 per cent load for 30 minutes. In fact the transformer subcommittee ("Overloading of Power Transformers," V. M. Montsinger and W. M. Dann, Electrical Engineering, October 1934, pages 1353–5) permits overloads up to 160 per cent for 30 minutes under emergency conditions following full load in 40 degrees centigrade ambient. However, 200 per cent load for 30 minutes is dangerous and would not leave a transformer in dependable condition.

Table I

	Ultimate Temperature at 150 Per Cent Load, Degrees Centigrade	
	Resistance Change Considered	Resistance Change Neglected
Ambient temperature	40	40
Oil temperature rise over ambient	82	68
Average coil temperature rise over oil	43	34
Hot spot temperature over average oil	28	22
Hot-spot temperature	193	164

It is unfortunate that Nichols did not publish the temperatures resulting from the various short time overloads that he suggests, since a knowledge of the actual temperatures involved would assist the reader in forming an independent judgment as to the probable severity of such an overload, and as to the probable extent of the injurious effect on the transformer.

The author's graphical solutions for problems of transient thermal behavior of transformers, as shown in figures 4 to 9, are very interesting, and will be useful where the range of temperature is limited, permitting neglect of resistance change.

H. H. Wagner (Pennsylvania Transformer Co., Pittsburgh, Pa.): This paper includes information of practical value on 2 important transformer problems: (1) the calculation of temperature rise, and (2) the effect of temperature on transformer life. Both of these topics have been discussed in detail in previous A.I.E.E. papers, and it appears worth while to include at the end of this discussion a short bibliography of papers directly relating to this subject.

The present paper contributes a useful addition to reference 1 of this discussion by explaining the construction of logarithmic scales for converting the heating curves to straight lines.

Reference 1 provides a detailed explanation of the method of calculating transformer temperature rise under various loading conditions, and includes in addition to the derivation of the heating formula, a discussion of the assumptions, errors, and restrictions in the use of the method; it also points out that for practical purposes the use of only one heating curve formula will serve for both the top oil rise and copper rise above oil temperature, the formula being the one used by Nichols in deriving the logarithmic scale of his figure 9. In any case, however, separate formulas for the time constants of oil and copper should be used as shown in references 1 and 3, and in the present paper. Incidentally, it is noted that an error appears in the formula for the oil time constant on page 1620, which should read

$$\frac{A\,(C + D + E)}{G}$$

I have applied this method several times in the past few years, using only the one heating curve formula, and the agreement between calculated and test results has been quite close.

With reference to the data on the effect of temperature on the life of insulation, it is interesting to compare figure 1 of Nichols with figure 11, page 784 of reference 5. The 2 curves differ quite widely at the lower temperature values, but if the curve of figure 11 is extrapolated to time values below one year, the 2 curves approach each other more closely above 150 degrees centigrade. Figure 1 of Nichols shows a life of $1^1/_4$ years at 105 degrees, and $3^1/_2$ years at 95 degrees; figure 11 of reference 5 shows a life of 7 years at 105 degrees and 16 years at 95 degrees. Based upon experience and upon the recommendations of A.I.E.E. Standards No. 100, it seems to me that Nichols' curve is quite pessimistic in the range around 100 degrees. A.I.E.E. Standards No. 100 recommend a temperature of 95 degrees for continuous operation on a temperature basis, and it therefore seems that $3^1/_2$ years would be an unreasonably short life to expect from such operation.

It is probable that part of the curve at the higher temperatures and lower time values is closer to actual conditions, as a result of the greater facility in making tests in this region because of the decreased time required.

The data in this paper serve to emphasize a danger not often recognized in transformer manufacture—that of using a high temperature in the compound treatment of transformer coils. The method of impregnation by compound which is in quite general use for small transformers (however, not used by the company with which I am associated) involves subjecting the coils to a temperature of approximately 150 to 160 degrees centigrade for a period of 12 or 15 hours. The curve in figure 1 shows, and the statement is made, that when a transformer is operated for 4 hours at 150 degrees, about 4.3 per cent of the life has been consumed. Therefore, on the same basis, a period of 12 hours at 155 to 160 degrees would consume approximately 25 per cent of the life of the insulation. Although the safety factor used in this calculation is probably quite conservative, it is indicated that temperatures of 150 degrees and higher should not be permitted for any length of time. This conclusion is substantiated also by A.I.E.E. Standards No. 13-250c which sets a temperature of 160 degrees to be reached for only an instant at the end of a one minute emergency operation.

References

1. Predetermination of Self-Cooled Oil-Immersed Transformer Temperatures Before Conditions Are Constant, W. H. Cooney. A.I.E.E. Trans., v. 44, 1925, p. 611–18.

2. The Thermal Time Constants of Dynamo-Electric Machines, A. E. Kennelly. A.I.E.E. Trans., v. 44, 1925, p. 137–47.

3. Discussion of reference 2, V. M. Montsinger. A.I.E.E. Trans., v. 44, 1925, p. 147–9.

4. Cooling of Oil-Immersed Transformer Windings After Shut-Down, V. M. Montsinger. A.I.E.E. Trans., v. 36, 1917, p. 711–30.

5. Loading Transformers by Temperature, V. M. Montsinger. A.I.E.E. Trans., v. 49, April 1930, p. 776–90.

6. Operating Transformers by Temperature,

W. M. Dann. A.I.E.E. Trans., v. 49, April 1930, p. 793–6.
7. Safe Loading of Oil-Immersed Transformers, E. T. Norris. A.I.E.E. Trans., v. 48, Oct. 1929, p. 1206–12.

E. A. Church (Edison Electric Illuminating Co. of Boston, Mass.): Several years ago the A.I.E.E. recognized that loads considerably above name-plate rating could be applied to oil insulated transformers when the ambient temperatures were below the standard 40 degrees centigrade. This was incorporated in A.I.E.E. Standards No. 100–5. These standards were all based on continuous loading.

Transformers are almost never operated, however, at a continuous load and it has been felt by operating engineers that considerably greater loads than allowed by Standards No. 100–5 could be allowed during the maximum of daily load cycles on account of the relatively large heat storage capacity of the oil and iron core. Engineers have been hesitant to apply overloads to transformers, however, because of the reluctance of manufacturers to guarantee them for loads exceeding name-plate rating.

In this connection we are interested to note the paper demonstrates that, if a transformer is actually operated at 55 degrees centigrade rise above the standard of 40 degrees and allowing the conventional 10 degrees for hot spots, giving 105 degree insulation temperature, the life of the transformer would be only $1^1/_4$ years. Even if the ambient is 30 degrees, which is the point below which one per cent overload may be applied for each degree lowering of ambient, the life would be only about 4 years, which would be considered entirely too short by the majority in the industry.

It appears that the present standards are entirely too liberal for continuous loading, and perhaps too conservative for cyclic loading. We therefore welcome the paper as a distinct advance in the theory of operation of transformers by temperature.

During recent years economic pressure has forced engineers to make maximum use of existing investment and so considerable need has been felt for a study of the thermal characteristics of transformers in order that the reservoir of heat capacity might be made use of in safely leading transformers to values considerably in excess of the continuous loading rating for a few hours daily. We, accordingly, undertook such a study during the latter part of 1932, some of the results of which will be interesting to note.

Temperature rises in transformers when operated under load cycles frequently met with in a metropolitan area such as on the Boston system have been calculated. These load cycles are illustrated in figure 1 of this discussion. Curve *A* is an average residential load cycle and curve *B* is a combined industrial and residential load cycle giving the highest load factor met with on the system.

Maximum temperatures have been calculated for various ambient temperatures and per cent rated load and the results incorporated in figure 2 of this discussion for the transformers listed in the figure. It should be emphasized that the list includes transformers of all sizes from 1,000 to 25,000 kva and hence the size of a transformer is not a criterion as to the amount of overload which it will carry under cyclic loading. This is apparent from the fact that the temperature rise with time of a transformer is determined by the product of the thermal capacity and thermal resistance, which product is within a narrow range for all sizes of transformers. The principal determining factors in temperature rise of the windings are the ratio of winding rise over oil to oil rise over ambient and the ratio of copper loss at rated load to the iron loss.

Curve *A* of figure 2 gives the load which the transformers listed will carry without exceeding 95 degrees centigrade hot-spot temperature when loaded with the residential load cycle shown by curve *A* of figure 1. Curve *B* gives the load which these transformers will carry without exceeding 95 degrees when loaded with the combined industrial and residential load cycles. Curve *C* shows the continuous load which these transformers will carry without exceeding 95 degrees. This curve is seen to check very closely the one per cent increase in load per degree ambient below 30 degrees as allowed by Standards No. 100–5.

Referring to figure 1 of the paper, if a transformer is operated at 95 degrees centigrade continuously, its life will be about 4 years. The life on the basis of operation on load cycles given by curves *A* and *B* can be estimated by the calculations given in tabular form in table II of this discussion. Oil temperature rise is assumed to be 44 degrees, hot-spot rise 65 degrees at rated continuous load, and ratio of copper loss to iron loss 1.5. The ratio of total loss/rated loss given in item 2 of the table is the total loss over a 24 hour period, divided by the total rated loss × 24.

The actual life will be somewhere between 4 years and the values given in the last item of the table. When we consider that the average summer ambient temperatures are usually lower than 30 degrees centigrade and that the heaviest loading on transformers in metropolitan systems occurs in winter, with ambients near 0 degree, it must be concluded that the transformers listed will have a very long life if loaded on the basis given by the curves of figure 2.

Transformers with different thermal characteristics from the ones listed will, of course, reach their maximum temperatures with different overloads than the ones listed. Calculations have been made and curves similar to those in figure 2 are available for transformers of practically all variations in thermal characteristics. These curves give overloads of the same order of magnitude as given by the figure, showing that transformers may vary widely in thermal characteristics without affecting the overload capacity to a very great extent.

Curves similar to those of figure 2 are being prepared for water and air-blast cooled transformers. Results so far indicate that very little overload capacity on a cyclic loading basis can be expected for these types of cooling. This is what might be expected, since the hot-spot temperature rise above oil temperature increases as the square of the loading and the copper has very little thermal capacity compared to the oil and core. The inherently greater ratio of copper to iron losses in water and air-blast cooled transformers will hence limit the overload capacity obtainable.

Table II

	Ambient Temperature, Degrees Centigrade			
	Curve A		Curve B	
	30	0	30	0
Copper loss factor	0.44	0.44	0.61	0.61
Ratio, total loss/rated loss	0.76	1.02	0.85	1.19
Average oil temperature rise, degrees	35.5	44.5	37.5	50.5
Average copper temperature rise, degrees	12.5	21.5	15.5	27.5
Average total temperature rise, degrees	50	66	53	78
Life on basis of average temperature rise, years	12	50	10	15

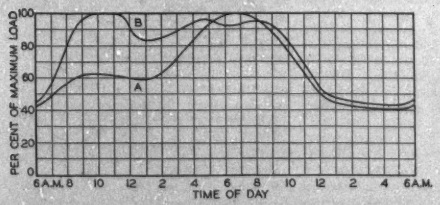


Fig. 1. Load cycles on metropolitan system
A. Residential load cycle
B. Combined industrial and residential load cycle

L. C. Nichols: Referring to the discussion of J. E. Clem, the present A.I.E.E. rules infer a long life of from 20 to 30 years when a transformer is loaded continuously at 100 per cent load, 40 degree centigrade ambient temperature. This condition is unusual but does occasionally occur, resulting in a shorter life than the user expected. Overloading does shorten the life of a transformer but is economically justified.

In answer to the discussion of W. H. Cooney, samples of many kinds of material were placed in oil at 90 degrees centigrade and kept at this temperature continuously for 5 years. Samples were periodically removed and tested. Mechanical tests were made, but the results from these were not conclusive. The best conclusions seemed to come from bending and from observation.

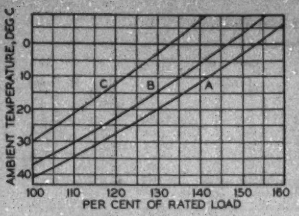


Fig. 2. Maximum load versus ambient temperature without exceeding 65 degrees centigrade hot-spot temperature rise

A. Residential load cycle
B. Combined industrial and residential load cycle
C. Continuous load

Transformer Number	Rating	θ	ϕ	KC
1	1,000	44	1.51	6.71
2	1,500	47	1.36	6.56
3	1,500	43	1.24	6.05
4	3,500	41	1.38	7.38
5	3,500	41	1.42	7.28
6	5,000	44	1.48	7.04
7	25,000	45	2.09	6.10
8	25,000	46	1.61	7.48
Average		44	1.51	6.83

θ = Measured top oil temperature rise
ϕ = Ratio of rated load copper loss to iron loss
KC = Product of thermal resistance and thermal capacity for oil temperature rise above ambient

"Fullerboard," 75 per cent and 100 per cent rag, became so brittle that the least bending would break it, and varnished cloth of various kinds showed the same result. Cotton covered wire showed the cotton had become a dark chocolate brown, was very brittle, and easily rubbed off.

It does not appear in my paper that a transformer has 100 per cent of initial strength until 100 per cent of its life is used up.

Whatever the method of loading a transformer, the mechanical strength decreases with age and deterioration is a function of temperature and time. My conclusion is that insulation will fail mechanically causing electrical failure before the reverse will occur, unless abnormal voltages are applied to the transformer. Under short-circuit conditions or overload the mechanical stresses are more severe than at normal load. The older a transformer is the less its mechanical strength.

When 100 per cent of the life is used up on the basis of my paper, there is great likelihood of failure under severe overloads due to mechanical failure. The transformer would probably last longer if not subjected to the mechanical strain of overloads.

In regard to W. M. Dann's discussion of the 8 degree rule, this has been accepted for a number of years by various authorities as being approximately correct, and I have also found it approximately correct, based on tests and actual operation of transformers in service.

It is granted that instead of the figure of $1^1/_2$ years which I used, someone else might say 3 or 5 years, but the insulation would be in a much worse condition. In my opinion $1^1/_2$ years is more nearly correct.

Replying to Philip Sporn's discussion, I would like to ask him if he ever operated a transformer for several years continuously at 95 degrees centigrade by resistance or 105 degrees centigrade hot-spot temperature. My opinion is that a transformer of any make will not have a long life under this condition. I know of one operator who tried to operate some transformers continuously at 100 per cent load in a 40 degree centrigrade ambient. The transformers burned out after less than 2 years' operation and were replaced with transformers of twice the original size to carry the load.

I am not trying to scare people into buying larger transformers than they need. In a few cases they should use larger transformers. In many more cases a smaller transformer could be used.

In answer to the discussion of Lynn Wetherill, in calculating the loss in life for an overload of 24 hours' duration in a given ambient, it makes practically no difference what the previous load was.

I do not agree with him that the hot-spot correction goes up with the copper loss. If the temperature is calculated from the resistance of the windings, 10 degrees centigrade is added for hot-spot temperature irrespective of the temperature obtained. This is, as I understand it, according to A.I.E.E. rules.

If the hot-spot temperature is calculated as shown by Wetherill, even short time overloads would be dangerous. A transformer of one design may have windings worked as hard at 100 per cent load as another transformer has at 200 per cent load; nevertheless, only 10 degrees is added for hot-spot temperature. Wetherill would add 10 degrees in one and 40 degrees in the other. This difference in calculation of temperature is the difference of a small per cent loss of life and a very large per cent.

Evidently H. V. Putman and I do not differ very much. There is no definite time to say when the life is used up; it is just like an automobile tire. Some people will throw away the tire when the tread shows considerable wear; others would run this tire twice as long or more.

The condition of the insulation in the transformer operated at 175 degrees centigrade for 2 days by Putman indicated in my opinion that the life was quite well used up.

The following typographical errors in the paper should be noted: page 1617, table I, "Overload in Per Cent of Rated Load" should read "Load in Per Cent of Rated Load," and page 1620, the unit of time τ is $A(C + D + E)$ divided by G.

Vibration Analysis—Transmission Line Conductors

Author's closing discussion of a paper published in the November 1934 issue, pages 1478–85, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935. Other discussions of this paper were published in the March 1935 issue, pages 334–5.

W. B. Buchanan (Hydro Electric Power Commission of Ontario, Toronto, Can.): The primary purpose in presenting this paper before the Institute was to invite criticism of a new method of test, radically different from any method hitherto published, which appears to make valuable information available in quite usable form. It is reassuring to know that the scheme was anticipated by Bate (paragraph 7 of his discussion) and to learn that it proved satisfactory so far as he used it. The author would be glad to compare notes with any other engineers who might be working on this or similar schemes.

A second purpose was to introduce the terminology of traveling wave phenomena into this subject in a perfectly rational manner and give public notice that such expressions are likely to be heard more and more as the merits of the method become better known. It might be considered with some justification that the term "vibration" to indicate the standing wave phenomena has little to commend it other than usage. A mental hazard has been introduced by the use of this term and the simplest way in the writer's opinion of minimizing this hazard is to provide an experimental model —some hundreds of feet in length—and observe that the nodes are not the fixed points they appear to be on paper, but depend on other conditions up and down the line, far and near. How otherwise could dampers near the clamps be relied upon to eliminate vibrations at the center of the span?

Two statements in the discussion by Stickley and Sturm seem to be based on a lack of complete understanding of the conditions of the test. Referring to the last sentence of paragraph 5, the cable is not "struck" because the waves introduced would be of quite too steep wave front. The impulse is applied at only one point and the pair of waves is the natural result. It will be found impossible to disturb a conductor near the center of the span without the disturbance proceeding simultaneously in both directions along the conductor.

This pair of waves gives some advantages in testing; twice as many records may be obtained on the same length of film, but a more important feature is that the conductor is subjected to complete reversals of the cycles of stress and hence more consistent values of the attenuation and reflection factors can be obtained.

Paragraph 8 by Stickley and Sturm is difficult to place in relation to anything the author had in mind. The increased length of the cable around the loop has a net over-all effect of slightly reducing the sag of the span as explained under example 5. The longitudinal stress discussed in this case is that associated with longitudinal motion of the conductor at a clamp. This motion is the factor which sets a string of insulators in motion or, if a long string of say 20 units, possibly in oscillation. Records have been obtained which tend to indicate that a 20 unit string of 10 inch insulators is capable of sustaining an oscillation with a 40 per cent damping factor after the application of one impulse and under normal conditions of line construction and loading.

These 2 points seem to be the only items on which there appears to be any disagreement among all correspondents. Any other apparent difference can be explained by a difference in the terminology used. Both contributions to discussion refer to the reaction taking place at clamps or other

Table I—Design Features and Lightning Performance of 220 Kv Lines

1	2	3	4	5	6	7	8	9	10	11	12		13	14	15		16	17	
Line No.	Name of Company	Line Designation	Date First in Service	Length of Line (Miles)	Avg Tower Span (Ft)	No. of Circuits	Circuits per Tower	Tower Design (Fig. No.)	Ground Wires per Tower	Height of Wires Above Cond. at Tower (Ft)	Ground Wire Location (See Figs.) (Feet)		Cond. Height Above Ground at Tower (Ft)	Conductor Spacing (Ft)	Conductor Clearance at Tower		Clearance Impulse (1x5-μsec pos.) Flash-over at Tower, Kv	Suspension Insulators	
											A	B			In.	At Deg Swing		No.	In. Spacing
20	Hydro Electric Power Commission of Ontario, Can.	Chat Falls-Leaside	10/1/28	199.1	1,056	1	1	1	2	13.5	12.6 ...		59.7	25.3	72	45	1,460	18	5
21		Paugan-Leaside	1/26/30	227.7	1,074	1	1	1	2	13.5	12.6 ...		59.7	25.3	72	45	1,460	18	5
22		Paugan-Leaside	10/15/31	227.9	1,062	1	1	1	2	13.5	12.6 ...		59.7	25.3	72	45	1,460	18	5
23		Beauharnois	10/20/32	129.7	1,036	1	1	1	2	13.5	12.6 ...		59.7	25.3	72	45	1,460	18	5
				784.4	1,045														

attached masses and their comments are quite valid. A caution, however, should be expressed; masses alone are not energy absorbers and it has, by this series of tests, been shown possible to attach 4 masses at irregular intervals (dissonance producing) adjacent to the clamp in one span and obtain a higher ratio of curvature at the clamp to that in the span than was obtained for the conductor alone. This result would hardly be anticipated from ordinary vibration theory, but it tends to indicate that energy absorbing devices are desirable rather than those having buffer or oscillating characteristics only.

In answer to questions covered by paragraphs 3 to 6 by Bate, the following information is outlined briefly:

A mechanical device using paper and pencil indicated that the arc of curvature due to bending at the clamp was constant from 24 inches down to about 3 inches. A series of readings were then taken by using the carbon pack curvature recorder set with different spacings between the centers of pressure of the clamps from about 2 to 5 inches. The tendency toward high concentration of the stress within a length of about twice the diameter of the conductor was demonstrated quite conclusively though exact figures were difficult to duplicate. Shortening the distance between the clamps reduces the length of arc of the curve being recorded, hence reduces the sensitivity of the recorder. Ratios of curvature at clamp to that in midspan as high as 35 were calculated from measurements and there seems to be no doubt that such ratios do occur in practice when the traveling components predominate as with galloping conductors.

The immediate object of these tests, however, was to determine the effects produced (absorptive or dissipative) of any devices being tried out and for this purpose records are made at the same set-up with and without the device and the answer obtained as a ratio. This avoids the necessity of calibration of units precisely and minimizes the chance of any errors in the results being introduced due to errors in calibration.

Stickley and Sturm present arguments in favor of testing with a multiplicity of waves originating with the wind. The multiplicity of unknown amounts of energy applied at from 50 to 100 different locations in a span is rather too complicated a problem *in toto* from which to derive design data. The advantage of isolating one unit from such a complex series corresponds to the anatomical study of a bee by individual analysis rather than attempting to dissect the entire swarm at once. The social or group influences of course are important and the final criterion is field experience. For purposes of analysis, however, the problem must be broken down somehow, somewhere into independent elements. If the method of test be sound and the methods of analyzing the results valid there need be no fear of the final answer not agreeing with that of any other scientifically correct method of solution.

Before concluding the discussion on this paper the net results accomplished should be reviewed and their significance pointed out as the latter has not yet been fully outlined. Some of the important types of information obtained have been mentioned, which combined with other data prompts the suggestion that natural vibrations should be regarded as a "symptom" rather than as the principal disease itself; a symptom indicative of construction having high reflection and attenuation factors and hence particularly susceptible to damage from all traveling waves.

The development of this problem has some features closely paralleling that of lightning studies. Prior to the use of the cathode ray oscillograph in the field, theoretical discussions were limited practically to discussion of induced charges and very little was said about direct strokes. As the result of knowledge obtained with this oscillograph, present day literature is directed to discussion of direct strokes, their magnitudes and effects, as it was found that induced charges were of approximately the same order of magnitude as switching surges and if insulation were satisfactory to withstand the latter there should be little hazard from the former.

Calculation of the increased stress in a conductor for some of the worst cases of natural vibration on record, supplemented by estimation of the components of stress as measured by these methods, indicates that the transient components associated with standing waves rarely reach 100 per cent of normal tension. Hence the normal factors of safety should be quite sufficient to give indefinite life to the conductor if such were the sole cause of failure. Considerably greater stresses can be set up by traveling waves and doubtless are if some of the moving pictures on this subject can be accepted as valid.

Hence the author respectfully suggests that protection against these waves, which do occur and have such drastic effects, is the vital part of the vibration problem rather than the suppression of standing waves which can be accomplished by comparatively mild palliative treatment. The solution to this problem automatically carries with it the possibility of extending span lengths and tensions to values more nearly approaching the most economical design. There appears to be a state of arrested development in the art at present due to this difficulty.

Test data available and field experience alike tend to indicate that conditions are more aggravated at the higher tensions. Supplementary devices can be added to reduce the attenuation factor to almost any value desired but their mode of action should be examined very critically. The method outlined seems to offer a satisfactory key to the solution of this problem. It would be instructive to have the entire scheme, apparatus, and analysis checked by an independent group of investigators.

Lightning Performance of 220 Kv Lines

Closing discussion of a paper prepared by the lightning and insulator subcommittee of the A.I.E.E. committee on power transmission and distribution published in the November 1934 issue, pages 1443–7, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935.

I. W. Gross (American Gas and Electric Co., New York, N. Y.): In preparing this paper, an attempt was made to obtain operating data on all 220 kv lines in the United States and Canada. At the time this paper was offered for publication, operating data on the 220 kv system of

Table I Continued—Design Features and Lightning Performance of 220 Kv Lines

18	19		20		21				22		23	24		25	26		27	28	
Insulator Impulse (1.5-μsec peak) Flashover of Tower, Kv	Type of Country		Nature of Soil		Tower Footing Resistance, Ohms				Additional Grounds at Tower		Lightning Severity	Avg Line Outages per 100 Miles of Line per Year		Grading Shields Used	Tower Flashovers per Year Avg		Isoceraunic Factor	Outages per 100 Miles of Line per Year at Isoceraunic Factor of 50	
					Avg		Max.												
	West Half	East Half	West Half	East Half	West	East	West	East	West Half	East Half		West Half	East Half		West Half	East Half		West Half	East Half
1,750	Rolling	Hilly	Clay	Rocky	28	240	170	1,000	None	None	Severe	0.20	2.37	None	0.23	2.08	[1]33	0.3	3.58
1,750	Rolling	Hilly	Clay	Rocky	28	[13]230	170	1,290	None	Limited crowfeet & counterpoise	Severe	0.33	2.48	None	0.36	2.88	[16]33	0.5	3.75
1,750	Rolling	Hilly	Clay	Rocky	28	[14]147	170	570	None	Limited crowfeet & counterpoise	Severe	..	3.07	None	..	2.64	[17]33	...	4.65
1,750	Flat		Clay		[15]16.2		300		Limited crowfeet & counterpoise		Mild		1.43	None		0.91	[17]14		5.12

13. After the addition of crowfeet or counterpoises to approximately 12 per cent of east half of the middle circuit, Paugan-Leaside, in the section of highest footing resistance, this resistance was reduced from an average of 540 ohms to 86 ohms for the towers checked. 14. After the addition of crowfeet or counterpoises on the south circuit, Paugan-Leaside, on 1/2 of the towers in the eastern half, the average tower resistance was reduced from 147 ohms to 50 ohms. This work was done during the summer of 1934 and hence the beneficial results are not yet apparent. 15. After the addition of crowfeet or counterpoises on occasional towers the ground resistance was reduced to 7.9 ohms. 16. These figures represent the average number of days per year on which storms occurred. 17. Storm days 1934 only. No definite record yet of a crowfoot equipped tower being struck. Except for 4 flashovers, practically all lightning trouble confined to east half of Paugan-Leaside line.

the Hydro Electric Power Commission of Ontario, Can., was not available. Since then the operating record of that company's lines has been received, and we are now submitting the data in table I of this discussion in the same form as presented in table II of the paper.

A few interesting points to note in connection with this company's lines are the use of 2 ground wires, 18 5-inch insulators at suspension assemblies, and, the tower footing resistances being quite high, the special means taken on some towers to lower the resistance by crowfoot counterpoises. Approximately 80 per cent of the lines are located in territory classed as subject to severe lightning. The outages per hundred miles of line per year for their entire system has been given as 1.4 actual, and on an isoceraunic basis of 50, vary from 0.3 to 5.12 with an average of approximately 2.5.

We are glad to be able to give the above record so that a rather complete and up-to-date record is now available on 220 kv line operation under lightning conditions.

Expulsion Protective Gaps on 132 Kv Lines

Authors' closing discussion of a paper published in the January 1935 issue, pages 66–73, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935. Other discussions of this paper were published in the March 1935 issue, pages 329–32, and in the May 1935 issue, pages 557–8.

Philip Sporn and I. W. Gross (both of American Gas and Electric Co., New York, N. Y.): Referring to Ackermann's comments on the type of tube mounting, we gave very careful consideration to this matter before adopting the parallel and V types of mounting, as we felt that the types of mounting which had previously been suggested with the tube fastened to the tower structure and tower arms presented a rather serious and dangerous cluttering up of the tower under operating conditions. For example, regular inspection is made of all towers and assemblies on the lines usually once each year, and for a man to climb up in a maze of tubes and braces and do a satisfactory inspection job would subject him to hazards which we feel did not warrant the tower mounted type of tube.

The parallel and V types of mounting were worked out particularly to enable the removal and installation of the tubes while the line was "hot," and it is believed that this can be satisfactorily done in the field in the same general way as hot line maintenance is done on all our 132 kv lines, although some special hot line tools might have to be developed to take care of this work.

In reference to the matter of measuring the tube erosion with the tube in service, it seems to us that this might be a rather hazardous procedure, although it is possible the scheme could be worked out with special tools for making such measurements.

Opsahl has concluded from the data that about 9 tubes gave indications of operation for each lightning stroke. Accurate figures on this feature are practically impossible to present as there is no way of telling from observing the tubes which have operated whether their operation was the result of one lightning stroke or more than one during a particular lightning storm. The data we have, however, show that several cases occurred where tubes at 4 adjacent towers were observed to have operated during a single storm, and these operations involved as many as 3 tubes on 2 of the towers and one or more tubes on the 2 towers farthest from the center of the disturbance. These tube operations may, of course, have been the result of one lightning stroke, a multiple lightning stroke, or several separate strokes in the same storm.

The suggestion Opsahl has made, that the greater number of tube flashovers on the Glenlyn-Roanoke line might be the result of the lower line insulation and therefore might require a much closer designing of the tube, apparently is not the answer, as the external physical dimensions of tubes and gaps were the same on both lines, and therefore the impulse flashover of the tube assembly when new would be the same.

The point regarding the cost of equipping a line with expulsion tubes mentioned by Hunter is, of course, important; presumably in all cases the economic justification of tube application will be gone into fully before any decisions to proceed are made. It is therefore most important that the first cost of maintenance of these tubes be kept within economic limits.

It is interesting to find that Bellaschi has evaluated the lightning stroke current by methods other than that given in our paper, and has arrived at substantially the same range of currents in the lightning stroke. The authors in their calculation used the effective surge impedance in the tower structure to ground as 100 ohms. On recalculating the tube currents on the basis of actual tower footing resistances, ignoring only the tower surge impedance, we find the tube currents range from 1,000 to 9,500 amperes per tube. This is in the same general range as given by Foust. Like most problems of this kind, the data on the type and location of the origin of the disturbance are uncertain, so that many assumptions must be made, and it is rather remarkable that such close agreement is found although different methods have been used. After all, extreme accuracy is not to be expected in measurements of this kind and the results obtained, where fundamental data are lacking, will be only of the same order of accuracy as the assumptions on which they have been based.

The additional protection against lightning flashover of an unprotected line (2-circuit construction) as brought out by McEachron by the application of tubes on one line seems to confirm our own actual experience in operating a 2-circuit 66-kv line with one circuit overinsulated. It was found that in all cases during the 2 years of operation of this line that all single circuit outages from lightning were confined

to the low insulated line, although there were some cases of 2 circuit outages. In other words, there was never a case where only the overinsulated line had tripped out. This feature of protection may also be of value in case of a tube failure where the flashover of the tube circuit, even though the tube occasionally does not clear the line satisfactorily, may prevent the second circuit tripping out, and in this way avoid a service interruption.

Multiple Lightning Strokes

Author's closing discussion of a paper published in the December 1934 issue, pages 1633–7, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935. Other discussions of this paper were published in the March 1935 issue, pages 332–3, and in the April 1935 issue, pages 444–5.

K. B. McEachron: G. D. Harding has given some details of the tests made in Pittsfield showing the effect of polarity in determining which wire would be struck. The tests seem to indicate that the polarity of the conductor has little to do with determining which one is to be struck, at least under laboratory conditions. I am not at all sure, however, that the method of propagation of the discharge through the air under laboratory conditions is sufficiently like that of natural lightning to be certain that the tests described are conclusive as to the effect of conductor polarity in determining which conductor would be struck. However, it does not seem likely that conductor polarity would have much effect in determining which conductor would be struck, unless operating above the corona potential, and even then its effect cannot be very great.

Since such a high percentage of positive polarity expulsion gap operations was found, and since it is known that most lightning discharges are from negative clouds, there seems to me to be no doubt but that ground wires or towers were struck in a majority of cases. This also agrees with the performance of other lines of similar conductor and ground wire configuration, which have shown material improvement when the tower footing resistances have been improved through the addition of the counterpoise. This would not have been true if line conductors had been struck by lightning in a majority of cases, rather the flashovers of the stricken phases would have remained unchanged, only the involvement of other conductors would have been reduced, except in so far as these are the result of communication of 60 cycle arcs. This effect is not dependent upon the mechanism of propagation of lightning to any appreciable degree, and is one which can be expected to make a real difference in the potential required to flash over tower insulation. Since on a 3 phase system the instantaneous positive potential on the conductors as a whole varies from 50 per cent to 100 per cent of the line to ground potential, and since the usual line insulation has a 60 cycle flashover of about 6 times the normal line to ground potential, a reduction in flashover of as much as 17 per cent might be experienced with a slow negative impulse wave applied. To evaluate this effect properly, the possible wave shapes of natural lightning at the point of inception needs to be known, since the traveling waves on overhead ground wires generally die out. The impulse flashover of a string of insulators may be increased by approximately 17 per cent if the polarity of the lightning and conductor are the same. A flashover of the negative phase presumes that the other 2 phases are positive, or one is zero, and has already flashed over. There is thus a possible variation of 34 per cent in insulation flashover, depending on conductor polarity and assuming flashover occurs at the crest of the power frequency potential. The spread between slow wave insulator flashover on all 3 phases simultaneously is likely to be as much as from 25 per cent to 29 per cent. The percentage effects will be less with steeper waves and higher line insulation. The effect can be easily calculated for any assumed wave and line insulation.

W. B. Buchanan has suggested that counter electromotive force from self-induction might account for the erratic path frequently followed by lightning discharges. This suggestion is interesting, but does not appear to me to be a likely explanation of the reason why lightning does not follow the shortest path.

The traveling wave theory is used only to explain the flow of current after a discharge path has once been established. The determination of the path which the discharge will take depends, I believe, upon chance ionization conditions existing in the atmosphere at the time. It would seem that at each point of its progressive travel a new determination is made, not of the shortest path, but of the easiest path.

The research of the next few years should add much to our knowledge of the mechanism of the lightning discharge.

With reference to the time interval between successive strokes, referred to by C. L. Fortescue, it should be noted that times shorter than $^1/_{60}$ of a second could not well be determined by the equipment available. Photographic evidence, reported by Alex Larsen (reference 16 of the paper), indicates times as short as 0.009 second between successive strokes. Additional work may disclose still shorter time intervals.

That reflections, as suggested by C. F Harding, could be the cause of successive expulsion gap operation is most unlikely, as the distances to reflection points are not sufficient to delay reflections so as to cause gap operations in succeeding half cycles. A half cycle is equivalent in time to 8,320 microseconds. This means that if an impulse occurred at the crest of a half cycle, the reflection point would have to be 787 miles away for the impulse to return at the crest of the succeeding half cycle. At a fractional part of such a distance, the original impulse would have attenuated to a negligible value. Therefore, reflections cannot be considered as being important in causing successive expulsion gap operations.

Rock Island Development on the Columbia River

The Rock Island hydroelectric plant of the Puget Sound Power and Light Company, on the Columbia River in central Washington. This plant, constructed in 1932, was the first electric power development on the Columbia River, and the first large low head installation on the Pacific Coast. It is connected with the Puget Sound area by 2 130-mile 110-kv transmission lines. The Rock Island plant, which was described in a paper published in Electrical Engineering for September 1932, pages 654–9, is one of several unusual installations which may be visited during the forthcoming Pacific Coast convention of the Institute in Seattle, August 27–30, 1935

News

Of Institute and Related Activities

Next Month, at Seattle—The Pacific Coast Convention

SEATTLE, Washington, will be host to the 1935 Pacific Coast convention of the Institute which will be held August 27–30, with headquarters in the Olympic Hotel in that city. The convention committee has arranged an excellent schedule of events consisting of 5 technical sessions, 2 Student sessions, entertainment, sports, inspection trips, and specially arranged trips for the visiting women. Also, the convention, which will be held during part of the week preceding Labor Day, will be an important part of the vacation plans of many members. Seattle and the Puget Sound area, bounded by high mountain ranges, are noted for beautiful scenery and attractive vacation possibilities.

A summary of all scheduled events, the technical program and other pertinent information relative to the convention features are given in the accompanying columns. Plan now to attend this interesting convention in the Northwest and keep in touch with the latest professional activities.

Technical Sessions

Five technical sessions in the fields of power transmission, electrical machinery, communication, electrophysics and measurements, and selected subjects embrace a number of timely papers. Many of the papers deal with western engineering developments and they have been prepared by well-known engineers on the Pacific Coast. The engineering features of the Boulder Dam-Los Angeles lines and the 287,000-volt coupling capacitors for the carrier current communication channels will be discussed at the power transmission session. A large part of the electrical machinery session will deal with the leakage reactance and effective armature resistance of synchronous machines. The communication session will have to do with radio telephony in Hawaii and in the Puget Sound area as well as the subject of resonant lines for the frequency control of radio transmitters.

Another session will have papers which will treat the electrophysics of the sphere gap under novel conditions, the direct measurement of surge currents, and the measurement of radio interference crest field strength. Still another session will have papers on several distinctly different subjects, such as the correlation of field data and laboratory data on lightning stroke currents, diesel-electric locomotives, and the production of steam from electric energy.

In addition, 2 Student technical sessions will be held during the convention and the Students from several colleges and universities in Districts 8 and 9 will present a number of interesting papers. These Student papers, as well as all other papers to be presented at the Pacific Coast convention, are listed in the accompanying "Tentative Technical Program."

Rules on Presenting and Discussing Papers

At the technical sessions, papers will be presented in abstract, 10 minutes being allowed for each paper unless otherwise arranged, or the presiding officer meets with the authors preceding the session to arrange the order of presentation and allotment of time for papers and discussion. Authors will be notified officially in each case about one month in advance.

Any member is free to discuss any paper when the meeting is thrown open for general discussion. Usually 5 minutes are allowed to each discusser for the discussion of a single paper or of several papers on the same general subject. When a member signifies his desire to discuss several papers not dealing with the same general subject, he may be permitted a somewhat longer time.

It is preferable that a member who wishes to discuss a paper give his name in advance to the presiding officer of the session at which the paper is to be presented. Each discusser is to step to the front of the room and announce, so that all may hear, his name and professional affiliations. Three typewritten copies of discussion prepared in advance should be left with the presiding officer.

Other discussion to be considered for publication must be submitted, typed double spaced, in triplicate to C. S. Rich, secretary of the technical program committee, A.I.E.E. headquarters, 33 West 39th St., New York, N. Y., on or before Sept. 13, 1935. Discussion received after this date will not be accepted.

Entertainment

Reception and Informal Dance—On Tuesday evening at 9:00 p.m. a reception and informal dance will be held in the Junior Ball Room at the Olympic Hotel.

Salmon Fishing Contest—Wednesday morning contestants will leave headquarters hotel one hour before sunrise as guests of the "Mystic Knights of the Sea" who will furnish tackle. Capital prize will be awarded for the largest salmon. Contestants will return to headquarters hotel at 8:00 a.m.

Banquet—On Thursday evening at 8:00 p.m. a banquet will be held in the Spanish Ball Room of the Olympic Hotel. Following the banquet district paper prizes, golf prizes and fishing contest prizes will be awarded. Tickets will be $1.50 per plate.

Golf—The annual golf tournament for the John B. Fisken trophy will be held on Thursday afternoon at Sand Point Golf and Country Club overlooking Lake Washington. Competition will be medal play on handicap in foursomes. Those expecting to enter the tournament should notify

Summarized Schedule of Events

Monday, August 26

3:00 p.m.—Registration, Olympic Hotel

Tuesday, August 27

9:00 a.m.—Registration, Olympic Hotel
10:00 a.m.—Opening of convention
10:15 a.m.—Technical session on power transmission
2:00 p.m.—Technical session on electrical machinery
9:00 p.m.—Reception and informal dance

Wednesday, August 28

One hour before sunrise, salmon fishing contest
9:00 a.m.—Technical session on communication
2:00 p.m.—Student technical session
2:00 p.m.—Entertainment for women—boat trip from Lake Washington through Government locks into Puget Sound
8:00 p.m.—Conference on Student activities by officers and counselor delegates of Districts 8 and 9

Thursday, August 29

9:00 a.m.—Technical session on electrophysics and measurements
1:00 p.m.—Golf tournament, Sand Point Golf Club
2:00 p.m.—Inspection trips for nongolfers
2:00 p.m.—Bridge luncheon for women, Sand Point Golf Club
8:00 p.m.—Banquet—Presentation of District paper prizes
Presentation of golf prizes
Presentation of fishing prizes

Friday, August 30

9:00 a.m.—Technical session on selected subjects
2:00 p.m.—Student technical session
2:00 p.m.—Automobile tour of Seattle for women

Saturday, August 31

Inspection trips

G. E. Quinan, Puget Sound Power and Light Company, Seattle, and advise him of their club handicap. The green fees will be $1.

Women's Entertainment

Boat Trip—A very pleasant boat trip is planned for the women on Wednesday afternoon. The boat will leave Leschi dock, cruising along the shore of Lake Washington and through the government locks into Puget Sound. After a trip around the harbor the boat will land at Coleman dock.

Bridge Luncheon—The women will be entertained with a bridge luncheon at the Sand Point Golf and Country Club on Thursday afternoon.

Automobile Trip—Friday afternoon the women will be taken for an automobile ride around Seattle's scenic boulevards. The trip will include the government locks, the University of Washington, city parks and the boulevard along Lake Washington.

Inspection Trips

The committee in charge of trips will conduct parties on local trips in the city. The committee will furnish full information and assist in arranging trips to points of scenic or engineering interest outside the city during and after the convention. Complete information on any of the longer trips may be secured from Wellington Rupp, Puget Sound Power and Light Company, Seattle.

Short City Trips

University of Washington
8000 kw electric boilers—Puget Sound Power and Light Company
Automatic Telephone Exchange—The Pacific Telephone and Telegraph Company
Government locks connecting Puget Sound and Lake Washington
Electrification Facilities of the Chicago Milwaukee and St. Paul Railway

Trips Outside the City

Mount Rainier national park
Bremerton—U. S. Navy Yard
Snoqualmie Falls power plant of Puget Sound Power and Light Company
Cedar Falls power plant of City of Seattle Lighting Department
Victoria, British Columbia

Suggested Trips at Close of Convention

Skagit River development of the City of Seattle lighting department
Baker River development of the Puget Sound Power and Light Company
Lake Cushman development of the City of Tacoma lighting department
Rock Island development of the Puget Sound Power and Light Company on the Columbia River
Grand Coulee project on the Columbia River near Spokane
Bonneville project on the Columbia River near Portland

Hotel Accommodations and Registration

The Olympic Hotel in metropolitan Seattle has been designated as the convention headquarters hotel. On Monday, August 26, a general information and registration desk will be opened in the lobby of the hotel where delegates and guests will register and receive badges. Information relative to the various convention activities will also be available to aid the delegates in programing their convention schedule.

The Olympic Hotel rates for delegates are:

	Rate per Room
Single room with bath	$3
Double room with bath	$4
Double room (twin beds) with bath	$5 and $6
Students (several per room)	$1

A number of other hotels and apartment hotels within walking distance are available at approximately the same rates as quoted above. It would be appreciated if members could make their reservations in advance. In so doing please address reservations to E. B. Hansen, The Pacific Telephone and Telegraph Company, 820 Fairview No., Seattle, Washington.

A small fee of $1 for members and $0.50 for Students will be charged to defray a part of the convention expense. A registration fee of $2 will be charged all nonmembers, except Enrolled Students and the immediate families of members. Tickets for the banquet and golf fees may be purchased separately by members interested in these events.

Committees

In the following list are given the members of the 1935 Pacific Coast convention committee, which includes the 7 subcommittee chairmen, as indicated.

E. A. Loew, *chairman*
L. B. Robinson, *vice chairman*
G. H. Walker, *secretary*

F. J. Bartholomew	F. O. McMillan
A. M. Bohnert	E. O. Osburn
Walter Brenton	H. T. Plumb
Fred Garrison	C. E. Rogers
R. H. Hull	R. W. Sorensen
F. C. Lindvall	J. A. Thaler

G. L. Hoard, meetings and papers
E. B. Hansen, hotel and registrations
L. B. Robinson, finance
R. U. Muffley, entertainment
Wellington Rupp, transportation
G. E. Quinan, golf
R. B. Kistler, publicity

Tentative Technical Program

All papers except those in the student sessions are scheduled for publication in Electrical Engineering prior to the convention. For the papers which already have been published reference to the issue and page is given after each title in the list which follows. The remaining papers are scheduled for publication in the August issue.

Tuesday, August 27

10:15 a.m.—Power Transmission

Engineering Features of the Boulder Dam-Los Angeles Lines, E. F. Scattergood, Bureau of Power and Light, City of Los Angeles
May issue, p. 494–512

*287,000-Volt Coupling Capacitors for Boulder Dam, E. D. Eby, General Electric Co.

Informal discussion of the Grand Coulee and Bonneville power projects on the Columbia River

2:00 p.m.—Electrical Machinery

Test Values of Armature Leakage Reactance, T. A. Rogers, University of California
July issue, p. 700–5

Tests on Armature Resistance on Synchronous Machines, B. L. Robertson, University of California July issue, p. 705–9

Steady State Solution of Saturated Circuits, Sterling Beckwith, Allis-Chalmers, Milwaukee July issue, p. 728–34

Time-Temperature Tests to Determine Machine Losses, M. D. Ross, Westinghouse Electric and Mfg. Co. May issue, p. 512–5

Wednesday, August 28

9:00 a.m.—Communication

*Resonant Lines for Frequency Control of Radio Transmitters, C. W. Hansell, R. C. A. Communications, Inc.

*The Hawaiian Radio Telephone System, W. I. Harrington, Mutual Telephone Company of Hawaii, and C. W. Hansell, R. C. A. Communications, Inc.

*Harbor Craft Ship-to-Shore Radio Service in the Puget Sound Area, E. B. Hansen, Pacific Tel. and Tel. Co.

2:00 p.m.—Student Technical Session

Torque in a Bipolar Induction Type Instrument, Ralph Morton, University of British Columbia

Taxation of Private and Municipal Power Systems in Washington and Idaho, Clement Strefius, University of Idaho

Vacuum Tube Voltmeter for Measurement of High Voltages, E. C. Ryan, University of California

High-Capacity Low-Voltage Bus-Bar Design, Preston L. Adkins, Oregon State College

Precise Speed Control of a D-C Motor, Edward Simmons, California Institute of Technology

A Laboratory Beat-Note Oscillator, Stephen S. Stevens, University of Southern California

Thursday, August 29

9:00 a.m.—Electrophysics and Measurements

The Sparkless Sphere Gap Voltmeter, R. W. Sorensen, J. E. Hobson, and Simon Ramo, California Institute of Technology
June issue, p. 651–6

*Spark Lag of the Sphere Gap, Abe Tilles, University of California

Direct Measurement of Surge Currents, C. M. Foust and J. T. Henderson, General Electric Co. April issue, p. 373–8

Measurement of Radio Interference Crest Field Strength, F. O. McMillan and H. G. Barnett, Oregon State College

Friday, August 30

9:00 a.m.—Selected Subjects

Lightning Stroke Currents—in Field and Laboratory, P. L. Bellaschi, Westinghouse Electric and Mfg. Co.

Diesel-Electric Motive Power for Railroads, A. H. Candee, Westinghouse Electric and Mfg. Co.

Production of Steam From Electric Energy C. R. Reid, Shawinigan Water and Power Co.
July issue, p. 712–9

2:00 p.m.—Student Technical Session

Stereophonic Phonograph Recording, John T. Mullin, University of Santa Clara

Polarity Characteristics of Sphere Gap Spark-Overs, James Biele and Don Pugsley, University of Utah

Experimental Study of Resonant Lines as Radio Circuit Elements, L. M. Hollingworth, Stanford University

Five Meter Transceivers, Harold Backen and Austin Nelson, Montana State College

Ultra Short-Wave Communication, Gordon Clothier and Gilbert C. Larson, University of Washington

* These papers are under consideration for presentation at the Pacific Coast convention, but up to date of going to press have not been officially placed upon the program.

President Johnson's Address at the A.I.E.E. Summer Convention at Ithaca

THE Institute's fifty-first annual summer convention, held this year on the campus of Cornell University, Ithaca, N. Y., June 24–28, opened auspiciously. The first day's registration totaled 550, even though none of the technical sessions started until the second day. At the annual business meeting held as part of the opening session on Monday, 330 persons were present, and the several preliminary conferences were well attended. A full report of this convention is scheduled for the August issue.

Received in time for inclusion in the present issue, however, was the president's address delivered at the opening session. This address, read for President J. Allen Johnson by Vice President R. B. Bonney, who presided for him at the opening session, was as follows:

It is with the deepest regret that your president finds it impossible, due to illness, to attend this convention in which, for obvious reasons, he has a very special interest. However, he is glad to be able to send you this brief message.

During the past several years the Institute has suffered a considerable loss in membership. To the extent that this loss has been due to the industrial depression it is neither surprising nor necessarily serious, but I do not think that we should thoughtlessly assume that all of these losses have been due to the depression.

Electrical science, art, and industry, although their main branches of light, heat, power, communication, etc., have long been established, are still undergoing processes of vigorous growth. These processes, in common with all growth, include constant division and differentiation resulting in greater and greater specialization.

Now if the Institute is to maintain its place in this picture as a forum for discussion and a repository of information, it seems to me quite obvious that it must keep pace, in its various activities, with the growth of the science, art, and industry. This means, of course, greater and greater differentiation in its technical committees and subcommittees and also more and more opportunities for discussion among more and more though perhaps smaller groups. In other words, if the Institute is to keep in step with the art it must plan to conduct its technical activities on a finer and finer scale as time goes on.

You will note from your programs that at this summer convention there have been scheduled no less than 14 "technical conferences" or round table discussions, in addition to the 10 technical sessions. It seems to me that a convention held, as this one is, at a great university where almost unlimited meeting rooms are available, lends itself particularly to this type of activity. When you combine with this condition the extremely low cost of living accommodations it seems to me you have a very happy combination of circumstances which ought to result in a large attendance, especially on the part of our younger members, with a resultant very desirable broadening of the usefulness of our summer conventions.

I think the Institute owes a debt of gratitude to Cornell University for its generosity in placing its facilities at our disposal for this pioneering venture in a new type of Institute summer convention. It is my earnest hope that in future years others of our great technical schools having suitable accommodations may likewise open their doors to us, and that the success of this convention may be such that our future boards of directors will be moved to hold many future summer conventions under similar conditions. Should this practice, indeed, develop into a tradition, I feel sure that engineering executives of large enterprises, under whose charge so many of our younger members work, could easily be persuaded to require these young men, as a matter of course, to attend the annual midsummer conventions of the A.I.E.E. in ever-increasing numbers to the obvious benefit of all concerned.

Additional Awards for 1934 Institute Papers

In addition to the national and District prizes for papers presented before the Institute during the calendar year 1934, as announced in ELECTRICAL ENGINEERING for June 1935, page 677, announcement now has been made of the award of prizes for Districts No. 1 and No. 2. These awards are:

DISTRICT No. 1

Prize for best paper awarded to R. H. Bancker (A'23, M'30) and E. M. Hunter (A'28) for their paper "Distance Relay Action During Oscillations," published in ELECTRICAL ENGINEERING for July 1934, pages 1073–80 and discussed at the North Eastern District meeting, Worcester, Mass., May 16–18, 1934.

Prize for initial paper awarded to E. W. Kimbark (A'27) for his paper "Experimental Analysis of Double Unbalances," presented at the North Eastern District Meeting, Worcester, Mass., May 16–18, 1934.

DISTRICT No. 2

Prize for initial paper awarded to C. K. Gieringer (A'35) for his paper "A New Alternating Current Null Indicator," presented at meeting of the Cincinnati Section, May 14, 1934.

Branch Activities at University of Arizona

The Institute's University of Arizona Branch at Tucson completed its most successful year, with considerable activity evidenced on the university campus. Meetings were held, with few exceptions, every week, with a topic discussed by a student or professor, followed by a general talk in which all took part. These talks covered a variety of subjects, ranging from illumination installations, through radio television, to a description of a trip through a manufacturing plant.

Besides the regular weekly meeting, several field trips were arranged. Among these were the following: Southern Pacific Railroad signal and repair shops and inspection of Brill gasoline-electric rail car; Department of Commerce radio communication and radio beacon installation at U.S. Army airport; Mountain States Telephone Company and American Telephone and Telegraph Company equipment; refrigerating plant of Pacific Fruit Express; inspection of projectors and sound equipment under actual operating conditions at Fox West-Coast Theatre; and a power plant at Colossal Cave, limestone caverns near Tucson.

It is planned to increase the number of field trips and expand the interests of the Branch during the coming year.

Additional Plans for Great Lakes District Meeting

Plans are progressing rapidly for the meeting of the Great Lakes District of the A.I.E.E. which will be held at Purdue University, West Lafayette, Ind., October 24–25, 1935. Headquarters will be in the Electrical Engineering Building.

The technical program now being arranged by the program committee with C. Francis Harding, chairman, will be of a high technical order. In addition to the subjects announced for this meeting in ELECTRICAL ENGINEERING for June, page 669, interesting papers in the fields of electrophysics and electrical machinery have been prepared. Some of these papers deal with the characteristics of luminous tube circuits, Fourier series analysis of rectifier circuits, and a multiharmonic electrostatic audiofrequency generator. Others have to do with split phase starting of 3 phase induction motors, simultaneous loads at full and half-voltage from a transformer bank with delta connected secondary, and the magnetic field in and near the copper conductors of electrical machinery.

In conjunction with the Great Lakes District meeting at Purdue a Student convention also will be held.

Future AIEE Meetings

Pacific Coast Convention,
Seattle, Wash., Aug. 27–30, 1935

Great Lakes District Meeting,
West Lafayette, Ind., Oct. 24–25, 1935

Winter Convention,
New York, N. Y., Jan. 28–31, 1936

North Eastern District Meeting,
New Haven, Conn., May 1936

Summer Convention,
Los Angeles, Calif., June 22–26, 1936

Middle Eastern District Meeting,
Akron, Ohio (date to be determined)

Leipzig Fair. The Leipzig (Germany) Trade Fair will be held this fall, August 25–29, 1935. The historic fair has been held for 700 years.

The E.C.P.D. Program to Gain Recognition for the Engineering Profession

WHO is an engineer, and by what right does he use that title or undertake to practice engineering? At present there is no single criterion by which an engineer's qualifications can be measured, either by his fellows or by the public that uses his services. The legal status of an engineer is determined in some states by a process of examination, registration, and licensing. His educational status may be indicated by a college degree, and his technical qualifications by his grade of membership in a national society of high repute. Not all engineers are licensed. Neither do they all possess college degrees nor hold membership in a technical society. From the point of view of professional solidarity the situation is chaotic.

As part of its plan to enhance the professional status of the engineer, the Engineers' Council for Professional Development has undertaken to define minimum qualifications of education and experience, the fulfillment of which will entitle an engineer to be recognized as such among his fellows and in his relations with the public. E.C.P.D. is a conference of engineering bodies directly representing the professional, educational, technical and legislative phases of an engineer's life. The participating bodies are the American Society of Civil Engineers, American Society of Mechanical Engineers, American Institute of Electrical Engineers, American Institute of Mining and Metallurgical Engineers, American Institute of Chemical Engineers, Society for the Promotion of Engineering Education, and the National Council of State Boards of Engineering Examiners.

Through its committee on professional recognition, on which the participating bodies are represented, E.C.P.D. has proposed a "minimum definition of an engineer," and a "program of certification into the profession." The definition of an engineer, sets up minimum qualifications of technical education and practical experience, supported by examinations designed to indicate the individual's ability to be placed in responsible charge of engineering work and to render him a valuable member of society. These proposals are now before the governing boards of the constituent bodies of E.C.P.D. When approved they will provide the criterion and the mechanism for professional recognition of engineers.

The program of certification into the profession was drafted by Dr. D. B. Steinman who represents the National Council of State Boards of Engineering Examiners on E.C.P.D. He is also a member of the committee on professional recognition of which Conrad N. Lauer, president of the Philadelphia Gas Works, is chairman. The certification program recognizes the fact that the equivalent of a "grandfather clause" must be applied to permit automatic certification of those who are now recognized and accepted as engineers by legal authorities and by the profession. It also contemplates a reasonable transition period for the progressive adjustment of requirements and tightening of standards until the full program of E.C.P.D. for certification can be put into effect. Thus licensed engineers and certain members of technical societies will be automatically eligible to receive certificates according to a chronological plan up to January 1, 1938, at which time a prescribed procedure leading to certification will be put into effect. When that goal is reached it is hoped and expected that certification of an engineer by E.C.P.D. will set a minimum standard of professional training and experience by which he will be accepted and recognized among his fellows and in his relation with the public.

With the foregoing considerations in mind, the following program of certification is recommended for adoption by the constituent societies, in order to provide smooth, practical transition from present operating procedure to the procedure projected by E.C.P.D. This program was formally approved by the board of directors of the A.I.E.E on June 26, 1935.

PROGRAM

1. It is recommended that E.C.P.D. be authorized to publish an annual roster of all engineers certified by E.C.P.D. No filing fees should be charged for listing in the roster, but a charge should be made for copies of this directory to defray the cost of assembling and printing. This roster should preferably list the engineers geographically, by states and territories, also in a comprehensive alphabetic index. The main listings should give the names, educational degrees, professional designations and addresses of the certified engineers. The roster will list between 40,000 and 100,000 engineers.

2. It is recommended that E.C.P.D. be authorized to offer to certified engineers a certificate suitable for framing and display. For any such certificates ordered, a fee should be charged sufficient to defray the cost.

3. It is recommended that E.C.P.D. be authorized to notify all engineers when they are certified, requesting filling out of card with information desired for the roster and enclosing order blanks for rosters and certificates.

4. Until January 1, 1936, the following engineers should be granted certification by E.C.P.D.:

(*a*). All those who are registered or licensed as engineers by the legally constituted authorities of any state or territory of the United States.

(*b*). All those who have been granted certification by the National Bureau of Engineering Registration.

(*c*). All those who are enrolled in the following grades of membership in the following national engineering societies:

A.S.C.E.—Associate Member, Member, Honorary Member
A.S.M.E.—Associate Member, Member, Honorary Member
A.I.E.E.—Member, Fellow, Honorary Member
A.I.M.E.—Member, Honorary Member
A.I.Ch.E.—Active Member

(*d*). All those who have once been qualified under *a*, *b*, *c*, may be granted certificates upon application.

(*e*). Nothing in the previous paragraphs shall be construed as qualifying for certification any person whose license or membership has ever been revoked for unprofessional conduct.

5. Until January 1, 1937, the following engineers should be granted certification by E.C.P.D. (in addition to those previously certified by E.C.P.D.):

(*a*). All those who are registered or licensed as Engineers in any state or territory having statutory requirements at least the equal of those specified in the "model registration law."

(*b*). All those who are certified by the National Bureau of Engineering Registration as having met the requirements specified in the "model registration law."

(*c*). All those who are admitted to the following grades of membership in the following national engineering societies:

A.S.C.E.—Associate Member, Member, Honorary Member
A.S.M.E.—Associate Member, Member, Honorary Member
A.I.E.E.—Member, Fellow, Honorary Member
A.I.M.E.—Member, Honorary Member
A.I.Ch.E.—Active Member
} or equivalent grade

6. After January 1, 1937, certification by E.C.P.D. should be only on individual application. By that date E.C.P.D. should have set up a bureau of certification with a secretary and staff to receive and review applications, to check references and credentials, and to conduct examinations. (It may be desirable to make this a joint agency with the National Bureau of Engineering Registration which is already functioning in such capacity.) A fee should be charged for each application and examination, and a smaller fee for each reconsideration or re-examination requested by the applicant. These fees should be no larger than necessary to make the E.C.P.D. bureau self-supporting. Each applicant must submit, on suitable forms prepared and furnished by E.C.P.D., full information on education and experience, with names of references for verification.

Membership—

Mr. Institute Member:

Even though it is summer time the Section membership committees are active in contacting those whose names you are sending in.

For May 1935, the number of membership applications received was 53 as compared with 42 applications received during May, 1934—an increase of 26 per cent.

Ernest Fisher

Chairman National Membership Committee

7. Until January 1, 1938, the E.C.P.D. bureau of certification may waive either written or oral examination, or both, in the case of applicants of obvious fitness as evidence by their records of performance.

8. After January 1, 1938, certification by E.C.P.D. should be strictly on the full requirements of the E.C.P.D. standard as embodied in the "minimum definition of an engineer" with the provision that no new applicants shall be excused from examination. The submission of a satisfactory original thesis or published professional paper covering an engineering project executed by the applicant and preferably including an analysis of economic aspects of the project may be accepted as the equivalent of the required written technical examination. The submission of a certified list of courses taken and books studied on cultural, civic and economic subjects, together with a satisfactory original essay or published paper on a cultural, civic or economic subject may be accepted as the equivalent of the required written examination on economic and cultural subjects. The oral examination may be conducted by a local committee of 2 or more engineers or engineering educators, designated by E.C.P.D., and should include a test-review of the applicant's recent reading in cultural and economic subjects, of his continued post-college study of technical subjects, and of his professional growth through observation and experience in his daily work.

9. Arrangements should be made, so far as practicable, to secure agreements to recognize E.C.P.D. certification as *prima facie* evidence of qualification for registration or licensing by state boards and for admission to the corporate membership grade (preferably designated "member") in the national engineering societies. Such agreements to recognize E.C.P.D. certification should be mentioned in the announcements and printed matter of E.C.P.D.

10. The foregoing time-schedule for the progressive development of the E.C.P.D. program of certification is planned to allow necessary time for the development to functioning of the other activities of E.C.P.D., including specifically the accrediting of engineering schools and the post-college training of recent graduates. So far as practicable, the development of these other activities of E.C.P.D. should be timed so as not to delay the putting into operation of the program of certification as herein scheduled.

The goal should be complete functioning of the E.C.P.D. program in its interrelated functions by January 1, 1938.

A.S.T.M. Awards Medal. The Charles B. Dudley medal for 1935, awarded annually by the American Society for Testing Materials, to the author or authors of the paper presented at the preceding annual meeting which is of outstanding merit and constitutes an original contribution to research in engineering materials, has been awarded to C. A. Hogentogler, senior highway engineer, and E. A. Willis, assistant highway engineer, U.S. Bureau of Public Roads. The winning paper presented in 1934 by these 2 authors was entitled "Subgrade Soil Testing Methods." The medal was formally awarded to the authors at the annual A.S.T.M. dinner June 26, 1935, during the thirty-eighth annual meeting of the society in Detroit, Mich.

Transit Association to Meet. The 54th annual convention of the American Transit Association will take place at the Ambassador Hotel, Atlantic City, N. J., September 23–25, 1935. Meeting with the American Transit Association will be its 4 affiliated associations, accountants' association, claims association, engineering association, operating association, and the newly formed bus division. The usual manufacturers' exhibition will be dispensed with this year. Committee meetings in connection with the convention will be scheduled for September 21 and 22.

May Be Visited After the Pacific Coast Convention

CUSHMAN power house number 2 of the department of public utilities of the City of Tacoma, Wash. This plant, 1 of 2 supplied with water from Lake Cushman, is in the Olympic Mountains near Seattle. It is one of the many hydroelectric plants which may be inspected following the A.I.E.E. Pacific Coast convention in Seattle, August 27–30

A Marriage Between 2 Institute Members

An event, unusual in the history of affairs of Institute members, was the marriage in Los Angeles, Calif., on June 7, 1935, of Mabel MacFerran (A'28) and E. W. Rockwell (A'21, M'35) both being members of the Institute. In addition, they are both successful electrical engineers, active in their profession.

The former Mabel MacFerran, now Mrs. Rockwell, studied at Bryn Mawr College, subsequently obtaining the degree of bachelor of science in mathematics from Massachusetts Institute of Technology, and that of engineer in electrical engineering at Stanford University. She spent one summer as assistant in the standardizing laboratory of Leeds and Northrup Company, Philadelphia, Pa., and in 1926 joined the Southern California Edison Company Limited as apprentice testman. She then became technical assistant to the operating engineer of the company, and in 1932 was made an assistant electrical engineer of the Metropolitan Water District of Southern California, at Los Angeles, which position she has since held. She has been active on work dealing with high voltage power transmission and has presented several papers and discussions before the Institute.

Mr. Rockwell received the degree of bachelor of science in electrical engineering from the University of Southern California, and from 1920 to 1931 was in the engineering department of the Southern California Edison Company Limited in charge of electrical substation design. Since 1931 he has been an electrical engineer with the Metropolitan Water District of Southern California, at Los Angeles, engaged on the design and layout of the construction power system for the Colorado River Aqueduct, and the design of the transmission and power system for delivery of power from Boulder Dam to the Colorado River Aqueduct.

Three other couples, both members of which are members of the Institute are:

Ellis Blade (A'35) heat treatment engineer, John Chatillon and Sons, New York, N. Y.; and Mrs. Mary Francis Blade (A'35) interviewer, New York State Employment Service, Brooklyn, N. Y. Mrs. Blade is a daughter of H. T. Plumb (A'03, M'21, and past vice president) engineer for the General Electric Company, Salt Lake City, Utah. Both Mr. and Mrs. Blade were Enrolled Students previous to becoming Associate members.

Roland R. Miner (A'30) electrical engineer, Kansas Gas and Electric Company, Wichita; and Mrs. Roland R. Miner (A'29) Wichita, Kansas.

Fred P. McBerty (A'12) general manager, Federal Machine and Welder Company, Warren, Ohio; and Mrs. Zella A. McBerty (A'24) secretary and treasurer, Federal Machine and Welder Company, Warren, Ohio.

A list of the 10 women who at the time of the publication of the 50th anniversary (May 1934) issue of ELECTRICAL ENGINEERING were members of the Institute was given on page 835 of that issue. Two of these have since resigned, and with the recent addition of Mrs. Blade, 9 women are members at the present date.

Institute Treasurer Honored. Walter I. Slichter (A'00, M'03, F'12, and treasurer) was recently honored by a testimonial dinner given by the members of the staff of the department of electrical engineering of Columbia University, New York, N. Y., to celebrate the completion of 25 years as head of the department. Both present and former members of the staff and other officers of the university and their wives took part in the event, which was also marked by the presentation of a handsome desk set. Professor Slichter has served the Institute as its national treasurer continuously since 1930.

The 8 Joint Functional Organizations of the National Engineering Societies

To provide an effective opportunity for an increase in knowledge, understanding, and general interest in the various phases of the work of the several joint organizations created by the national societies to serve the engineering profession, a special meeting was held in the Engineers' Club in New York, N. Y., on Monday evening, May 20, 1935. Those present at this dinner and general discussion meeting included a large proportion of the officers and directors of the national societies of civil, mining and metallurgical, mechanical, and electrical engineers, together with members of the governing bodies of their several jointly sponsored functional organizations, and a few special guests. A total of 89 persons were in attendance. Of these, 27 were members of the A.I.E.E., their names being given in the news report of the meeting published in ELECTRICAL ENGINEERING for June 1935, pages 676–7.

Carefully prepared concise statements covering the scope and significance of the work of each of the 8 jointly sponsored organizations were delivered at the meeting. In order that the membership of the Institute may be acquainted with the work of these organizations, essentially full text of these statements is presented herewith. The first statement, that describing United Engineering Trustees, Inc., is in the form of the president's report for work accomplished during the year 1934. The other 7 are general descriptions of the respective organizations.

United Engineering Trustees, Inc.

By Harold V. Coes, President

PRESIDENT'S REPORT, 1934

The United Engineering Trustees, Inc., entered 1934 with its budget stripped of all operating expenditures which could be postponed. Some active problems which faced the trustees included: (*a*) meeting occupancy competition with other buildings, necessitating study of the condition of the Engineering Societies Building, certain replacements and repairs being inevitable; (*b*) as trustees of funds, the income of which provides for active research, the responsibility was great in obtaining income while maintaining the security of the principal; and (*c*) in an effort to help its founder societies and associates, the rebates in occupancy assessments were continued, and budgets were reduced below minimum of necessary operating costs, but expenses have been kept within these budgets. Fortunately, the business recession seemed to turn upward during the year and the use of the meeting halls and facilities was somewhat better than had been anticipated. Some income producing office space was released, but much of this was filled promptly, and the return from investments were fully up to expectation.

Properties for which the corporation is responsible (real estate at cost, funds at book value and library as appraised) total nearly $4,000,000. The aggregate book value of investments on December 31, 1934 was $1,338,852.98 and the market value was $1,236,677.25. It is noteworthy that the market has advanced during 1934, on practically all securities held by the Corporation.

One very important action of the trustees was the revision of by-laws, for the purpose of meeting changing conditions which necessitated changes in practices, procedure, and personnel. After a very earnest study by the Committee, and thoughtful discussion by the trustees, covering several months, the final draft was referred to the founder societies, and has been approved.

Owing to the study several years ago, of ways and means to rebuild, maintenance on the present Engineering Societies Building has been deferred until some parts reached the stage where criticism demanded that some action be taken. Accordingly a building improvement committee examined conditions and complaints, and authorization was granted by the trustees for redecorating the fifth floor assembly halls, the main floor lobby, reupholstering the auditorium seats and lobby furniture, providing new chairs for the assembly halls, new and adequate illumination in office space and assembly halls, repairing leaky windows and conserving heat and comfort. General commendation indicates appreciation on the part of users of the hall and offices for the improvements.

The board of trustees has recognized that its function is to act for the founder societies in certain important activities which have been entrusted to it, and to incur no new obligations unless so requested by the founder societies. During the past year the board has endeavored to clarify procedures, by-laws and methods, in order to transact the business before it in an expeditious and efficient manner, and the business could be greatly expedited if it were not due to the difficulties from trustee absences. In many cases none of the trustees of a founder society is present, or in other cases not enough of them are present to put through the required votes. The members of the board have ever kept before them that they represent the founder societies. In this group, under its charter and organization, the founder societies have a vehicle which is physically and legally competent to expand its activities for the societies in their joint undertakings, thus eliminating the necessity for new machinery or additional organizations for joint activities in many cases that may arise. The trustees hope that through the founder societies' individual trustees they will call the attention of the board to such matters they wish the board to undertake for them jointly and also to such matters as will, in the judgment of any society, improve the service.

The annual audit shows the affairs entrusted to the corporation by the founder societies, to be in good condition. Several highly important things have been accomplished in 1934 which would tend to unify further the co-operation among the great professional societies and the understanding and sympathy toward their mutual problems. The trustees appreciate the cordial assistance given by the societies, their officers and staffs in making possible the accomplishments of 1934.

The Engineering Societies Library

By Walter I. Slichter, Chairman

Our Engineering Societies Library was established in 1907, when 3 of the founder societies combined their separate libraries into one collection in common quarters.

In 1913 these were formally organized into the Engineering Societies Library, and in 1916 the American Society of Civil Engineers joined us by adding their very considerable collection to the joint venture.

This library is the largest maintained by any professional organization and has a world-wide reputation. To it come daily questions from all parts of the world, from engineers in search of information on every kind of professional question.

The collection has grown steadily from 62,000 volumes in 1914 to 145,000 in 1935, an increase of 114 per cent, and the number of persons using it has increased even more substantially from 14,000 in 1914 to 41,000 in 1934, almost 3-fold.

Probably no library has more widely scattered users or does more of the work by mail. Engineers in 45 states and 21 foreign countries were helped by loans of books, copies or translations of articles, or by direction to the literature upon the subject in which they were interested.

One fourth of those who consulted the library in 1934 did so by correspondence without ever setting foot inside the building. This is important in that it shows that the benefits of the library are not confined to those in New York City.

The cost of operating the library in 1934 was $48,500, of which the founder societies contributed only $30,000, or 60 cents per member. $8,500 was earned by special services and the remainder came from our small endowment. There was added to the collection 4,100 volumes, moderately appraised at $15,000.

The yearly increase in the money value of the library is an item to which I call your attention, as few realize that we are gradually building up a quite considerable capital investment which is now appraised at $500,000. Not all the money we contribute to the library is gone for good. We have something tangible to show for some of it.

Our library is well catalogued and indexed with 476,000 cards, which condition makes it easy for any individual to find what he wants.

There are great possibilities for work with the industries of the country and for great advantages to manufacturers. For this to be realized, however, it will be necessary for the industries to assume some responsibility for the support of this agency which they use so freely. To expect the whole burden to be borne by the engineer as an individual may have been proper in the day when the engineer was an independent professional man; today when so many engineers are employees of large corporations, these corporations should provide library facilities as they provide other business requirements. This they can do in the most effective way by building up the Engineering Societies Library to even greater effectiveness.

Of late there has been a desire for closer co-operation between the library and the membership of the societies living at too great a distance to be able to visit the library in person. To meet this desire we started some years ago a circulating library to which any member of the 4 founder societies may apply for any book that is purchasable. If we have not the book in our auxiliary collection we purchase it, send it to the member and charge a reasonable rental. In this way we are building up a lending library with no expense charged to our budget because it is self-sustaining. It should be understood that no library lets any "only" copy of a volume leave the building.

We now desire to enlarge our usefulness to our distant membership and have 2 new plans on foot to accomplish it.

The first, which is in process of being put into effect, is to encourage and assist the public libraries in the various towns and cities, to provide better facilities for the engineers of the neighborhood. This will be accomplished by making up a list of highly useful and desirable books and arranging that every librarian gets a copy, and incidentally to encourage the individual librarians to call upon us for help, advice and suggestions in building up their engineering sections.

The second proposal is to build up a more ambitious auxiliary lending library of the books most useful and generally in demand, and lend these on request by mail. This will require capital for the purchase of the books and operating expense to administer the system for the best interests of all concerned. It is a plan which we hope to put into execution as soon as financial conditions make it possible.

The Engineering Foundation

By H. P. Charlesworth, Chairman

A little over 20 years ago our beloved associate, Ambrose Swasey (HM'28) of Cleveland, Ohio, conceived a great undertaking for the benefit of the engineering profession and of aid in human advancement. In 1914 as a result of this high purpose and through

An Outline of the 8 Joint Functional Organizations

The 4 "founder societies," all having headquarters in the Engineering Societies' Building, New York, N. Y., with their dates of organization are: American Society of Civil Engineers, 1852; American Institute of Mining and Metallurgical Engineers, 1871; The American Society of Mechanical Engineers, 1880; and American Institute of Electrical Engineers, 1884. These founder societies jointly sponsor 8 functional organizations of national scope. An outline of these functional organizations, listed in order of establishment, and including definition, functions or activities, and personnel, follows:

1. United Engineering Trustees, Inc., 1904

The holding corporation and administrator of joint real estate and financial affairs for the founder societies. A national foundation for "the advancement of the engineering arts and sciences in all their branches."

The board of trustees (including all members of the corporation) exercises the powers and performs the functions of the corporation. There are 12 trustees, 3 appointed by each founder society. The board has a finance committee and a real estate committee. It manages various "funds."

General manager and staff operate Engineering Societies Building.

The corporation has 2 departments, Engineering Societies Library, and The Engineering Foundation. It is permitted to have others.

2. Engineering Societies Library, 1913 (Department of U.E.T., Inc.)

A free public engineering reference library, having one of the most comprehensive, carefully selected and best organized collections in the world of information on engineering and related sciences and history.

The library answers request for information by visitors and correspondents; makes searches on specified subjects; compiles limited or comprehensive bibliographies; translates articles from or into any language; makes abstracts; makes photostatic copies of articles or books; lends books by special arrangement; reviews books; advises on selection of books; manages publication of *Engineering Societies Monographs*.

Serves inquirers throughout the United States and in many countries.

Library board: 3 members designated by each founder society, 3 members-at-large, one trustee, secretaries of founder societies, director of library; total, 21.

3. The Engineering Foundation, 1914 (Department of U.E.T., Inc.)

An institution "for the furtherance of research in science and engineering, or for the advancement in any other manner of the profession of engineering and the good of mankind."

Its endowment funds are held and managed by U.E.T., Inc. The Foundation board has discretionary power in the disposal of moneys received from the board of trustees or other sources.

The Foundation aids the support, organization, and co-ordination of selected researches in engineering and related sciences, including economics and the human aspects of engineering.

Foundation board: one trustee from each founder society, 2 members nominated by each founder society, 3 members-at-large, the president of U.E.T., Inc.; total, 16.

4. American Standards Association, 1918

An association providing means for industries, technical organizations, and governmental departments to work together in developing acceptable national industrial standards and to prevent over-standardization.

Preliminary studies, determination, and publication of standards for engineering and industrial materials, equipment, tools, processes, products, and practices.

Composed of member-bodies, associate members, company members, and individual members. Board of 16 directors. The Standards Council, 117 members and alternates.

5. Division of Engineering and Industrial Research of N.R.C., 1919

One of the 7 divisions of science and technology of the National Research Council.

Functions: to encourage, initiate, organize, and co-ordinate fundamental and engineering research in the field of industry; to serve as a clearing house for research information of service to industry.

Division has 27 members representing the founder societies, American Society of Refrigerating Engineers, American Society for Testing Materials, American Society for Metals, American Society of Heating and Ventilating Engineers, Illuminating Engineering Society, Western Society of Engineers, Society of Automotive Engineers, American Welding Society; 3 members-at-large, and the chairman; total, 31.

6. Engineering Societies Employment Service, 1919 and 1923

A service supported by the founder societies to aid their members in obtaining employment or in finding engineering assistants. Offices in New York, Chicago, and San Francisco.

Registration and placement of engineers and engineering assistants; service to employers of engineers.

Board: the secretaries of the founder societies.

7. American Engineering Council, 1920

A central agency to further the public welfare wherever technical and engineering knowledge and experience are involved, and to consider and act upon matters of common concern to the engineering and allied technical professions.

Comprises 220 groups of organized engineers located in 41 states, including 7 national societies (202 local sections), 4 independent state societies, and 14 local societies.

A service unit providing a clearing house for information, a forum for deliberation, and a means of giving national expression, through 12 standing and special committees, to the aims of the engineering profession as a whole, dealing with relations of engineers to the public and to governments in matters of engineering content.

Membership of annual assembly, held in Washington, D. C., 36 representatives of the constituent member bodies.

8. Engineers' Council for Professional Development, 1932

A conference of engineering bodies organized to enhance the professional status of the engineer through the co-operative support of those national organizations directly representing the professional, technical, educational, and legislative phases of an engineer's life.

Enhancement of the professional status of the engineer. Vocational orientation of prospective engineering students. Formulation of criteria for colleges of engineering. Plans for further professional development of engineering graduates and of nongraduates, devising methods whereby engineers attaining suitable standards may receive corresponding recognition. Acts as agent to effect these objectives when so designated.

Constituents: the founder societies, American Institute of Chemical Engineers, Society for Promotion of Engineering Education, National Council of State Boards of Engineering Examiners.

his generosity, there came into being The Engineering Foundation.

Beginning in that year, Doctor Swasey made the first of 4 gifts to the founder societies as a "nest egg" for nucleus to which other persons would add to build up a great endowment. Recognizing the advantages of utilizing the facilities of an organization already established for carrying on the joint undertakings of the societies, the fund was entrusted to United Engineering Trustees, Inc., and The Engineering Foundation was organized as a department of this corporation, but given full discretionary powers.

The Foundation is unique in many respects. It is so far as I know, the only institution of its kind in the engineering field. It is composed of representatives of the founder societies instead of being a closed self-perpetuating group. Its charter has been wisely chosen to safeguard its perpetual existence by giving wide latitude of operation to conform to changing conditions as time goes on. Doctor Swasey in his wisdom did a very important thing in making this charter so simple and by making it possible for succeeding generations to modify, as they saw fit within the broad limits of its purpose, the conditions under which it should from time to time operate. By the nature of its organization it will at all times have at its command the voluntary and supreme efforts of outstanding men from our engineering ranks to administer this great trust in behalf of the profession and mankind generally.

To assure the continued usefulness of the fund, the objectives and functions were stated in very broad language. The Engineering Foundation devotes its resources to human as well as technical aspects of engineering problems of wide interest. It aids activities for "the furtherance of research in science and engineering and the advancement in any other manner of the profession of engineering and the good of mankind."

The Foundation board has discretionary powers in its use of the income from funds held by United Engineering Trustees or from other sources. Its principal duty is the selection or initiation of projects most likely to advance the profession in its service to the public. Proposals recommended by the founder societies are given preference, other things being equal.

The Foundation endeavors within its sphere of influence to effect co-ordination of research and related activities and avoid duplication of effort wherever practicable.

The Foundation resources have been a growing endowment yielding $5,000 income in 1915 and $40,000 in 1934. An additional $230,000 in contributions have passed through its accounts. Also, a large total in money and materials has been contributed by co-operating bodies as well as the services of outstanding engineers and scientists who have served on boards or committees or individually.

The Foundation has no laboratories nor research staff. Needed facilities and personnel have been furnished by colleges or other existing establishments for carrying on the research it sponsors or assists.

It has been the founder's conception that the Foundation should not be merely an allocator of grants but should also initiate large projects of broad interest.

Being an instrumentality of national societies, the Foundation aids undertakings of benefit to our whole country. Some have been beneficial in many countries. It has selected capable agencies on the West Coast, in the Mountain Region, the Central Valley, the Lake Region and on the Eastern Seaboard. Universities, governmental bureaus, trade associations, industries, bankers, technical and scientific societies and numerous individuals have co-operated.

The assistance rendered by Foundation to various activities has been directed along lines which would, so far as practicable, bring to the undertaking other contributions of money or services.

The results of competently directed research are constantly needed to satisfy the demands of advancing civilization for greater and more efficient structures, for machines and processes. Also, there exists the need for independent thought and far-sighted business and engineering judgment looking to the adaptation of technical progress to human advancement. Engineering Foundation aids in these matters wherever practicable. Important ways in which The Foundation functions in connection with these activities are (1) assisting in the development and training of men, (2) promoting important worthwhile projects (3) fostering co-operative projects, this being increasingly important in the growing complexity of science, engineering, and industry, and (4) aiding in the actual organization of co-operative groups and starting them into effective action.

Foundations are known by their deeds. The following examples attest the scope, variety, and range of magnitudes of undertakings which the Foundation had aided or carried on in the 20 years since its board organized in April 1915:

EDUCATIONAL AND SOCIOLOGICAL

Assistance in establishment of National Research Council, Highway Research Board, Personnel Research Federation, Engineers' Council for Professional Development.

Publication of *Research Narratives*, other pamphlets and books.

Betterment of engineering education through investigations of institutions, methods, and needs; summer schools for engineering teachers; production and distribution of the guidance booklet, "Engineering: a Career—a Culture."

Ten "Courses for Disengaged Engineers," on technical, financial, and personal subjects, given to 600 engineers in the Engineering Societies Building.

TECHNICAL RESEARCHES

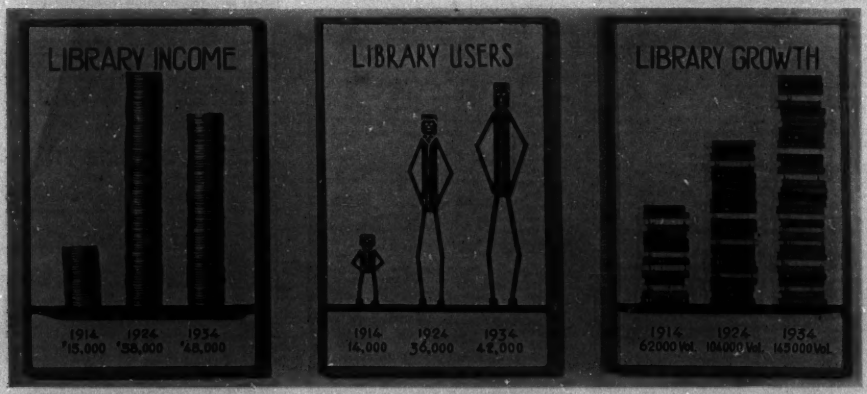
In civil engineering, investigations of arch dams, earths and foundations, concrete and reinforced concrete arches, plastic flow of concrete, steel columns, hollow-crested weirs.

In mining and metallurgy, collation of knowledge of mining methods; researches in blast furnace slags, barodynamics, alloy steels and irons.

In mechanical engineering, properties of steam, lubrication of machinery, strength of gears, use and care of wire ropes for lifting and hauling effect of temperature on metals, metal cutting.

In electrical engineering, studies of insulation and fundamentals of dielectrics, and welding research, the latter being developed into a co-ordinated, comprehensive program.

The Foundation's work enriches human life. Knowledge gained flows through 4 principal channels: the engineering colleges,



A quickly visualized record of the dollar income, number of users, and growth in size of the Engineering Societies Library since 1914

by teaching and reports of research; the profession, by practice; the industries, public utilities and public works, by supply of community needs; the engineering societies, by meetings and publications.

The benefits of these and other activities have been great and far reaching. In the 20 years since the Foundation was organized there has been a steady growth in appreciation of the great usefulness and possibilities of this institution, through which the co-operative activites of scientists, engineers and industrialists can contribute to research and in other ways to the advancement of engineering and the good of mankind. Great as have been the contributions already made, we are confident that they mark but the beginning of far greater services to be rendered by the Foundation in the future.

American Standards Association

By Howard Coonley, President

When small groups of engineers began more than 20 years ago to discuss informally the organization of an activity which was destined to become the American Standards Association, I doubt that even the most far-sighted of them could have foreseen that more than 3,000 technologists and other experts would be working on more than 200 standardization and safety code projects now underway or in the process of revision.

The American Standards Association was organized in 1918 as the American Engineering Standards Committee by 5 major engineering societies—the mechanicals, electricals, civils, and mining, and the American Society for Testing Materials. Two years later several government departments and bureaus became "member-bodies."

The standardization movement in this country was given its first great impetus during the World War, when mass production of ordnance and war supplies of all kinds brought about the regeneration in manufacturing which has made the United States the greatest manufacturing nation on earth. Interchangeability, a corollary of mass production, demands standardization of measurements and tolerances. Component parts of various kinds of war equipment produced in New England, the Atlantic Seaboard and Mid-Western manufacturing states had to be interchangeable.

This natural and logical movement toward standardization was then organized by industry to serve its ends. Starting as it did in machine shops with screw thread standards, fits, and industrial safety codes, it has outgrown the narrower confines of the shops into every major manufacturing industry and into the homes of consumers, and today American Standards and Safety Codes are used in every state of the union.

But the functions of the American Standards Association remain the same today as when the American Engineering Standards Committee was first organized. It is the central clearing house for American Standards and Safety Codes. Any national group may bring standards or safety codes projects to the American Standards Association and the Association will undertake to organize the projects under its procedure and determine whether industry and the consumers interested really want the work carried on.

Because no standard or safety code is worth the paper it is printed on unless a substantial majority of interested groups are willing to use it, the function of determining a consensus is one of the primary purposes of the organization. This also means that every group that may have an interest or a stake in the proposed project must be invited to send its representatives to co-operate in working out the standard.

The organization went through a major reorganization in 1929 when the old American Engineering Standards Committee was changed into the American Standards Association. Today the Association is going through another reorganization which again will refine certain details of its operation to fit more perfectly into the changing industrial and economic picture of the nation.

But to those of us interested in the standardization movement, one important phase is striking. Through these 2 reorganizations no reason has been found to change the fundamental functions of the Association. Today, as always, a democratic forum must be maintained for variant points of view, and a consensus is just as essential today as ever before. Obviously, with the wider ramification of industrial activities, democratic representation is more difficult to achieve and agreement offers more problems than ever before. The changes in the Association's set-up are simply calculated to expedite work without jeopardizing the right of industries, and consumers and governmental agencies to present their respective cases in court. The sectional committees, which might be termed the lower courts, and Standards Council, to carry the analogy a little further, the higher court, are made up of manufacturing, distributing, and consumer groups interested in standards and safety codes.

In passing, let me say that nearly a half of the 524 approved NRA codes carry standards provisions. Several hundred of these include safety codes, many of which were developed through the American Standards Association and represent the approval of technical societies, manufacturers, consumers and interested governmental agencies.

A large number of states of the union have written American Standard Safety Codes into their regulatory provisions. Our work on building codes, now under way, will carry the work of the Association into every hamlet and city in the nation.

The reorganization of the Association recommended by our committees provides for a closer co-ordination of the individual fields of standardization which are now under way and which we expect will be undertaken if, as, and when industrial, consumer, or governmental groups initiate other projects. That is all.

Thirty-nine national associations are represented by 35 "member-bodies" on the Standards Council, which finally approves American Standards and Safety Codes. An additional 11 national groups are represented by 10 "associate-members." 3,000-odd technical experts represent the points of view of about 600 national groups. These include a number of governmental departments and bureaus.

Our Association is a member of the International Standards Association. This gives American industry representation in the standards forum of 19 nations of the world.

For the past 6 years I have been interested in the work of the American Standards Association, representing the American Society of Mechanical Engineers. I can honestly say that the range of activity is many times as large today as when I attended my first meeting as a new member of the board. And we are on the threshold of a vista which baffles my imagination as I see more and more groups interested in the national standardization movement. Each comes to us with a problem which holds the answer to some important economic question involving other industries and groups.

Conversely, some of these problems cannot be met and dealt with without these impingent groups also becoming active in the work. This is expressing our membership problem from the viewpoint of our own present membership. In this broader aspect we have the support of many industrial leaders of the country who have personally given impetus to our membership campaign.

As long as industry has the machinery to adjudicate its own problems, we can resist inroads contemplated by government. The machinery of the American Standards Association has been tested for a long time, and it works. Today we are gearing it to an accelerated pace, to perform the duties and the obligations which will be imposed upon us tomorrow by manufacturers, distributors, and consumers.

Division of Engineering and Industrial Research, N.R.C.

By D. S. Jacobus, Vice Chairman

The purposes of the division of engineering and industrial research of National Research Council are to encourage, initiate, organize, and co-ordinate fundamental and engineering research in the field of industry, and to serve as a clearing house for research information of service to industry. In its primary functions the division attempts to maintain a balance between: (1) the demonstration of research methods and techniques through large, national research projects representative of the major fields of engineering; (2) the promotion of research in the field of industry, largely through trade associations by such methods as addresses, literature, meetings, conferences, radio talks, research laboratory inspection tours; and (3) a research information service.

By its plan of organization as part of the National Research Council, the division is especially fitted to bring together scientists and technologists, able and willing to contribute the variety of knowledge and experience requisite for successful attack on research problems. Its quasi-governmental status makes it possible to obtain the co-operation of the various departments of the government, universities, technical societies, other divisions of the Council. Industrial co-operation has been utilized to an ex-

tent which would not be obtainable by many organizations. In a national emergency, National Research Council stands ready as a national advisory service organization to mobilize scientific, engineering, and technical resources for the public interest.

As a division of National Research Council, the division of engineering and industrial research is unique in organization and flexible through co-operative relationships. Division membership is largely comprised of representatives from national engineering societies. It co-operates with Engineering Foundation, which furnishes it office space in the Engineering Societies Building. Engineering Foundation has assisted National Research Council, as well as the division, in many ways. The division is in touch with the 1,600 industrial research laboratories in this country; and also in correspondence with 100 laboratories in the principal research centers abroad. Its varied activities are designed to maintain constant contact with universities, trade associations, and private research laboratories.

The division depends upon interested industry for support of specific research projects. The division's administrative expenses are paid from endowment funds of Research Council.

Research committees and projects demonstrate successful utilization of research methods, techniques, and apparatus, and selection of personnel. Stimulation of research by selected projects in fields of engineering and industry follows the general policy of National Research Council. Yardsticks to evaluate projects before they are undertaken have been developed. In organizing research committees 3 types of personnel are drawn upon: scientists to lay out the research program, engineers to develop tests, industrialists to direct industrial applications.

The Highway Research Board demonstrates the functional operation of the division. In this project 4 essential functional features are combined:

1. A national clearing house for highway research data.
2. Co-ordination of federal highway research activities with state research activities.
3. Development of new university research centers in the highway field.
4. Distribution of highway research abstracts to stimulate industrial research and eliminate duplication.

Other division projects include electrical insulation, heat transmission, industrial lighting, and relationships between university research and industry. Each of these projects in its development has operated through the whole gamut of functional purposes in initiating research, encouraging research, effecting co-ordination, and eliminating duplication.

The annual proceedings of the electrical insulation committee examplifying international interest which appear in the American Institute of Electrical Engineers' publication ELECTRICAL ENGINEERING are closely followed by technologists abroad.

Promotion of industrial research requires experimentation to develop effective methods. The trade association has proved to to be the most effective channel to reach an industry as a whole. Records of current industrial research activities of representative industries have been compiled, catalogued and studied to develop opportunities for service. Oftentimes a leading trade journal takes the initiative in starting a campaign for research. After conferring with those in the industry who are particularly interested, the division recommends the appointment of a small research committee. Research committees have been taken on a tour of inspection to successful research laboratories operating in the same or closely allied fields of industry. The division continues to serve in an advisory capacity if requested.

Some industries with which the division has successfully developed co-operative research activities include: brick and clay, chemical, combustion utilities, fisheries, gas, glass container, lithographic, porcelain enaniel, cotton textile, and commercial aviation.

An average of 30 articles and addresses a year are prepared and delivered by officers of the division. The resulting action has been evaluated in terms of division objectives. The comparative effectiveness of the address, article, popular science radio broadcast, motion picture have been developed as implements for promotion of research.

A committee on relationship between university and industry was organized to hold 8 regional university conferences. The primary purpose is to bridge the gap between university and industry research. University contacts with industrial laboratories were established. Through such a common pool the resources, facilities, and personnel of universities' laboratories are made available to specific research needs of industry.

Actual demonstrations of research organization and operation were sought by many executives who contemplated establishing research laboratories or expanding them. Two inspection tours of representative research laboratories for a select number of executives and bankers were organized and conducted under division auspices. The first tour exemplified research as conducted by large industrial companies, and the second was through smaller laboratories.

Two unusual projects deserve mention to demonstrate the division's strategic position as a flexible mechanism in organizing and mobilizing scientists and engineers for national and international movements. The American committee of the World Engineering Congress held in Japan in 1929–30, was organized by the division in co-operation with the national engineering societies; and through the congressional charter of the National Academy of Sciences the Council arranged for a number of the members of the American committee to participate in the congress. A representative group of distinguished engineers and their families numbering 225 attended; 80 papers covering significant engineering achievements were presented. The other project was the assisting in the formation of a science advisory committee for the Chicago "Century of Progress" exposition, and 34 sub-committees. The division gave assistance to the central office of National Research Council and to the science advisory committee during the 2 years activity of the exhibition.

An increasing volume of inquiries on all research subjects makes it necessary for the division to be geared to shifting trends in research. Surveys are continually being made to obtain facts from industry on research expenditures, types of problems, significant trends and emphasis in research programs, trade association research, and the effect of the depression on research activities. This material is published and distributed by the division to libraries, trade associations, government bureaus and foreign laboratories. Research data have been supplied to research directors to assist in presenting a case to their boards of directors to maintain research appropriations.

A supplementary activity of the division is the administration of grants in aid in engineering and industrial research. Some fields covered by National Research Council grants-in-aid include welding, electrical insulation, radio, highway, and cement. Recent policy from Council headquarters, after consultation with the division, indicates that grants-in-aid will only be available in engineering and industrial research, where the lack of industrial support is demonstrated.

To aid in the National Recovery Administration, President Roosevelt issued an executive order creating "a science advisory board with authority, acting through the machinery and under the jurisdiction of the National Academy of Sciences and the National Research Council, to appoint committees to deal with specific problems in the various departments." The division of engineering and industrial research has continuously served the science advisory board since its inception. It has materially assisted in development of such projects as co-ordination of railroad research, decentralization of industry, patent system as related to new industries, technological reports of foreign commerce officers, radio signaling to avoid collision in fog at sea, and co-ordination of scientific and technical activities in the department of commerce.

Engineering Societies Employment Service

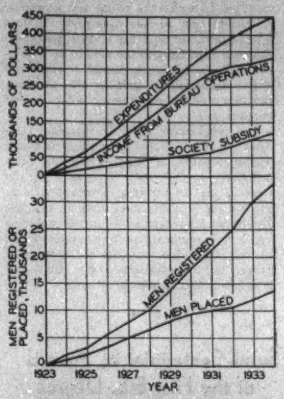
By George T. Seabury, Chairman, National Committee

The first joint effort of the engineering societies in the establishment of an employment office was in 1918. The service was managed by a board made up of the secretaries of the 4 founder societies, and the funds for its maintenance were provided by the societies. Prior to 1918, each of the 4 national engineering societies had operated free employment services to their members for various periods. On January 1, 1921, the management of the bureau was taken over by the Federated American Engineering Societies (now American Engineering Council) and was known as the Employment Service for that organization.

Later, in 1923, the management was taken over by the founder societies, the boards of direction inaugurating a new policy respecting the service. This action was based upon the report of a joint committee, representative of the 4 societies, which recommended among other things a co-operative plan of operation. Under this new arrangement, free service was discon-

tinued in favor of a plan to be financed in part by the societies and in part by those who benefited in having received positions through the efforts of the service.

This plan also called for the establishment of offices throughout the country as conditions permitted so that in time the service might become more truly national in scope.



A summary of the operations of the Engineering Societies Employment Service over the 11¼ years of its existence previous to 1935

All values are cumulative totals since beginning operation the later part of 1923

Pursuant to this policy, an office of the service was opened in Chicago in 1925 which was administered by representatives from the local sections of the founder societies in Chicago in co-operation with the Western Society of Engineers, which assisted in its financial support. Another office was opened in San Francisco in 1926, this office being administered by representatives from the local sections of the founder societies in San Francisco and in financial co-operation with the California Section of the American Chemical Society and the Engineers' Club of San Francisco.

The New York office differs from the other 2 offices in that its administration has been assigned to the assistant secretaries of the 4 societies.

The direction and management of the several offices of the employment service as a whole is under a board consisting of the 4 national secretaries. This board allocates the funds to each of the offices in accordance with the needs, sees that the policies as established are carried out, and otherwise acts as the executive head for the entire joint enterprise.

Use of the service is confined to the members of the 4 national societies and co-operating organizations. The establishment of 3 offices has enabled an exchange of positions and the publication of bulletins of positions available for the use of members seeking opportunities, thus accomplishing in part the making of the service more truly nationwide.

In normal times, the employment service is self-supporting and in exceptionally good times, such as prevailed from 1927 to 1929, the Service was able to build up a surplus to help meet such conditions as have prevailed since 1930. During the past 5 years there has been a dearth of employment opportunities and a great reduction in the normal income received through placement contributions with the result that this surplus has been exhausted and a large proportion of the cost of operating the 3 offices been borne by the founder societies.

Something of the effectiveness of the employment service may be gauged by the fact that for the 11¼ year period, from 1923 to 1934 inclusive, 33,372 engineers have been registered in the 3 offices, 28,721 positions have been received for filling, and 13,870 placements have been made.

This is indeed a remarkable showing when it is considered that about 25 per cent of the combined memberships of the founder societies have been assisted by the service upon one or more occasions. In view of the extent to which the employment service has served the members as well as the needs of employers in all phases of engineering and industry, it appears that this activity should be continued, improved, and expanded.

American Engineering Council

By John F. Coleman, President

The American Engineering Council was organized in November 1920, to act as a central agency for groups of organized engineers throughout this country. Its membership includes national engineering societies, representing various branches of the profession, and state and local engineering organizations. Council does not direct the activities of its members, but is a service unit providing a clearing house for information including employment sources, a forum for the deliberation of joint problems, and a means by which engineers may express themselves collectively on public problems.

Some 60,000 engineers are represented by the American Engineering Council, at the present time, through 7 national, 9 state, and 25 local societies.

We are rapidly establishing ourselves as the "Washington Embassy" of American engineers and engineering, and perfecting a nation-wide organization that will truly represent the profession. This is being done through state public affairs committees which are to function 2 ways: first, to engage themselves in local and state problems along the general lines of Council's purpose; second, to become corresponding committees on national policies which may grow out of the consideration of state and local problems.

State and local societies are showing a renewed interest in Council and some 15 new societies have joined or are in the process of joining under a membership plan which provides affiliation for a reasonable fee. Their connection with Council will strengthen the national professional organizations and also give the local groups an opportunity to participate in national questions in an organized and constructive way.

Council functions through committees of experienced men who study legislative measures and policies which effect both business and industry, and government agencies. They furnish advice and assistance to congressional committees and government agencies; and to business and industrial organizations on all questions or matters where it is evident that trained engineering minds may be of service.

Just now the federal and state programs are of first importance, but the majority of engineers are in private industry; therefore the development of technology in backward industries is considered the main field for the future growth of the profession.

Other objectives include the raising of the prestige and purposes of engineers in the public mind through a program of public education; and the clarification of engineering-economic purposes among engineers themselves.

Our officers firmly believe that there is a great need and a real opportunity to advance the engineering profession by promoting the purposes of functional organizations and establishing co-ordinated committees between existing agencies, rather than starting new societies.

We appreciate the wonderful co-operation we are receiving from the organizations which support us; and I personally wish to express my gratification at this opportunity for the exchange of ideas with those representing other organizations serving the profession.

I feel that each of our representative organizations is deriving advantage from co-operating with the others and it is sure that the most effective co-operation may be brought about by a clear understanding on the part of each of us as to what the other is trying to do.

Engineers' Council for Professional Development

By C. F. Hirshfeld, Chairman

The Engineers' Council for Professional Development is a comparatively new agency of the engineering profession, having been brought into being in October 1932. It was formed as a result of a very general recognition of 2 facts, namely:

(a) The time has arrived when engineering must take its place among the learned professions.

(b) The engineer must prepare himself for a greater and more extended degree of usefulness if he is to measure up to the demands that the present social structure is certainly preparing to place upon him.

The purpose of the E.C.P.D. is the enhancement of the professional status of the engineer. It aims to co-ordinate and promote aspirations and efforts directed toward higher standards of education and practice, greater solidarity of the profession, and greater effectiveness in dealing with technical, social, and economic problems.

The E.C.P.D. is necessarily a joint body because the purposes for which it was formed could not conceivably be achieved except through the most intense and sympathetic co-operation of national organizations representing several different interests in the profession. It consists of 21 mem-

bers, 3 appointed from each of 7 participating bodies:

American Society of Civil Engineers
American Institute of Mining and Metallurgical Engineers
The American Society of Mechanical Engineers
American Institute of Electrical Engineers
American Institute of Chemical Engineers
Society for the Promotion of Engineering Education
National Council of State Boards of Engineering Examiners

It is believed that the 5 first named represent adequately the major branches of the practice of engineering. The sixth obviously represents the educational interests. The seventh, a national organization formed by members of the boards set up by the different States for the registration of engineers, is obviously a necessary participant since it represents the increasingly important legal aspect of and legal responsibility of the profession. In growing numbers the States are enacting laws to give professional status to engineers meeting certain requirements with respect to education, accomplishment, and character.

The E.C.P.D. is not a self-continuing nor an independently acting organization. The members are appointed by the 7 participating bodies so that the latter always have it in their power to make its membership what they will. Further, it functions by studying questions within the range of its objectives and making recommendations to the governing boards of its sponsor bodies. Such recommendations are with respect to activities or procedures that it considers would be of value in enhancing the professional status of the engineer. It has no authority to undertake to do more than this unless specifically authorized to do so by those who formed it. Nor does it have authority to administer recommended procedures unless these have been approved by the governing boards of the participating societies and then specifically assigned to E.C.P.D. for administration.

Enhancement of the professional status of the engineer is a most intangible sort of thing. This very intangibility gives rise to many different views of the methods that might be pursued. The E.C.P.D. has taken the view that the soundest procedure is for the engineer so to improve himself and his capacity for service that he certainly will measure up to any demands that society may find it necessary or desirable to make upon him. It believes that the ability to serve adequately in professional capacity is bound to bring adequate professional recognition.

Such ideas make possible the preparation of a very definite program. Parts of this program already have been submitted to the governing boards of the participating societies; some of these have been approved and are now active projects.

The E.C.P.D. started by appointing 4 subcommittees, each charged with the study of a certain field of endeavor with instructions to report back to the E.C.P.D. These subcommittees are:

1. Committee on student selection and guidance.
2. Committee on engineering schools.
3. Committee on professional training.
4. Committee on professional recognition.

With the explanation that student selection and guidance refers to the entry to colleges of engineering, it becomes obvious that these subcommittees cover the entire span from the time the boy considers seriously his entry into a college of engineering until he has reached the full stature of a professional man.

The committee first named is under the chairmanship of Dean R. L. Sackett. Its function is to report to E.C.P.D. schemes for the educational and vocational orientation of young men with respect to the characteristics of an engineering education and the responsibilities and opportunities of engineers, in order that only those who have the high qualities, aptitude, and capacity required to obtain intellectual satisfaction therefrom may seek entrance to such courses.

The committee on engineering schools is chairmaned by Dr. Karl T. Compton. Its function is to report to E.C.P.D. means for bringing about greater and more effective co-operation between the engineering profession and the engineering schools as well as to report criteria for colleges of engineering which will insure to their graduates sound educational foundations for the practice of engineering.

The committee on professional training is under the chairmanship of General R. I. Rees. Its duty is to report to E.C.P.D. plans for the further personal and professional development of young engineering graduates and young men who are entering the profession without formal scholastic training.

The last of the subcommittees is headed by Conrad N. Lauer. Its function is to report to the E.C.P.D. methods whereby engineers who have met suitable standards may receive corresponding professional recognition.

All the subcommittees have already made reports to E.C.P.D. and the latter, as a result, has already made a number of definite recommendations of a constructive nature to the governing boards of the sponsor bodies. Some of these recommendations have received favorable action, others still are before one or more of the boards for consideration.

The engineer has done a marvelous technical job. He has in a comparatively short space of time converted the abstract findings of scientists to the practical use of man in an astounding profusion of technical inventions and their materialistic embodiments. He has, in fact, completely changed the tenor of human work and life. Even the man in the street appreciates a lot of what the engineer has done for him.

But the engineer has failed to take proper cognizance of the social and economic results of his works. He appears, in most cases, to have been content to devise and to execute in an altruistic spirit those material improvements which now stand to his credit without giving thought to the less materialistic but equally real problems that he was bringing into being. If he gave any thought to such matters at all, he appears to have believed that others would take care of them as their share provided he took care of his.

It now appears that we have failed to preserve a proper balance between inventions of 2 radically different sorts. Inventions in science and its application appear to have outstripped inventions of social and economic types. And, it appears that we shall have to make real efforts toward the restoration of a more nearly perfect balance if the works of the engineer are not to prove of less real value to the race than he has fondly hoped.

E.C.P.D. does not have any inflated notion of the engineer's abilities outside the technical field; but it does believe that the engineer is best able to interpret his own works. And it does believe that, if properly educated in extra-technical subjects, he can be of great assistance to those normally expected to make the social and economic inventions now so sorely needed. It does believe that the time has arrived when the engineer must expand the field of his activities while remaining technically sound and while continuing to consider the planning and execution of engineering works as his primary job.

The program of E.C.P.D. therefore visualizes the production of an engineer of much greater breadth of vision than has been customary in the past. It stands for the soundest sort of training in technical matters but aims at the same time to develop that broad appreciation of human problems that it feels necessary in the engineer of the future. By such a route it sees the engineer growing to full professional status and to full recognition as a professional man.

Semi-Centennial of Award of the First E.E. Degree

The Massachusetts Institute of Technology reports that on August 31, 1882, it announced its pioneer course, and on June 2, 1885, awarded the first electrical engineering degree in America. The event was celebrated at Cambridge, Mass., June 3, 1935, by a semi-centennial symposium in which electrical engineering education in the United States during the past 50 years was reviewed with particular reference to the influence which the Massachusetts Institute of Technology has had on its development.

The principal speakers were Dr. F. B. Jewett (A'03, F'12, and past-president) president of the Bell Telephone Laboratories, Inc.; Dr. A. A. Potter, dean of engineering at Purdue University; and Dr. Vannevar Bush (A'15, F'24) vice president and dean of engineering at the Massachusetts Institute of Technology. Professor D. C. Jackson (A'87, F'12, member for life, and past-president) head of the department of electrical engineering, presided.

Following the symposium a testimonial luncheon was held in the Walker Memorial for Professor Jackson, who retires this year after directing the electrical engineering division for 28 years. The speakers at the luncheon included Herbert G. Pratt, president of the Samson Cordage Works; C. A. Stone (A'91, M'07, and member for life), chairman of the board, Stone and Webster, Inc.; Gerard Swope (A'99, F'22, and member for life) president of the General Electric Company; Professor W. S. Rodman (A'07, F'28) dean of engineering at the University of Virginia; Professor G. C. Dahl (A'22, F'33) representing the electrical engineering faculty at M.I.T.; Dr. K. T. Compton (F'31) present of the Massachusetts Institute of Technology; and E. L. Moreland (A'11, F'21) who succeeds Professor Jackson as head of the department of electrical engineering. Professor Jackson responded,

and Alexander Macomber, consulting engineer and public utility executive, presided.

In the electrical engineering laboratories special demonstrations were made of calculating machines, electrical communication, sound measurement, modern illumination, developments in electronics, stroboscopic measurement, insulation research, electrophysiological research, and super high-voltage engineering. A statistical and historical exhibit will illustrate the development of electrical engineering education at M.I.T.

Tennessee Electric Power Company Receives Award. The annual award of the Charles A. Coffin Foundation, established by the General Electric Company in 1922, has been awarded for 1934 to the Tennessee Electric Power Company, of Chattanooga. The award, comprising the Charles A. Coffin gold medal, a certificate, and a check for $1,000 to be deposited in the treasury of the utility's employee welfare association, was received by Jo Conn Guild, president of the Tennessee company, during the recent annual convention of the Edison Electric Institute at Atlantic City, N. J., June 5. Faced with a difficult and competitive situation, the entire personnel of the company, under the leadership of its president, proceeded to develop one of the most unique sales programs ever carried out by a public utility, in the opinion of the judges. Every individual in the organization, regardless of his position, became a salesman for the company's kilowatt output. The award was made on the basis of substantial rate cuts, substantial increases in appliance sales, and a 26 per cent increase in residential consumption, all accomplished in the face of an unprecedented situation in the Tennessee Valley, partly affected by the work of the Tennessee Valley Authority. The company conducted well organized efforts to improve public relations, maintained safety activities, improved plant operation, and effected substantial engineering improvements in relaying. It co-operated in the sale of appliances with dealers, with the T.V.A., and with the E.H.F.A. The committee of judges consisted of T. N. McCarter, president of the Edison Electric Institute, K. T. Compton (F'31) president of the Massachusetts Institute of Technology, and F. W. Smith (A'05, M'12) *chairman*, president of the New York Edison Company.

Conant, was approved. Two fundamental needs for a national water resources policy are named as: (1) complete and correlated data; and (2) comprehensive study of water control legislation. A federal bureau of water resources is endorsed in principle and an interdepartmental board of water resources investigations is recommended to correlate investigational functions of federal units. Extension of the work of the water planning committee is recommended through a national advisory water planning agency for comprehensive, integrated drainage basin planning.

As to legislation, it is pointed out that bills in Congress often stress the importance of water power beyond the other urgent needs for water; also overlook the known facts which limit the economic development of available power sites. Intensive study by engineers is therefore desirable.

Opposition to the establishment of additional river basin authorities along the lines of T.V.A. at the present time was adopted as a policy of Council.

Membership of state and local societies newly united with Council was approved; as were the new assembly members from these groups. It is planned to use the rating system of the Engineers' Council for Professional Development in determining the eligibility of members of the assembly. Procedure for handling new membership applications was simplified.

American Engineering Council

Status of Government Construction Programs

Following are excerpts from the current "news letter" of American Engineering Council:

Administrators of government funds of the several agencies of government are scrutinizing with renewed care the exact phraseology of the legislation which gives them their authority. One immediate effect, therefore, of the hundreds which flow from the U.S. Supreme Court decision is to call attention both on the part of those who administer the work relief program and those who are expected to benefit by the work relief program, to its exact provisions. This re-defining of authority now taking place is further affected by the interrelations between state law and federal law on relief. This situation tends for further confusion in straightening out the organization and expenditure of the work relief program.

In A.E.C. items published in previous issues of ELECTRICAL ENGINEERING, the general status of the work relief measure and the amounts of the work relief appropriations have been given. Because of the confusion that exists both outside and inside of Washington at the moment, it seems worth while to restate the fundamental philosophy and purpose of the work relief bill for the benefit of engineers and engineering:

(a). This bill was conceived and passed to provide funds to employ 3,500,000 people for one year, heads of families now on relief. It was conceived as a relief measure primarily and not as an employment measure. The 4 billion dollars was established on the basis of actually averaging to pay a man on relief $50 a month. This sum is the approximate average allowance per head of a family of from $19 to $94 a month. This compensation for relief was purposely set at this relatively low figure so that men on relief would prefer jobs outside of relief, rather than to continue on types of work paid on a relief basis.

(b). The bill provides that this work shall be carried out within the locality of a man's present place of residence. In other words, local projects of such character that lend themselves to relief work would employ men and women on local relief rolls.

(c). The type of any given project is to be determined by the training and experience with the available relief labor within the locality of that project.

(d). This whole program is predicated on the intention that work relief shall be made unattractive.

(e). The bill includes provisions for administration expenses. The payment for such administration expenses is not on the basis of the relief compensation, but is to be established on the basis of the going local rates or fees for such work.

American Engineering Council has followed this program from its beginning. The staff of Council is familiar with the details of the program from its inception. The summary above in the long view represents our understanding not from newspapers' comments, but from an analysis of the law itself and of the executive orders so far issued.

The Recent Executive Committee Meeting of A.E.C.

The executive committee meeting of Council in New York, N. Y., May 20, 1935, covered a wide field of professional subjects. The water resources committee report prepared under the chairmanship of W. S.

Other Items of A.E.C.

Cases are being studied where engineers who have qualified under civil service feel that the rating did not give them the guarantee of employment to which they are entitled. Arthur W. Berresford (A'94, F'14, and past-president), past-president of A.E.C., has begun a preliminary survey of the general relationship of engineers to the civil service.

Boards of civil service appeals, to settle differences between federal civil service employees and their superiors, are proposed in the Sirovich bill (H. R. 3980). On a 3-man board to hear a given case, one member would represent the employee, 1 the civil service commission, and 1 the federal unit involved in the dispute. An engineer could be represented by a delegate from his engineering society.

The Anti-Gasoline-Tax-Diversion Association has asked Council to support the idea of restricting gasoline taxes to highway purposes. The executive committee suggests that this will be a desirable project to refer to state public affairs committees when they are formed, but state and local societies need not delay action on their own initiative.

Council's support of a program of aviation research under the National Advisory Committee for Aeronautics was recommended unanimously by the A.E.C. committee on aeronautics and was approved by the executive committee. The desired program is set forth in a paper by Dr. Alexander Klemin, secretary of the A.E.C. committee. Copies are available on request. Briefly, the recommendation is that the N.A.C.A. receive $50,000 per year of federal funds earmarked for research

to be done by universities and other institutions of public standing; not for educational purposes, buildings, or basic equipment. Scientific workers at approved institutions desiring to do research would submit formal plans. Results would be published in the form of N.A.C.A. technical reports or technical notes. A committee representing the N.A.C.A., Army, Navy, and Department of Commerce would supervise.

Numerous patent bills were considered and Council's opposition to the Sirovich bill (H. R. 4523) for the registration of patent pooling agreements, previously voiced by the committee on patents, was confirmed by the executive committee.

Participation of Engineers in Public Affairs

As reported in previous letters, Council is working toward increased participation of engineers in public affairs through a plan which ultimately will result in the setting up of state and regional public affairs committees composed of keymen in each area. The system of membership committees, now rapidly developing to encourage state and local societies to join Council under the new plan of nominal dues, is a step toward the final network of organized groups. Each new member society is asked to appoint a man to keep Council informed as to public affairs in his region and a complete setup in 1 or 2 states in order to test the plan is being made.

Meanwhile, there is a preliminary phase in which all can help. It is the feeling of A.E.C. that, if engineers really are to bear weight in public affairs, the field must be developed along lines of engineering analysis just as the technique of the profession has taken form over the past several decades. There is now an extensive literature of engineering technique so that a specialist in any branch of the profession may read the record of successful experience in relation to his problems. But the equally broad field of public affairs has not been fully explored and charted by engineers. Council, therefore, is seeking to assemble material in an effort to build up a practical record of experience along this vital line of activity.

Individuals can help by sending in general observations as to the proper relationship of engineers to public affairs together with accounts of actual cases with which they are familiar.

News for State and Local Engineering Societies

Through the distribution of its monthly "news letter" and discussion contributed thereon A.E.C. is working toward a clearing house arrangement which will promote a quick exchange of thought between the widely separated engineering groups throughout the country. Discussion of "news letters" is encouraged. The following items will suggest the type of suggestions desired.

A committee on educational economics has been organized by the Grand Rapids Engineers' Club to analyze the expenditures for heat, light, and power in the local schools, at the request of the board of education.

Engineering fairs, held by colleges or otherwise, are a means to acquaint large numbers of people with technical progress and to give the engineers themselves an insight into developments among the many specialized branches of the profession.

At the University of Washington, a biennial open-house is sponsored by the Engineers' Council.

An industrial museum and library are being promoted by the Engineers' Society of Milwaukee, which is also investigating the possibility of securing federal funds so as to proceed under a professional work-relief project.

If suggestions or material for speeches within the field of Council are wanted for use at meetings, write to the A.E.C., 744 Jackson Place, Washington, D. C. State and local societies, whether or not members of Council, are requested to keep Council up to date on officers, boards of direction, announcements of meetings, and other matters of interest so that the profession can be kept advised as to what is going on.

Standards

New Committee Organized on Electric Magnitudes and Units

Dr. A. E. Kennelly (A'88, F'13, HM'33, past-president, and member for life), professor emeritus of electrical engineering, Harvard University, was elected chairman of the new Sectional Committee on Electric and Magnetic Magnitudes and Units, and E. C. Crittenden (A'19, M'22), assistant director, National Bureau of Standards, was elected vice-chairman, at the organization meeting of the committee in the Engineering Societies Building, May 2. J. W. McNair, Electrical Engineer of the American Standards Association, was elected secretary of the committee.

The new sectional committee, which is working under the sponsorship of the Electrical Standards Committee of the American Standards Association, replaces a former special committee of the U.S. national committee of the International Electrotechnical Commission, the sole function of which was to advise the U.S.N.C. of opinion in regard to international standardization work on electric and magnetic magnitudes and units.

A subcommittee, of which E. C. Crittenden was elected chairman, was authorized to study and report upon fundamental systems of equations and units as employed in the sciences of electricity and magnetism. The subcommittee will thus explore the entire field of electric and magnetic magnitudes and units to see if it is possible to recommend a single system of electric and magnetic magnitudes and units for use by physicists to replace the present rather confused situation involving several systems.

The sectional committee also will collect in the form of a single pamphlet all of the decisions which have been made in the past by the International Electrotechnical Commission in respect to electric and magnetic magnitudes and units in order that they may be available to authors and workers in the field. Such of the decisions as appear to be suitable for American adoption will be considered by the sectional committee, with a view to recommending them to the American Standards Association for approval as American Standard.

The membership of the new sectional committee includes all of the members of the former special committee, together with representatives of other organizations. This new representation was provided because, in order to comply with the basic principles upon which sectional committees of the A.S.A. are organized, it is necessary to have representation from all concerned with the subject.

Members of the committee and the organizations they present are:

A. E. Kennelly (A'88, F'13, HM'33, past-president, and member for life), American Institute of Electrical Engineers, *Chairman*

E. C. Crittenden (A'19, M'22), National Bureau of Standards, *Vice Chairman*

J. W. McNair (A'25), American Standards Association, *Secretary*

American Institute of Electrical Engineers, A. E. Kennelly, C. H. Sharp (A'02, F'12, and member for life), W. I. Slichter (A'00, F'12, member for life, and national treasurer), V. Karapetoff (A'03, F'12, and Life Member)

American Association for the Advancement of Science, A. P. Wills.

American Institute of Physics (to be appointed later)

American Society for Testing Materials, H. L. Curtis (A'21, F'26), W. J. Shackelton

A.S.A. Electric Light and Power Group (to be appointed later)

A.S.A. Telephone Group, W. J. Shackelton (A'12), H. S. Osborne (A'10, F'21)

Institute of Radio Engineers, J. H. Dellinger

National Bureau of Standards, E. C. Crittenden

National Electrical Manufacturers Association, J. J. Smith, I. M. Stein (A'18, M'27), R. E. Hellmund (A'05, F'13), W. N. Goodwin, Jr. (A'06, F'13)

National Research Council, Leigh Page

Society for the Promotion of Engineering Education, Harold Pender (A'06, F'14), C. V. O. Terwilliger (M'25)

The membership of the subcommittee will be selected.

Engineering Foundation

A Survey of the World's Welding Literature

Engineering Foundation has appointed a welding research committee to: (*a*) initiate and conduct a critical review of world welding literature; (*b*) render modest aid to worthy individual projects functioning under the fundamental research committee of the American Bureau of Welding; and (*c*) sponsor specific research investigations. The project will be started by funds contributed by Engineering Foundation supplemented by funds and services supplied by

industry. The project is jointly sponsored by the A.I.E.E. and the American Welding Society. (A previous announcement of this project was made in ELECTRICAL ENGINEERING for May 1935, page 571.)

Among the first proposed activities of the committee is a canvass of industry for the purpose of determining what services can be counted upon by the committee in the formulation of a program which will most effectively utilize the total of the resources which will be available to it. These contributed services will doubtless be of various kinds: reviews of literature and translations of foreign language articles which have been or are being made for private purposes; technical assistance, materials, and the loan of apparatus in connection with specific research investigations; and unpublished research data. A maximum of contribution in the form of such services can be made by industry at a minimum of additional cost.

It is also proposed to collect information from which can be prepared a list of research projects now under way and being planned that can be made available to the committee. Suggestions will be solicited for research projects which are recommended for prosecution under co-operative auspices. Another plan being considered is the setting up of a clearing house for translations and abstracts dealing with welding literature so that unnecessary duplication may be avoided and a maximum of co-operation secured in the critical abstracting of such literature.

The personnel of the committee is as follows: C. A. Adams (A'94, F'13, past-president and member for life), Harvard University, *chairman;* William Spraragen (A'17, M'26), American Welding Society, *secretary;* J. H. Critchett, Union Carbide and Carbon Research Laboratories; J. J. Crowe, Air Reduction Sales Company; H. M. Hobart (A'94, F'12, and member for life), General Electric Company; D. S. Jacobus (A'03), Babcock and Wilcox Company; G. F. Jenks, Ordnance Department, U.S. Army; and F. T. Llewellyn, United States Steel Corporation. Communications should be addressed to William Spraragen, American Welding Society, 33 West 39th Street, New York, N. Y.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or to reject them entirely.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

A New Source of "Kilocycle Kilowatts"

To the Editor:

I was much interested in L. D. Miles's article entitled, "A New Source of 'Kilocycle Kilowatts,'" which appeared in ELECTRICAL ENGINEERING, March 1935, pages 305–7, since some years ago we had occasion to set up and use a similar device in the Westinghouse research laboratories. This kilocycle power supply was used for determining the iron losses in thin laminated material for a range of frequencies from 3,000 to 50,000 cycles. The results were described in "High Frequency Iron Losses" by Thos. Spooner, published in the JOURNAL of the A.I.E.E., volume 39, Sept. 1920, pages 809–13. The tube consisted of 2 spherical tungsten electrodes mounted on stems, much as shown by Mr. Miles, in an atmosphere of hydrogen and mercury vapor. A 500-volt commercial d-c supply was used as a source of power. For this particular application a sine wave of current was desirable so a double tuned circuit was set up instead of the single oscillating circuit shown by Mr. Miles.

We found this device very useful as a laboratory tool but did not feel that it had much value for commercial application due to its rather low efficiency. Mr. Miles's article would have been much more valuable had it not been for a number of omissions of pertinent information. To illustrate, what is the function of the third electrode shown in figure 1; this is neither mentioned in the text nor indicated in the diagram of figure 2? What is the most suitable gas and pressure for a tube of this kind? Why cannot the magnetic field and choke of figure 2 be combined into one unit? Is the magnetic field coupled with the tube? What is the minimum d-c voltage required for satisfactory operation and also what is the inductance necessary in the input circuit? In figure 4 is the large coil in the foreground the choke or the magnetic field? What is the device mounted behind the 3 single pole knife switches and what is the function of the 3 single pole knife switches? What is the maximum efficiency obtainable with a device of this kind? Finally, since the larger outfit described has only 500 watts output the use of kilowatts in the title of the article may be questioned.

Very truly yours,

THOS. SPOONER (A'12, F'29)
(Manager, General Division, Westinghouse Research Laboratories, E. Pittsburgh, Pa.)

To the Editor:

In response to questions concerning my paper "A New Source of 'Kilocycle Kilowatts'" published in the March 1935 issue of ELECTRICAL ENGINEERING, pages 305–7, I submit the following:

Since the preparation and submission of this paper it has become apparent that this method of producing high frequency power has for the present certain limitations that will preclude its immediate successful application in industry except under special conditions.

Arc instability, power losses in choke and stabilizing resistor, and cost of the extremely pure gases necessary are some of the factors that have so far precluded the building of an equipment commercially practical, from an economic standpoint.

The third electrode of the arc tube is an auxiliary electrode to simplify initial starting and has no function in operation.

The optimum gas pressure varies according to tube sizes and electrode spacings. In general, satisfactory results will be found using one atmosphere of hydrogen.

If a magnetic field is used it is coupled transverse to the arc stream. For most frequencies the choke and electromagnetic field may obviously be incorporated in one unit, providing no control of operation is desired by field intensity adjustments.

Operation for very small power outputs and low efficiency may be had below 100 volts direct current. However, stability and efficiency are considerably increased with voltages of 250 to 500 direct current. The input inductance is governed entirely by frequency of operation.

The coil in figure 4, which shows an experimental setup for giving 50 watts of kilocycle frequency power directly from 250 volts direct current, is the choke. No magnetic field is used. Behind the 3 knife switches are 3 condensers of the oscillatory circuit, which may be connected in parallel at will by the switches for frequency change. This small power low voltage equipment gives an over-all efficiency of about 25 per cent, which may be increased to 35 per cent by use of a magnetic field and 50 per cent by use of about 500 volts.

Very truly yours,

L. D. MILES (A'33)
(Vacuum Tube Engg. Dept., General Electric Co., Schenectady, N. Y.)

Internal Price Levels and Foreign Trade

To the Editor:

No nation can long survive and maintain decent living conditions for its people that does not adopt 1 of 2 commercial policies.

It must either establish a price level comparable with that of other nations and trade with them or it may establish any convenient price level and not trade with them, except for those products it has not the facilities to produce.

With free and unrestricted trade among nations all, or nearly all, the manufacturing will naturally and necessarily be done in those countries having the lowest price level.

The original and principal cause of the depression in this country during the past 6 years, is the fact that we have been trying to increase or hold up the price level and manufacturing cost in this country and at

the same time maintain world trade.

These 2 things are not only incompatible but impossible of attainment.

While so-called progressives and new dealers have been frantically demanding that trade barriers between this and other countries be lowered or removed, they have been madly striving to increase or hold up the price level and manufacturing costs in this country far above that of neighboring countries, and while they have been limiting production in this country, they have been demanding that products of other lower price level countries be allowed to come in free into this country.

No more insane or destructive policy could be conceived by mortal man or an incarnate fiend bent on destroying the country and all of its inhabitants in the shortest possible time.

This policy cannot be excused on the plan that it is an experiment for the reason that every sane and intelligent person knows that there can be but one result if this policy is long continued.

Either the United States of America will not long survive as a free and independent nation or it will revert to a second or third class nation with the greater part of the population living in degradation, as many of them are now doing in all the newer additions in all cities and towns in the United States, with the possible exception of Washington, D. C., Muscle Shoals, Boulder Dam, Grand Coulee, Bonneville, and other tax supported government project communities of the country.

Very truly yours,

E. R. Cunningham
(A'96, M'14, and member for life)
(726 S. W. Salmon St., Portland, Ore.)

A Method of Electrical Prospecting

To the Editor:

I have read the article "Methods of Electrical Prospecting" by Donald G. Fink in the March 1935 issue of Electrical Engineering, pages 293–6, with great interest.

In connection with it, your readers may be interested in knowing that an instrument using the "commutated d-c method" described on page 295 of that issue is commercially available.

I have been licensed to build an instrument of this type—the so-called Gish-Rooney apparatus—under patents held by the Carnegie Institution of Washington. The U.S. Geological Survey has been using my instruments very successfully in geological reconnaissance on dam sites.

There is an account of the application of the Gish-Rooney method to prospecting for road gravel, in the February 21, 1935, issue of the *Engineering News-Record*. Some of your readers may be interested in this.

I shall, of course, be glad to have questions concerning electrical prospecting referred to myself.

Very truly yours,

Shelley Krasnow (A'32)
(Instrument Designer, 817 G Street, N. W., Washington, D. C.)

Personal Items

A. E. Kennelly (A'88, M'99, F'13, HM'33, Life Member and past-president) professor emeritus of electrical engineering, Harvard University and Massachusetts Institute of Technology, Cambridge, Mass., has been elected honorary president of the U.S. National Committee of the International Electrotechnical Commission. Doctor Kennelly has been honorary secretary for many years and has served on the committees on rating of electrical machinery and as chairman of the committee on electrical and magnetic magnitudes and units. He served 2 terms as vice president of the Institute, 1892–94 and 1897–98, and was a manager 1894–97 and president 1898–1900. In 1933 he was awarded the Institute's Edison medal for his work in electrical science and engineering. Doctor Kennelly was appointed professor of electrical engineering at Harvard University in 1902, and became professor emeritus in 1930. He has served on the Institute's standards committee almost continuously since 1906 and on the research committee since 1920, as representative on the U.S. National Committee of the International Electrotechnical Commission since 1907, and as a member of the radio advisory committee of the Bureau of Standards since 1925, as well as on a number of others. He recently became chairman of the newly formed sectional committee on electric and magnetic magnitudes and units under the sponsorship of the electrical standards committee of the American Standards Association, which replaces the former special committee of the U.S. National Committee of the International Electrotechnical commission.

J. Allen Johnson (A'07, F'27, and president) chief electrical engineer, Buffalo, Niagara and Eastern Power Corporation, Buffalo, N. Y., has been awarded the 1934 A.I.E.E. national prize for best paper in engineering practice as co-author with R. T. Henry (A'24, M'29, F'33) of the paper "Fundamentals of Design of Electrical Energy Delivery Systems." Mr. Johnson is a native of Massachusetts, and was graduated from Worcester Polytechnic Institute in 1905 with the degree of bachelor of science in electrical engineering. He was then employed by the Ontario Power Company at Niagara Falls, Ont., and was appointed electrical engineer in 1912. This company was purchased by the Hydro-Electric Power Commission of Ontario in 1917, and Mr. Johnson added the duties of assistant engineer. The following year he became chief engineer of the Cliff Electrical Distributing Company and Hydraulic Power Company at Niagara Falls, N. Y., which in a consolidation that year became The Niagara Falls Power Company with Mr. Johnson as electrical engineer. He held this position during the time of rapid development of Niagara power, and since 1929 has been in his present office. A number of papers have been contributed to the Institute by Mr. Johnson, who received honorable mention in the 1933 A.I.E.E. prize awards for best paper in engineering practice. Since 1905, when he was the first chairman of the Worcester Polytechnic Institute Branch, Mr. Johnson has been active in Institute affairs, serving on a number of committees and as a director 1928–32, and a vice president 1932–34. As president he is chairman of the executive committee, and he is also a member of the Edison medal and Charles A. Coffin fellowship and research fund committees, representative on the American Engineering Council assembly, and representative on the John Fritz Medal Board of Awards. A signal honor was recently conferred on Mr. Johnson by Worcester Polytechnic Institute, in the awarding to him of the honorary degree of doctor of engineering on June 14, 1935. In Mr. Johnson's absence, caused by illness, the diploma and doctor's hood were received for him by his son, a member of the graduating class. The citation for Mr. Johnson's degree was, in part: "A leader in the development and application of electrical energy from Niagara Falls, he has for years directed power production at that grand center. From a humble private in the army of electrical engineers . . . . . he has risen to high command, to be an authority in his chosen field . . . . . And this year his fellows in the national American Institute of Electrical Engineers have conferred upon him the highest office within their gift, the presidency of that great organization. . . . ."

R. T. Henry (A'24, M'29, F'33) electrical engineer in charge of design, Buffalo, Niagara and Eastern Power Corporation, Buffalo, N. Y., with J. Allen Johnson (A'07, F'27, and president) co-author of the paper "Fundamentals of Design of Electrical Energy Delivery Systems," has been awarded the 1933 A.I.E.E. national prize for best paper in engineering practice. Mr. Henry was born at Stronghurst, Ill., and attended schools at Niagara Falls, N. Y., and the General Electric engineering school at Lynn, Mass., where he was engaged as a draftsman in 1908, leaving a year later to join the Niagara Falls Hydraulic Power and Manufacturing Company at Niagara Falls, N. Y. In 1912 he became assistant electrical engineer with the Hooker Electrochemical Company in Niagara Falls, and shortly afterward was employed by the Edison Illuminating Company in Detroit, Mich. In 1914 he returned to Niagara Falls as assistant superintendent of the Niagara Electric Service Corporation, where he was concerned with distribution systems. From 1918 to 1929 he was assistant electrical engineer for The Niagara Falls Power Company, one of a group of companies in the Buffalo, Niagara and Eastern Power Corporation in which he has had his present title since 1929. Mr. Henry served on the Institute's protective devices committee 1931–35, being chairman 1932–34, which automatically made him a member of the technical program committee during those years. During the year 1929–30 he was chairman of the Niagara Frontier Section.

H. A. Affel (A'18, M'23) engineer, Bell Telephone Laboratories, Inc., New York, N. Y., has received honorable mention with co-authors R. W. Chesnut (A'19) and R. H. Mills (A'33) of the paper "Auditory Perspective—Transmission Lines" in the 1934 A.I.E.E. national prize awards for best paper in engineering practice. Mr. Affel graduated from Massachusetts Institute of Technology with the degree of bachelor of science in electrical engineering in 1914, and for 2 years he was research assistant in electrical engineering. From 1916 to 1934 he was employed in the engineering and development and research departments of the American Telephone and Telegraph Company at New York, N. Y., being transferred to the Bell Telephone Laboratories in 1934. His early work was concerned chiefly with investigation of high frequency phenomena on wires and the development of multiplex carrier telephone and telegraph systems. More recently his work has included the broader phases of long distance telephone transmission, repeaters, program circuits, and vacuum tubes, and a number of patents have been issued to him. Mr. Affel has previously presented papers to the Institute, and has addressed several Sections recently on the subject "Precise Frequency and Time Over Wires."

R. W. Chesnut (A'19) carrier telephone engineer, Bell Telephone Laboratories, Inc., New York, N. Y., with his co-authors H. A. Affel (A'18, M'23) and R. H. Mills (A'33) has received honorable mention in the 1934 A.I.E.E. national prize awards for best paper in engineering practice. Mr. Chesnut was born at Kiowa, Kan., in 1892 and was graduated from Harvard University with the degree of bachelor of arts in 1916. He then went to Europe where he spent several years, first as a traveling fellow, from Harvard University, then with the bureau of war inventions of the French Government at Paris engaged on the application of acoustics to war problems, and last as a lieutenant in the U.S. Signal Corps, where he had charge of the research and development of sound ranging of airplanes. Since 1920 Mr. Chesnut has been in the engineering department of the Western Electric Company and its successor, the Bell Telephone Laboratories. Most of his work has been on the development of carrier telephone and long wave radio systems, and a previous Institute paper on carrier telephone cable was prepared by him as a co-author. He is a member of the American Physical Society.

R. H. Mills (A'33) telephone engineer, Bell Telephone Laboratories, Inc., New York, N. Y., shares with his co-authors H. A. Affel (A'18, M'23) and R. W. Chesnut (A'19) honorable mention in the 1934 A.I.E.E. national prize awards for best paper in engineering practice. Mr. Mills, who was first elected an Associate in 1919, was born at Natick, Mass., and graduated from Massachusetts Institute of Technology in 1916 with the degree of bachelor of science. He was employed by the Western Union Telegraph Company as a cable engineer until 1918, when he joined the Western Electric Company in submarine detection work, later engaging in various transmission problems. The Bell Telephone Laboratories were formed in 1924, and since then Mr. Mills has been concerned with the development of selective electrical networks and with apparatus for carrier frequency communication systems.

C. F. Hirshfeld (A'05) chief of research department, Detroit Edison Company, Detroit, Mich., has received the 1934 A.I.E.E. national prize award for best paper in public relations and education for his paper "Engineers of the Next Generation." Doctor Hirshfeld was born at San Francisco, Calif., and studied at the University of California from which he received the degree of bachelor of science in electrical engineering in 1902. Three years later he received his master's degree in mechanical engineering at Cornell University, and in 1932 Rensselaer Polytechnic Institute conferred upon him the honorary degree of doctor of engineering. Between 1903 and 1914 he was successively instructor, assistant professor, and professor of mechanical engineering at Cornell University, at the same time carrying on a consulting practice. He has been chief of the research department of the Detroit Edison Company since 1913 and consulting engineer since 1919, and was chief engineer of the Electric Railway Presidents' Conference Committee of the American Electric Railway Association in 1930. He is the author of numerous papers and articles, including a previous Institute paper, and is a member of a number of societies, among them The American Society of Mechanical Engineers of which he has been a vice president. Doctor Hirshfeld was a member of the Institute's power generation committee 1922–31, of the standards committee 1923–30, and of the electrical machinery committee 1926–27, and has been chairman of Engineer's Council for Professional Development since its inception.

C. L. Dawes (A'12, M'15) associate professor of electrical engineering, Harvard University, Cambridge, Mass., has received honorable mention in the 1934 A.I.E.E. national prize awards for best paper in public relations and education for his paper "Encouraging Initiative in the Engineering Student." Professor Dawes last year received the 1933 A.I.E.E. North Eastern District prize for best paper. He was born at Somerville, Mass., and in 1909 received the degree of bachelor of science in electrical engineering at Massachusetts Institute of Technology, where he was an assistant until 1911. He then went to Harvard University as an instructor. For a time he was absent on leave to be professor of electrical engineering at the United States Naval Academy, and was an instructor at the Naval Aviation Ground School at Massachusetts Institute of Technology when it was combined with Harvard University from 1915 to 1919. From 1919 to 1931 he was assistant professor of electrical engineering at Harvard University, and for some years has been engaged in consulting work for a number of electrical industries. Several papers on engineering and educational subjects have been written by him.

F. W. Smith (A'05, M'12) president, New York Edison Company, and United Electric Light and Power Company, New York, N. Y., has been elected president of the Consolidated Gas Company of New York to succeed G. B. Cortelyou, who is retiring. Mr. Smith has had a long career in the electrical industry, having first entered it in 1880 when he was employed by the United States Illuminating Company, which subsequently became a part of the United Electric Light and Power Company. He was elected secretary of the latter in 1905, vice president in 1912, and was appointed general manager in 1916. This company was originally formed for the purpose of developing the a-c system, so that Mr. Smith has been actively identified with this development. In 1926 he was elected chairman of the board of directors of the New York and Queens Electric Light and Power Company, and in 1929 was elected president of the Brush Electric Illuminating Company. He was elected vice president of the New York Edison Company in 1931, and the following year became president of this company and of the United Electric Light and Power Company. In addition, he has served as director of a number of other companies. Mr. Smith is a member of the board of trustees of the Edison Electric Institute, a past-president of the National Electric Light Association, and a member of the Electrical Association of New York, New York Electrical Society, and other technical organizations.

J. ALLEN JOHNSON

R. T. HENRY

C. F. HIRSHFELD

J. R. MEADOR

H. S. BLACK

H. S. BLACK (A'23, M'33) member of the technical staff, Bell Telephone Laboratories, Inc., New York, N. Y., has received the award for best paper in theory and research in the 1934 A.I.E.E. national prizes, for his paper, "Stabilized Feedback Amplifiers." Mr. Black was born at Leominster, Mass., in 1898 and received the degree of bachelor of science in electrical engineering at Worcester Polytechnic Institute. He joined the engineering department of the Western Electric Company at New York in 1921. This department later became the Laboratories. Mr. Black has participated in the development of many aspects of carrier telephone systems, including repeaters and line filters, and is the inventor of the amplifier described in his paper. In recent years he has had charge of a group devoted primarily to carrier repeater development. Mr. Black has written other technical papers, and is a co-author of a previous Institute paper on a carrier telephone system for short toll circuits.

J. R. MEADOR (A'34) electrical engineer, General Electric Company, Pittsfield, Mass., has been awarded the 1934 A.I.E.E. national prize for initial paper, his contribution being "Calibration of the Sphere Gap." Mr. Meador was born at Dallas, Texas, in 1905 and received the degree of bachelor of science in electrical engineering at Texas Agricultural and Mechanical College in 1927, obtaining his master's degree the following year. He then entered the testing department of the General Electric Company, and in 1930 transferred to the power transformer department, where he spent 2 years in the high voltage engineering laboratory. He is engaged at present in research and devtelopment relating to the cooling and insulation of transformers.

I. E. MOULTROP (A'10, M'12, F'29) chief engineer and superintendent of construction bureau, Edison Electric Illuminating Company of Boston, Mass., has been elected a trustee of Northeastern University, Boston, and was appointed a member of the visiting committee by President Speare of the university. Mr. Moultrop has been a member of the Institute's power generation (formerly power stations) committee since 1916, and has served on the automatic stations committee since 1930. He has also been active on several other committees in recent years.

H. S. HAMILTON (M'24) telephone engineer, Bell Telephone Laboratories, Inc., New York, N. Y., has received honorable mention in the 1934 A.I.E.E. national prize awards for initial paper, for his paper "Wide-Band Open-Wire Program System." Mr. Hamilton was born at Marblehead, Mass., in 1893 and received the degree of bachelor of science in electrical engineering at Tufts College. From 1916 to 1934 he was employed by the American Telephone and Telegraph Company in transmission development work, and since 1934 has been in the transmission development department of the Laboratories. He was first engaged particularly in repeater development, and during 1918 directed a field group in a campaign to improve the service between New York and Washington, D. C. Following this Mr. Hamilton directed the unloading of transcontinental circuits and equipping them with new repeaters. Since 1923 he has been closely associated with the development of circuits for radio program transmission, among the more recent projects being the wide band program system for open wire lines inaugurated in 1931 and the special 15 kilocycle circuits between Philadelphia, Pa., and Washington in 1933 for the demonstration of auditory perspective, on which he prepared an article for the *Bell Telephone Quarterly*. Recently Mr. Hamilton has been engaged in development of carrier telephone systems for open wire circuits.

J. V. LAMSON (A'29) instructor in the college of engineering, University of Washington, Seattle, has received honorable mention in the 1934 A.I.E.E. national prize awards for initial paper, for his paper "Trolley Wire Lubrication Improved." He was born in Illinois in 1902, and after graduation from the University of Washington in 1926 worked in the test department of the General Electric Company for almost 2 years, applying a considerable portion of the time in the electric railway and heavy machinery fields. For the following 2 years he was an assistant engineer in the electrification department of the Chicago, Milwaukee, St. Paul and Pacific Railroad at Seattle, Wash., where he became interested in contact line and current collection problems. In 1930 he became an instructor in the department of general engineering at the University of Washington. Facilities in the laboratory made possible the study of current collection in heavy traction systems which led to the preparation of his paper. Mr. Lamson is at present, during the summer, making a study of current collecting devices for the Ohio Brass Company.

H. S. VASSAR (A'06, M'18) laboratory engineer, Public Service Electric and Gas Company, Irvington, N. J., has been nominated for president of the American Society for Testing Materials. Mr. Vassar, a graduate of Pratt Institute, Brooklyn, N. Y., has been in charge of electrical, mechanical, and chemical testing for the company since 1911, having previously been with the United Electric Company and the Public Service Railway Company, both in Newark, N. J. He was a member of the Institute's electrophysics committee 1920–21, and of the instruments and measurements committee in 1920 and 1922–25. For the past year he has been vice president of the American Society for Testing Materials, of which he has been a member since 1915, and is active in the work of the committee on electrical insulating materials, serving as its chairman 1926–30.

W. B. SANFORD (A'04, M'30) plant manager, Bell Telephone Laboratories, Inc., retired from the laboratories on May 1, 1935, after more than 31 years of active service. In 1901 Mr. Sanford entered the factory engineering department of the Western Electric Company upon the completion of the mechanical engineering course at Cornell University. Although he left the department 2 years later, he returned in 1905 and in 1909 was appointed factory engineer, in charge of plant operation and construction. In 1913 he was given supervision of the shop departments, and was transferred to the general purchasing department in 1915. During the war period he superintended the manufacture of vacuum tubes for government use, and since then has superintended practically all physical alterations in the laboratories' building.

A. N. GOLDSMITH (M'15, F'20, and Life Member) consulting engineer, New York, N. Y., has had the honorary degree of doctor of science conferred upon him by Lawrence College at Appleton, Wis. The citation made by President Wriston of the college stated that the degree was in part conferred "in recognition of the unique place which Doctor Goldsmith has made in his chosen field." Doctor Goldsmith is a past-president of the Institute of Radio Engineers and of the Society of Motion Picture Engineers and is a member of numerous engineering and scientific societies.

H. E. IVES (F'29) director, electro-optical research, Bell Telephone Laboratories, Inc., New York, N. Y., has been appointed a fellow for research in color science at the Fogg Art Museum of Harvard University, Cambridge, Mass. Doctor Ives was formerly in charge of experimental work in airplane photography for the aviation section of the U.S. Signal Corps, and is the holder of the John Scott medal for pioneer work in electrical telephotography and television. He served on the Institute's committee on production and application of light 1932–34.

J. E. Allen (A'21) chief of tests, Pennsylvania Water and Power Company, Baltimore, Md., with his co-author G. J. Gross (A'30) has been awarded a James H. McGraw prize by the Edison Electric Institute for one of the 3 most meritorious papers on any engineering or technical subject relating to the electric light and power industry during the year. Mr. Allen was a member of the A.I.E.E. protective devices committee 1929–31.

G. J. Gross (A'30) test engineer, Pennsylvania Water and Power Company, Baltimore, Md., shares with his co-author J. E. Allen (A'21) a James H. McGraw prize awarded by the Edison Electric Institute for one of the 3 most meritorious papers on any engineering or technical subject relating to the electric light and power industry during the year.

M. L. Waring (A'29) system engineering department, New York Edison Company, New York, N. Y., has been awarded a James H. McGraw prize by the Edison Electric Institute as author of one of the 3 most meritorious papers on any engineering or technical subject relating to the electric light and power industry during the year.

Obituary

Orville Hiram Ensign (A'04, M'05, F'13, and member for life) one of the Los Angeles Section's most prominent members, died at his home in Pasadena, Calif., June 1, 1935. Mr. Ensign was born at Ithaca, N. Y., July 8, 1863. After completing 2 years of work in the course of "mechanical arts" with the class of 1884 at Cornell University he was, until 1893, variously employed by the Edison United Electric Company of New York City on construction work, and by the General Electric Company, Schenectady, N. Y., successively as machinist, draftsman, in charge of railway motor test work, and finally for $2^1/_2$ years as chief inspector for the factory. In 1893 Mr. Ensign moved to California as consulting engineer for the Redlands Electric Light and Power Company in connection with the completion and the placing in service of the "first 3 phase power transmission plant in the United States," the historic Mill Creek plant near Redlands, Calif. During 1894–95 Mr. Ensign was electrician and superintendent of motive power for the Pasadena and Los Angeles Electric Railway and the Los Angeles and Santa Monica Electric Railway, constructing and operating the former and partially constructing the latter. From 1896 to 1904, Mr. Ensign served as electrical and mechanical engineer for the Redlands Electric Light and Power Company and its successors, the Southern California Power Company and the Edison Electric Company (now the Southern California Edison Company, Limited). Mr. Ensign had entire charge of the design and construction of the plants built by these 3 companies, and in 1896 undertook the development of an 83-mile 33,000-volt transmission line from Santa Ana Canyon near Redlands to Los Angeles, the first "long distance" high voltage polyphase line. In 1904 Mr. Ensign became chief electrical engineer for the U.S. Reclamation Service, which position he held until 1915 when he retired to assume private practice as a consulting engineer in Los Angeles. Also at that time Mr. Ensign founded the Ensign Carburetor Company of which at the time of his death he was president and chief engineer. He retired from general consulting practice in 1927. One of the most notable services rendered by Mr. Ensign was his membership on the board of consulting engineers for the bureau of power and light of the City of Los Angeles, which was actively used during the formative and construction period of the bureau's hydroelectric and distributing systems from 1910 to 1921.

Edward Allen Colby (A'89, M'89, and member for life) consulting engineer and secretary, Baker and Company, Inc., Newark, N. J., died June 2, 1935. He was born at St. Johnsburg, Vt., August 1, 1857, and entered the Sheffield Scientific School of Yale University in 1877, receiving the degree of bachelor of philosophy in 1880. For a short time he taught natural science, and in 1881 was employed by the United States Electric Lighting Company at New York, N. Y., installing the first incandescent lighting on Hudson River ferryboats. The following year he became assistant to Edward Weston (A'84, M'84, HM'33, past-president, and member for life) having charge of the lighting department in the laboratory at Newark, N. J. In 1887 Mr. Colby invented an induction electric furnace for the melting of metals, which is the basis of the present electric steel melting industry. In recognition of this invention he was awarded a medal and diploma by the Franklin Institute. A process for the melting of platinum was perfected by him in 1893. Mr. Colby had left Newark in 1887, but returned to the Weston Electrical Instrument Company in 1889. About 1900 he became chief engineer and superintendent of the Baker Platinum Works in that city, retiring from this position in 1930, although he continued as consulting engineer and secretary until his death. Mr. Colby was also a member of the American Chemical Society, Society of Chemical Industry, and American Electrochemical Society.

Lawrence Dorsy Bale (A'10, M'26) superintendent of power, Cleveland Railway Company, Cleveland, Ohio, died May 16, 1935. He was born at Louisville, Ky., January 22, 1882, and studied electrical engineering at Rose Polytechnic Institute. He was employed by the Western Union Telegraph Company in 1899 at Louisville, and in 1901 went to St. Louis, Mo., where he was employed by the United Railways Company. In 1908 he was employed in Cleveland, Ohio, by the Municipal Traction Company, later the Cleveland Railway Company. While superintendent of substations for this company Mr. Bale made an extensive study of automatic substations, and in 1919 the first automatic substations for metropolitan service were installed. In 1923 the first comprehensive remote supervisory control system was designed and installed in connection with these substations. Mr. Bale was appointed superintendent of power in 1925. He was the author of an Institute paper on automatic substations and at the time of his death was a member of the automatic stations committee of the Institute, on which he served since 1928. During 1922–23 he was chairman of the Cleveland Section, and since then had served on the Section's advisory board. Mr. Bale was also a member and past-president of the American Transit Engineering Association, now the American Transit Association.

Talbot Grant Martin (F'32) president, Associated Electric Laboratories, Inc., Chicago, Ill., died April 10, 1935. He was born in Cumberland County, Pa., October 6, 1865, and in 1889 entered telephone work with the Chicago Telephone Company. In 1893 he became connected with the Strowger Automatic Telephone Exchange, a manufacturing company, and from 1901 to 1931 was with the Automatic Electric Company and Automatic Electric Incorporated. In 1931 he became vice president and director of development and research of Associated Electric Laboratories, Inc., and subsequently president. Mr. Martin had been actively engaged in the design of Strowger automatic telephone systems since 1893, and was recognized as a leading authority in this work. In the period from 1904 to 1926 there were issued to him 105 United States patents covering telephone systems and apparatus, representing many important practical advancements. The success of the Strowger automatic system, which is widely used in the United States and foreign countries, is credited largely to his inventive genius. Among his developments were arrangements for trunking between manual and automatic exchanges and a system for transmitting music over subscribers' lines which would be cut off by a telephone call.

Charles Frederick Lacombe (A'06, M'09, F'13) consulting engineer, Babylon, N. Y., died May 26, 1935, one day before his seventieth birthday. He was associated with W. S. Leffler (A'24) in a consulting practice with headquarters in New York, N. Y. Mr. Lacombe was born at New York May 27, 1865, and graduated from the Columbia University School of Mines in 1885. After several years of mining work in western states he was engaged in enlarging and operating an electric light plant in Colorado, and at this time, in 1890, formed the Mountain Electric Company, for which he acted as president, general manager, and electrical engineer. The company erected a number of electric power plants in Colorado, New Mexico, and Utah, and with the development of long distance transmission about 1895 built some of the first long lines. In 1901 a plant he designed for street lighting in Denver, Colo., was completed, and shortly afterward Mr. Lacombe went to New York, where he took charge of the lighting bureau of the city in January 1903. Other

duties subsequently added led to the title of chief engineer of light and power, with charge of the lighting and electrical inspection in the 5 boroughs of the city. In 1915 Mr. Lacombe became a consultant in rate cases and street lighting, but 2 years later entered military service. In 1918 he was assigned to the power section of the War Industries Board at Washington, D. C., and was executive assistant to the power director of the United States. Two years later he wrote the report of the National Electric Light Association on national power resources, and in 1921 became director of economics and statistics for the Brooklyn Edison Company, Brooklyn, N. Y. After 6 years in this position he again engaged in consulting practice at New York. Mr. Lacombe was also a member of The American Society of Mechanical Engineers, Illuminating Engineering Society and other technical organizations.

Charles Newbold Black (A'90 and member for life) vice president, Ford, Bacon and Davis, Inc., San Francisco, Calif., died May 15, 1935. He was born at New York, N. Y., March 16, 1867, and attended Princeton University, from which he received the degrees of bachelor of arts and electrical engineer in 1888 and 1890, respectively. Mr. Black was general superintendent of the Brush Electric Company, Cleveland, Ohio, until he became connected with Ford, Bacon and Davis at New York in 1899 as an engineer, and in 1905 became vice president and general manager of the Kansas City Railway and Light Company. Two years later he undertook similar duties with the United Railroad of San Francisco, becoming president of its successor, the Market Street Railway, from 1922 to 1925. During 1916–18 Mr. Black was head of the export department of J. P. Morgan and Company, negotiating contracts for war supplies, and later was a colonel of ordnance on the staff of General Pershing. He had been a trustee of Princeton University, and was a member of the University, Engineers, and Princeton clubs of New York, and the Pacific Union, Bohemian, and University clubs of San Francisco.

Basil Lanphier (A'18, M'22) American Gas and Electric Company, New York, N. Y., died in April 1935. He was born at Lohrville, Iowa, and received the degree of bachelor of arts at Creighton University, Omaha, Neb., in 1912. The following year he entered Massachusetts Institute of Technology, where he received the degree of bachelor of science in electrical engineering in 1916. He was then engaged in maintenance work for the Bethlehem Steel Company, Lebanon, Pa., until 1918, becoming assistant to the chief engineer. In that year he accepted the position of assistant engineer with the Interborough Rapid Transit Company, New York, N. Y., and 2 years later was appointed electrical research engineer in charge of power station and substation tests and purchase of various equipment. Since 1923 he had been connected with the American Gas and Electric Company. Mr. Lanphier was a co-author of a 1932 Institute paper on automatic equipment on the American Gas and Electric system.

Eli Judson Blake (A'04) partner, Blake and Van Nieukerken, Philadelphia, Pa., died May 17, 1935. He was born at Newark, N. J., June 2, 1879, and received the degree of bachelor of arts from Princeton University in 1901, after which he was employed in the apprentice courses of the Westinghouse Electric and Manufacturing Company and the General Electric Company. In 1904 he entered the electric department of the New York Central Railroad at New York, N. Y., being assistant engineer in 1913 when he accepted a position as electrical engineer with the Hall Switch and Signal Company, Garwood, N. J. He became electrical engineer for the Gould Coupler Company, Depew, N. Y., engaging in the development of apparatus for train lighting, in 1917, and in 1926 continued this work with the Gould Car Lighting Company, Rochester, N. Y. Two years later he became car lighting engineer for the American Brown Boveri Electric Company at Camden, N. J., and a year later was appointed general engineer. Since 1930 he had been engaged in consulting engineering.

Frederick Louis Pierce (A'10) director, Cutler-Hammer, Inc., Milwaukee, Wis., died April 16, 1935. He was born at Milwaukee July 8, 1860, and after several years manufacturing experience became treasurer of The Cutler-Hammer Manufacturing Company in 1897, retaining this position until 1929. From 1903 to 1909 he was also treasurer of the Bliss Electric Car Lighting Company, Milwaukee, and for several years was treasurer of the National Battery Company, Buffalo, N. Y. In addition to his directorship of Cutler-Hammer, Inc., Mr. Pierce was a director of the Marine National Exchange Bank, Schweitzer and Conrad, Inc., and Columbia Hospital, and a trustee and member of the finance and executive committees of the Northwestern Mutual Life Insurance Company.

J. Logan MacBurney (A'15) sales engineer, the Electric Storage Battery Company, Philadelphia, Pa., died May 26, 1935, 2 weeks after his election as chairman of the Philadelphia Section for the coming year. Mr. MacBurney was born at Philadelphia April 7, 1890, and graduated from the electrical engineering department of the University of Pennsylvania in 1911, when he entered the construction department of the Electric Storage Battery Company. In 1915 he was transferred to the engineering department, and since 1922 he had been sales engineer. For the past 6 years Mr. MacBurney had been secretary of the Institute's Philadelphia Section, and on August 1, 1935, he would have assumed the office of chairman.

James Simcoe Fitzmaurice (A'93, M'94, and member for life) consulting electrical and mechanical engineer, Adelaide, South Australia, died in April 1935. He was born at Victoria in 1861, and was for many years assistant electrical engineer in the Postmaster Generals Department at Sydney, having previously been chief engineer in the light branch at Balmain, New South Wales. In 1912 Mr. Fitzmaurice became electrical engineer in the Postmaster Generals Department at Perth, West Australia, and in 1919 was appointed state engineer at Adelaide, South Australia. Since 1928 he had been engaged in consulting engineering. For many years Mr. Fitzmaurice was a local honorary secretary of the Institute. He was also a member of the Institution of Electrical Engineers of Great Britain.

Arthur Jean Townsend (A'10) executive vice president, Rotary Electric Steel Company, Detroit, Mich., died June 1, 1935. He was born at Apollo, Pa., October 5, 1887, and in 1909, after study at Ohio University, became connected with the Canadian Sheet Steel Corporation, Morrisburg, Ont., Can. Two years later he was employed by the Portsmouth Steel Company, Portsmouth, Ohio, until he became electrical engineer for the Berger Manufacturing Company, Canton, in 1914. In 1917 he became vice president and works manager of the National Pressed Steel Company, Massillon, and in 1922 vice president of The Columbia Steel Company, Elyria. For several years following 1927 he was a consulting engineer at Canton.

Norman James Wilson (A'02) electrical engineer, J. G. White and Company, London, England, died July 31, 1934, according to word just received at Institute headquarters. He was born at Stockport, England, November 5, 1873, and received his technical education at Bristol and London. In 1900 he became connected with the British Westinghouse Electric and Manufacturing Company, and for a time studied American methods and practices at the East Pittsburgh, Pa., plant of the Westinghouse Electric and Manufacturing Company. He later engaged in consulting engineering in Liverpool until assuming the position of electrical engineer with J. G. White and Company in 1913.

John G. Kleindienst (A'30) sales engineer, Delano Coal Company, New York, N. Y., died recently. He was born at Mahanoy City, Pa., October 10, 1900, and received the degree of bachelor of science in electrical engineering at Drexel Institute in 1928, having previously been employed for short periods of time by the General Electric Company at Philadelphia, Pa., and by the Pennsylvania Power and Light Company. Prior to his position with the Delano Coal Company he had been employed by the Brooklyn Edison Company, Brooklyn, N. Y.

James Francis Greene (A'27) Los Angeles, Calif., died in February 1935. He was born at Blackstone, Mass., August 18, 1899, and received the degree of bachelor of science in the electrical engineering course at Rhode Island State College in 1922. He then entered the employ of the Victor Talking Machine Company, being located at Camden, N. J., and Buenos Aires, Argentina, until he went to Culver City, Calif., in 1929 as recording supervisor at Hal Roach Studios, Inc.

Membership

Recommended for Transfer

The board of examiners, at its meeting of June 19, 1935, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Member

Brouwers, Peter W., div. plant engr., New England Tel. & Tel. Co., Providence, R. I.
Burris, Harry L., master mechanic, Great Western Electro-Chemical Co., Pittsburg, Calif.
Card, Read H., engr., American Tel. & Tel. Co., New York, N. Y.
Champe, Willard, editorial dept., A.I.E.E., New York, N. Y.
Eilerman, Louis H., asst. supt., testing labs., City of Los Angeles, Bureau of Power & Light, Los Angeles, Calif.
Fetzer, John E., pres., WKZO, Inc., Kalamazoo, Mich.
Fort, Tomlinson, central sta. repr., Westinghouse Elec. & Mfg. Co., New York, N. Y.
Hartung, Arthur F., assoc. engr., Burns & McDowell Engg. Co., Kansas City, Mo.
Howard, Alan, engr., General Electric Co., Schenectady, N. Y.
Morgan, Alva B., rate and pwr. consultant, Edison Electric Institute, New York, N. Y.
Mueller, George V., asst. prof. of elec. engg., Purdue University, W. Lafayette, Ind.
Murray, John M., elec. engr., Simplex Wire & Cable Co., Cambridge, Mass.
Purnell, Clayton S., transportation repr., Westinghouse Elec. & Mfg. Co., New York.
Ransom, Glen B., engg. employee, American Tel. & Tel. Co., New York, N. Y.
Rivers, Fabian N., technical employee, American Tel. & Tel. Co., New York, N. Y.
Schlossberg, Victor E., asst. supt. elec. & pwr. depts., Inland Steel Co., E. Chicago, Ind.
Sterbis, Ernest J., member, technical staff, Bell Telephone Labs. Inc., Deal, N. J.
Taylor, Frank W., high voltage engr., Hollinwood, England
Tripp, William A., engr., Jackson & Moreland, 31 St. James Ave., Boston, Mass.

19 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before July 31, 1935, or Sept. 30, 1935, if the applicant resides outside of the United States or Canada.

Ackley, O. B., S. S. White Dental Mfg. Co., Princess Bay, Staten Island, N. Y.
Ahlquist, R. W., Univ. of Pittsburgh, Pittsburgh, Pa.
Alexander, E. L., 504 West 135th St., New York, N. Y.
Atwood, P. W., R. F. D. No. 2, Windsor, Vt.
Baily, O. Q. (Member) American Tel. & Tel. Co., New York, N. Y.
Baines, L. E., Central Stamping Co., Newark, N. J.
Baumsweiger, B., Univ. of Cincinnati, Cincinnati, Ohio.
Bergdahl, M. A., Okonite Co., Detroit, Mich.
Berger, W. R., United Elec. Lt. & Pwr. Co., New York, N. Y.
Boyd, S. F. Jr., Black Point Inn, Prout's Neck, Me.
Brown, C. E., Driggs Ordnance and Engg. Co., New York, N. Y.
Callahan, J. L. (Member), R. C. A. Communications, Inc., New York, N. Y.
Carroll, S. O., Union Gas & Elec. Co., Cincinnati, Ohio.
Clarke, T. C., Northern Elec., Vancouver, B. C., Can.
Cole, O. I., American Tel. & Tel. Co., Cleveland, Ohio.
Cotman, C. A., Chain Products Co., Cleveland, Ohio.
de Villa, F., c/o M. del Corral & Co., New York, N. Y.
Dalton, J. P., 51 W. 170th St., New York, N. Y.
Downing, W. C. Jr. (Member), Lincoln Meter Co., Springfield, Ill.
Duffy, G. E. Sr., General Railway Signal Co., Rochester, N. Y.
Farnum, P. T. (Member), American Tel. & Tel. Co., New York, N. Y.
Faust, C. A., Transit Journal, New York, N. Y.
Fifer, W. H., Naval Research Lab., Bellevue, D. C.
Gallagher, J. J., Standard Shipping Co., New York, N. Y.
Goldenberg, F., Pennsylvania Water & Power Co., Baltimore, Md.
Haglund, C. E., Pacific Gas & Elec. Co., San Francisco, Calif.
Helwith, E. E., 66 Worth St., New York, N. Y.
Hermanson, E. W., U.S. Naval Academy, Annapolis, Md.
Hertzler, E. A., Pratt Inst., Brooklyn, N. Y.
Holmes, W. M. (Member) Ventura Junior Coll., Ventura, Calif.
Jones, F. C., c/o B. F. Sturtevant Co., Hyde Park, Mass.
Kemerer, M. P., Southern Calif. Edison Co. Ltd., Alhambra.
Knoderer, C. L., American Tel. & Tel. Co., New York, N. Y.
Lane, C. A., 14 E. 80th St., New York, N. Y.
Lannert, K. E., Carter Carburetor Corp., St. Louis, Mo.
Liddy, C. E., All America Cables Inc., Cristobal, Canal Zone.
Malloy, C. T., 8019 So. Mariposa Ave., Los Angeles, Calif.
McDermott, J. A., Barr, Irons & Lane, New York, N. Y.
Miller, C. R., Village Hall, Winnetka, Ill.
Moore, R. K. Jr., Scranton Elec. Co., Scranton, Pa.
Murphy, J. J., 101 E. 31st St., Brooklyn, N. Y.
Newman, W. L. (Member), American Tel. & Tel. Co., New York, N. Y.
Organic, W. V., Carnegie Steel Co., Youngstown, O.
Plautz, A. C., 10358 Rosebury Place, Los Angeles, Calif.
Ponsolle, W. J., 73 W. 88th St., New York, N. Y.
Ring, I. P., Abbott Machine Co., Wilton, N. H.
Rink, K. S., U.S. Coast & Geodetic Survey, Jacksonville, Fla.
Rutherford, B. J. (Member), American Tel. & Tel. Co., New York, N. Y.
Sayres, D. B. Jr., Wirt Co., Philadelphia, Pa.
Santacruz y Carral, C., General Elec. S. A., Mexico, D. F., Mexico.
Short, B. H., Purdue University, West Lafayette, Ind.
Silver, H. S., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Stanwin-Hay, W. H., General Electric Co., Bridgeport, Conn.
Westcott, D. B., 7 East St., Northfield, Vt.
Whistler, J. K., 2612 N. E. 23rd, Oklahoma City, Okla.
Willson, A. R. (Member), Dept. of Public Wks., Olympia, Wash.
Woolley, H. W., Freshman Coll., Sandusky, Mich.
Yamashita, H., Hotel Kokumai, New York, N. Y.

58 Domestic

Foreign

L. E. Metz, G. Messrs. Metropolitan Vickers Elec. Co. Ltd., Manchester, Eng.
Shivapuri, P. R. N., Punjab Elec. Pwr. Co., Ltd., Gujrat, Lahore, India.

2 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the address as it now appears on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Bauer, Charles, 9 Royalton Place, Bloomfield, N. J.
Bock, F. S., 1642 W. Broad St., Richmond, Va.
Chiofalo, J., 203 Graham Ave., Brooklyn, N. Y.
Germenshausen, K. J., M.I.T., Dorm., Cambridge, Mass.
Golikoff, A., Main P. O. Gen. Del., Moscow, U.S.S.R.
Greene, F. M., 656—50th St., Brooklyn, N. Y.
Haddad, Raphael A., 500 Riverside Drive, N. Y. City.
Houston, Chas. E., 400—10th Ave., S. E., Minneapolis, Minn.
Kimball, Gordon S., 154 Elmer Ave., Schenectady, N. Y.
Martinoff, V. M., 2150 Queen St., Toronto, Ont., Can.
Nelson, Charles J., 1515 N. Lotus Ave., Chicago, Ill.
Rasmussen, David, 423 Hickory St., Ridgway, Pa.
Roman, Walter G., 511 Pitt St., Wilkinsburg, Pa.
Rozelle, P. M., 2018 Chestnut St., Harrisburg, Pa.
Schellberg, Kenneth O., 4115—51st St. S., Seattle, Wash.
Schlosser, Walter H., Dominion Elec. Power, Ltd., Regina, Sask., Can.
Smedley, A. B., 82 Warner Ave., Hempstead, N. Y.
Thomson, W. L., 3630 Spruce St., Philadelphia, Pa.
Verrier, E. J., Anglo Newfoundland Dev. Co., Grand Falls, Newfoundland.
Watson, J. Connell, 69 Cambridge Terrace, London, W. 2, Eng.

20 Addresses Wanted

Engineering Literature

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

HOT WATER and STEAM SUPPLY by ELECTRICITY. By F. C. Smith. Lond., E. & F. N. Spon, Ltd.; N. Y., Engineers Book Shop, 1934. 142 p., illus., 9x6 in., cloth, $3.50. An explanation of the thermal and electrical fundamentals, with description of various types of apparatus and their installation.

Introduction to ELECTRIC TRANSIENTS. By B. B. Kurtz and G. F. Corcoran. N. Y., John Wiley & Sons, 1935. 335 p., illus., cloth, $4.50. A text for class use giving an account of transient disturbances in both a-c and d-c circuits of varying degrees of complexity.

MARKETING INDUSTRIAL EQUIPMENT. By B. Lester. N. Y. and Lond., McGraw-Hill Book Co., 1935. 307 p., illus., 9x6 in., cloth, $3.50. An outline for a study of the distribution of capital goods of an engineering nature from the manufacturer to the ultimate user, discussing market and product analysis, economic distribution principles, and organization and operation of sales departments and sales outlets.

MECHANIZATION in INDUSTRY. By H. Jerome. N. Y., National Bureau of Economic Research, 1934. 484 p., illus., 9x6 in., cloth, $3.50. The nature and the results of progressive mechanization, and its social and economic consequences, are discussed at length, and much detail as to actual changes is presented.

PRACTICAL SOLUTION of TORSIONAL VIBRATION PROBLEMS. By W. K. Wilson. N. Y., John Wiley & Sons, 1935. 438 p., illus., 9x6 in., cloth, $7.00. The principles and computation details of torsional vibration in a manner suitable for everyday reference, with illustrative examples.

PROCEEDINGS of the FOURTH INTERNATIONAL CONGRESS for APPLIED MECHANICS, Cambridge, Eng., July 3–9th, 1934. Univ. Press, Cambridge, 1935. 283 p., illus., 11x7 in., cloth, £1. The 7 general lectures delivered at the congress including recent progress in analyzing machines, and vibration and turbulence problems.

PUBLIC UTILITY VALUATION for PURPOSES of RATE CONTROL. By J. Bauer and N. Gold. N. Y., Macmillan Co., 1934. 477 p., 9x6 in., cloth, $3.50. A comprehensive discussion of utility valuation, including economic and legal fundamentals, practical methods pursued, procedural aspects of valuation, and present system of rate regulation.

TABLES and OTHER DATA for ENGINEERS and BUSINESS MEN, compiled by members of the college of engineering of the University of Tennessee. Knoxville, U. of T. Co-operative Book Store. 139 p., tables, 6x3 in., lea., $.75. A convenient selection of mathematical, mechanical, and electrical tables and formulas which are constantly used by engineers.

THEORY of ALTERNATING CURRENT WAVE FORMS. By P. Kemp. Pittsburgh, Instruments Pub. Co., 1935. 218 p., illus., 9x6 in., cloth, $4.50. A discussion of nonsinusoidal waves, presenting the facts necessary for proper understanding, with short bibliographies to guide further study.

VDI JAHRBUCH, Die Chronik der Technik Berlin, VDI-Verlag, 1935. 183 p., 8x6 in., paper, 3.50 rm. A series of concise reports upon scientific and technical developments during 1934, with references to the original publications.

THOMAS' REGISTER of AMERICAN MANUFACTURERS. 25 ed. 1935, the Largest Classified Reference Book in the World. N. Y., Thomas Pub. Co., 1935. 10,914 columns, illus., 12 x 9 in., cloth, $15.00 (to advertisers and renewal subscriptions $10.00). A directory of manufacturers, manufactured products with the name of the makers, and trade names, with the addition of banks, commercial institutions, and trade papers.

Industrial Notes

Large Orders for Westinghouse.—The Westinghouse Elec. & Mfg. Co. has received an order totaling $299,000 from the J. G. Brill Co., of Philadelphia, for the Delaware River Bridge Joint Commission. The electrical equipment consists of four 100 hp motors and automatic electropneumatic battery control, and also includes the panels, fans, and other electrical accessories.

Another order, amounting to $100,000, covers the motor and control equipment for a new 42 inch reversible cold strip mill of the Republic Steel Co., at Warren, O., and includes a 1200 hp mill motor and two 300 hp reel motors.

American Sheet Promotions.—According to a recent announcement, O. E. Romig, former metallurgist, Gary sheet mill, has been appointed manager of the electrical sheet division of the American Sheet & Tin Plate Co., Frick Bldg., Pittsburgh. James B. Barton has been appointed sales engineer of the electrical sheet division, at Pittsburgh. He was formerly associated in a similar capacity with the Empire Sheet and Tin Plate Co., Mansfield, O.

Rockbestos Promotes Redfield.—Kendall A. Redfield, advertising manager of the Rockbestos Products Corp., New Haven, Conn., manufacturers of asbestos insulated electrical wires and cables, has been made assistant general sales manager. Herbert O. Anderson is general sales manager.

Owens-Illinois Glass Promotions.—Stanley J. McGiveran has been appointed to the position of manager of sales merchandising. W. M. Gates has been advanced to the position of assistant to the general sales manager. T. K. Almorth, as advertising manager, will continue to direct the advertising of the various divisions, together with glass block, Hemingray insulators, and industrial materials.

Smaller O-B Universal Strain Clamp.—The Ohio Brass Co., Mansfield, O., announces that it has extended the economy of its universal strain clamp by introducing the baby universal clamp. In principle of design this new strain clamp is exactly like the larger O-B universal. The primary snub, in combination with a modified "V" wire groove and a positive clamping member, makes this smaller clamp applicable to the range of conductor sizes and types used on rural electrification. It will take No. 6 to No. 2 solid or stranded cables. The only difference in the two universal strain clamps are size and cost.

Automatic Synchronous Device.—The Allis-Chalmers Manufacturing Co., Milwaukee, has placed on the market the "Synchro-Operator," an automatic control device which eliminates all human element and performs rapidly the combined functions of speed matching, synchronizing, and visual phase angle indicating; these formerly required a frequency matcher, an automatic synchronizer, and a synchroscope. The "Synchro-Operator" is not much larger than the usual synchroscope and can be mounted on a swinging bracket. It accurately synchronizes generator and bus even if there is a voltage difference and it is satisfactory for both stable and erratic frequencies. The control closing instant is advanced (at a phase angle proportional to the difference in frequency) to compensate for the inherent time lag in circuit breakers, thus making the breaker close at the exact point of synchronism. One "Synchro-Operator" will serve any number of generators and can be used in connection with existing governor control motors and station circuit breakers. It consumes little energy, operates through standard potential transformer metering circuits, requires no special features on prime mover or generator, and contains no vacuum tubes.

Trade Literature

Aluminum and Alloys.—Booklet, 92 pp., "Alcoa Aluminum and Its Alloys." Presents in concise form fundamental information concerning aluminum alloys now available. An appendix includes numerous tables showing physical properties, composition, dimension tolerances, commercial sizes stocked, etc. Aluminum Co. of America, Gulf Bldg., Pittsburgh, Pa.

Pyranol Capacitors.—Bulletin GEA-77H, 28 pp., "Improving Power Factor for Profit." Describes four general types of Pyranol capacitors for power factor improvement over a wide range of service conditions and for indoor and outdoor applications. General Electric Co., Schenectady, N. Y.

Power Cables.—Bulletin, 16 pp., "Advance in Cable Design." Describes the improvements in the design and manufacture of paper insulated power cable which incorporates in its construction part or all of the following features: "compack" strand, super-dense paper, Chase shielding tape, metal binder tape, interlocking of metal tapes, and CO_2 gas treatment. General Cable Corp., 420 Lexington Ave., New York City.

Surge-Crest Ammeter.—Bulletin GEA-1934A, 4 pp. This surge-crest ammeter equipment measures magnitude, polarity, and amount of oscillation of current surges and is readily adapted to cover any desired current range between 300 and 70,000 amperes. It is particularly valuable for the measurement of lightning surges in transmission- and distribution-circuit conductors and structures. General Electric Co., Schenectady, N. Y.

Cable Laying Plow.—Folder. Extensive trenching and backfilling is eliminated with this device; cable up to $1^1/_4$ inch can be laid at a depth of from 16 to 20 inches without danger of damage to the cable. Two cables up to 1 inch diameter can be entrenched in a single operation. The plow can be handled by four men and may be pulled by either truck, winch, portable winch, or tractor. Philadelphia Electrical & Mfg. Co., 1222 No. 31st St., Philadelphia, Pa.

Electric Water Gage.—Bulletin 351. Describes the new Millipoint electric water gauge, a self-contained portable device supplanting the old hook gauge for measuring water level, and developed by R. C. Burt Scientific Laboratories in co-operation with engineers of the United States Forest Service. The advantages outlined include compactness, portability, precision, identical results obtained by different observers, speed in taking readings, wide range, and the fact that no illumination is necessary at the water surface. R. C. Burt Scientific Laboratories, Pasadena, Calif.

Lightning Arresters.—Catalog 381, 92 pp. According to the foreword the bulletin not only covers the complete line manufactured by this company, but contains a wealth of technical information on the subject of lightning protection in general. The equipment described includes crystal valve lightning arresters for both high and low voltage a-c service and for low voltage d-c service; crystal valve tank type arresters; neutral arresters and co-ordinating gaps; Garton-Daniels lightning arresters for low voltage a-c and d-c service and for high voltage d-c railway service; ground testing equipment and ground fittings. Electric Service Supplies Co., 17th & Cambria Sts., Philadelphia, Pa.

Cable Accessories.—Bulletin GEA-1839, 92 pp. As a companion book to bulletin GEA 1731 "How to Make Cable Joints" issued last year, a new G-E publication, bulletin GEA-1839 "Cable Accessories" is now available. The two books should be of interest and assistance to those engaged in work that involves the jointing and terminating of insulated cable. GEA-1731 gives clear and concise instructions for splicing, jointing, and terminating all types of insulated cable. The bulletin on "Cable Accessories" describes all the materials required for this work—joints, connectors, terminals, reservoirs, etc., and includes prices. General Electric Co., Schenectady, N. Y.

Insulation Testing.—Pocket Manual of "Megger" Practice, 128 pp. According to the sponsor this new manual is devoted to the subject of electrical insulation as it concerns those who are responsible for the installation, care, and maintenance of practically all types of electrical apparatus and is intended to be up to date and comprehensive as far as the testing of insulation resistance is concerned. Also, the new manual does not render obsolete the previous editions bearing a similar title (dating back as far as 1923). It is intended to amplify the subject of insulation testing in a manner which should be appreciated by those having to do with this fundamental factor in electrical equipment. James G. Biddle Co., 1211 Arch St., Philadelphia, Pa.

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Seattle, Wash., host city to the Institute's 1935 Pacific Coast convention, August 27–30, as viewed from the city's waterfront

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In This Issue—

REPORTS of the different activities at the Institute's recent successful summer convention at Ithaca, N. Y., June 24–28, have been prepared and made available to the membership. The general features of the convention, including the annual business meeting, presentation of the Lamme Medal, entertainment, and sports included many items of interest (*pages 891–5*). The annual conference of officers, delegates, and members brought forth many illuminating discussions on affairs of importance to the Institute (*pages 898–901*). An innovation this year was the holding of informal round table discussions, called "technical conferences," in addition to the regular technical sessions; these conferences made possible a wide dissemination of information (*pages 901–7*).

ULTRA-HIGH frequencies are particularly useful for radiotelephone communication systems in relatively small areas. In the Hawaiian interisland system frequencies between 30 and 60 megacycles per second are used (*pages 822–8*); in the Puget Sound (Wash.) area, frequencies between 2 and 3 megacycles are used for communication between land and harbor craft (*pages 828–31*). Frequency control for the transmitters used in this type of service is provided conveniently by the use of resonant lines (*pages 852–7*).

REGISTRATION of engineers is a subject of considerable current interest. The principal arguments for registration, which means examination and ratification by legally authorized state boards of engineering examiners, are set forth in detail by Dr. D. B. Steinman, one of the leading exponents of registration (*pages 876–81*). A few additional comments on registration were made by L. W. W. Morrow during the recent summer convention of the Institue at Ithaca (*page 899*). Contributions commenting on Doctor Steinman's address, which was presented at the summer convention, are being received and in so far as possible will be published in the "Letters to the Editor" columns of future issues.

MANUFACTURERS of oil-impregnated paper-insulated cables have made practical use of insulation research by applying the findings directly to their manufacturing processes. The result—cables of improved and more uniform quality which enable users to obtain more satisfactory operating results and to effect substantial savings at the same time (*page 816–21*).

PHOTOGRAPHS of all officers of the Institute who took office August 1, 1935, are reproduced in this issue (*page 897*). The president holds office for one year, the 5 vice presidents for 2 years each, and the 3 directors for 4 years each. In addition to these newly elected officers there are 18 hold-over officers, whose photographs have been given in previous years.

LAST call for the Institute's Pacific Coast convention to be held at Seattle, Wash., Aug. 27–30, 1935, is being made. The schedule of events, technical program, and entertainment and other features were outlined in the July 1935 issue of ELECTRICAL ENGINEERING, pages 783–4. A few additional details are given in the present issue (*pages 895–6*).

THE increase in corona losses on high voltage transmission lines due to the grounding of one conductor on a system not having the neutral solidly grounded may affect the operation of Petersen coils. Tests have been made on a 230 kv line showing the increase in corona losses under certain conditions of operation (*pages 846–7*).

DIESEL-electric motive power is coming into rapidly increasing use on railroads. Although the further substitution of Diesel power for steam power is indicated, performance characteristics must be considered for each type of application. In switching service, the Diesel engine has an immediate field of application (*pages 863–5*).

MEASUREMENTS of the time lag of spark-over of sphere gaps made with a newly developed instrument show that spark lags fall into 3 distinct domains. A study of the data has made possible a better understanding of the theory of spark-over (*pages 868–76*).

PLANS for accrediting engineering schools in New England and the Middle Atlantic states have been completed by the Engineers' Council for Professional Development, which intends to extend the accrediting procedure throughout the entire country as soon as feasible (*page 895*).

A NEW design of coupling capacitors for conducting high frequency carrier current to high voltage power transmission lines has been developed. By combining 1 to 4 units in series, the capacitor may be used on 69, 138, 230, or 287 kv circuits (*pages 848–52*).

MANY problems in voltage regulation on distribution systems can be solved most economically by installing regulating devices on portions of the system beyond the substations; this is particularly true where load growth is nonuniform (*pages 832–7*).

CORRELATION of laboratory tests with the effects of lightning on electric power lines and equipment shows that lightning currents may be as high as 150,000 to 200,000 amperes with durations of from 40 to 100 microseconds (*pages 837–43*).

RESEARCH investigations in the field of radio communication indicate that rapid progress has recently been made in this field. A bibliography totaling 104 items has been compiled, giving references to the principal articles in this field (*pages 843–6*).

5 NEW elementary particles of matter were discovered by physicists during the 3 years 1931–34; these are discussed in this issue by a noted authority (*pages 808–16*).

AN instrument has been developed that is said to offer a better means of correlating radio interference measurements with interference effects (*pages 857–62*).

A Message From the President

Fellow Members of the American Institute of Electrical Engineers—

WHEN men find themselves the recipients of honors which their associates have bestowed upon them, I am sure that the emotion is always that which I feel as I endeavor to express my appreciation for having been chosen to serve the Institute as its president for the ensuing year. That feeling is one of wishing that you might fully comprehend what is in the heart of one newly elected to the highest office of our Institute and not be misled by the utter inadequacy of words to convey thought.

The emotion is one of mingled elation and humility. I could not receive so high an honor at your hands without being lifted up in spirit, but at the same time, there comes, with the realization of the obligation, a hope that I may be privileged to sustain that high quality which has ever characterized the Institute and its work and by which it has been known throughout the world.

Edward Bernard Meyer
A.I.E.E. President 1935–36

It has been my pleasure and privilege to have had direct contact with many activities which make up the routine of the Institute's every day work. Such duties as have been assumed throughout the years, on matters concerning the technical, financial, and administrative activities of our society's life, have each in turn brought their own reward for whatever of time and effort was given. For the most part, recompense has come out of the association with so many of the members, representing all phases of our professional life and all branches of industry.

It is with a very sincere feeling of gratefulness for this experience, for these opportunities to feel the pulse of things that concern us, that I look forward to the coming year and accept the responsibility for conducting as ably as I can the affairs of the Institute.

The American Institute of Electrical Engineers like all similar professional groups has passed through trying times and is not yet in all respects free of care. New problems confront us, many perhaps because of the fact that horizons are widening through effort and scientific work of our own and allied professions. But such conditions bring greater opportunities for service by people in all walks of life and I am proud of the extent to which engineers are equipped and ready to take the lead in all forward-looking movements.

Co-operation, then, on the part of all of those who understand the true significance of fellowship in such an engineering fraternity as the Institute, which represents but one aspect of our great engineering profession is vital—if our aims and purposes, our ideals, are to be realized.

The contribution that has been made by those who have been identified with the Institute from the time of its founding more than 50 years ago is today immeasurable. The services of these men have consistently furthered those things for which the Institute has always stood professionally and culturally.

Accomplishment in such an institution is the more permanent if consistently onward and upward with ideals held high regardless of the stress under which we have to carry on. It would, therefore, be my wish that with your help and counsel, throughout the coming months, we may find at the end of the year that we have placed on the Institute's curve of progress a point which not only maintains the slope of the curve at the correct value but reaches so high as to be beyond our greatest hope. There is no failure except in no longer trying.

I am confident that with your co-operation the affairs of the Institute will be conducted in such a manner that the end of the year will mark another period of distinguished service to the engineering profession.

The Newly Discovered Elementary Particles

By KARL K. DARROW, Associate A.I.E.E.
Bell Telephone Laboratories, Inc., New York, N. Y.

AS LATELY as 4 years ago—up to the autumn of 1931, to be precise—the only material or electrical particles recognized to be smaller than the known chemical atoms were the nuclei of these very atoms, and the negative electrons which link themselves with these nuclei to form the atoms or which alternatively wander as free corpuscles through metals or gases or empty space. In respect of mass, the lightest of these particles is the negative electron, and after it follow the nuclei of the known atoms in order of increasing weight. Thus as lately as 1931, the table of the known subatomic particles in order of increasing mass began in this way:

1. The negative electron.
2. The nucleus of the ordinary hydrogen atom, called the "proton."
3. The nucleus of the ordinary helium atom, called the "alpha particle."

After the alpha particle followed the nuclei of all the known isotopes of the heavier elements, already very abundant and now more numerous yet; before the alpha particle, however, came only the negative electron and the proton. Three short years changed this situation to a degree extraordinary even for the present rapid pace of physics. By the summer of 1934, the 2 kinds of corpuscle which were known to precede the alpha particle in the smallness of their mass, and therefore almost certainly outrank it in their simplicity, were joined by a host of no fewer than 5 others. The third member of the foregoing list is the eighth of the contemporary table.

Since the word "elementary" may be taken to mean "simple," or "indivisible," or "ultimate," I hasten to make clear that I am using it in no such sense. It is altogether probable that some of these corpuscles, notably the electrons, are truly ultimate and indivisible (and yet, such a statement as this can never be perfectly proved!); but it is certain that others had best be considered composite, while for yet others—the proton and the soon to be mentioned neutron—the question is unsettled and acute. We may, however, believe with great confidence that some of these bodies are the ultimate particles out of which electricity and matter are built, while the rest are the simplest possible structures which can be built out of the ultimate particles. Considered in this light, the members of the latter class are as important for us to study as the members of the former. We are indeed concerned not merely with the ultimate particles as free and independent objects, but also and equally with the laws according to which they attach themselves to one another in forming ordinary matter. To ignore or undervalue these would be as unwise as to ignore the rules of organizing bricks and stones and beams into a building, and devote one's self entirely to measuring the weight and size of isolated beams and stones and bricks with all possible care. Now evidently it is the simplest possible building constructed out of given units of construction, from which we are likely to learn most readily the laws of the combination of these units. The simplest possible structure built out of the fundamental particles of the material world was formerly supposed to be the alpha particle; now it is superseded by several which are apparently still simpler, and all of them together merit our attention as much as do the particles which are still supposed to be the ultimate units of their structures.

Before writing down the list of the particles with which we shall have to do, it is desirable to recapitulate some rather dry information about the charges and the masses of atomic nuclei and the notation for expressing them. A chemical element may, and usually does, have more than one kind of atom. What all the atoms of a given element possess in common is a characteristic value of the nuclear charge. This value is positive in sign, and equal in magnitude to some integer multiple Ze of the electron charge e. The integer Z is called the "atomic number" of the element, and is prefixed as a subscript to the chemical symbol thereof, so that $_1$H denotes hydrogen, $_2$He helium, $_3$Li lithium, and so on. What distinguishes the different kinds of atoms of a given element is, that their nuclei differ in mass. Atoms of a particular mass are said to belong to a particular isotope of the element. The customary unit of mass in this field is $^1/_{16}$ *of the mass of an atom of the commonest isotope of oxygen* (it is about $1.65 \cdot 10^{-24}$ gram). In terms of this unit, the mass of any atom is found to be nearly an integer, i. e., to differ from some integer by an amount very much less than unity: This nearest integer is called the "mass number" of the isotope. The mass

During the 3 years following the discovery of heavy hydrogen in the latter part of 1931, 4 additional elementary particles of matter lighter than the alpha particle (nucleus of the ordinary helium atom) have been discovered where only 2 were known previously. This is considered extraordinary even for the present rapid pace of physics which sometimes requires physicists to revise their fundamental concepts of matter almost overnight. These 5 newly discovered particles formed the subject matter of a highly interesting and instructive address delivered recently by Doctor Darrow at a meeting of the Institute's New York Section; the essential substance of this illuminating address is presented herewith.

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number A is affixed as a superscript to the chemical symbol of the element, so that ${}_1H^1$ (or simply H^1) denotes that isotope of hydrogen of which the atomic mass is nearly equal to 1, ${}_2He^4$ (or He^4) denotes that isotope of helium of which the atomic mass is nearly equal to 4, and so on.

I now give the list of the 20 lightest particles—not counting photons, and not counting certain unstable radioactive atoms such as the one denoted by ${}_7N^{13}$—which are at present known (see accompanying tabulation). All but the first 3 are nuclei of chemical atoms, and their masses are known with such accuracy that of the 4 significant figures which I shall quote, all are certain excepting that the fourth may in some cases be wrong by not more than one unit. (This is in fact a decided understatement of the accuracy of the best known values.) Actually the values standing in the table are not the masses of the nuclei, but those of the corresponding atoms: Since the atom is composed of the nucleus and Z negative electrons, the reader may deduce any nuclear mass by subtracting Z times the electronic mass from the given datum. The chief reason for citing so many nuclei more massive than the alpha particle is, that they take part in or spring forth from reactions of transmutation in which the lighter nuclei also are involved. As for the first 3 particles of the list, values of atomic number and of mass number have been assigned also to them, though this action requires a broadening of both concepts. The mass of the negative electron is 0.000548, the last significant figure being certainly not wrong by more than one unit. The masses of the positive electron and the neutron are going to be discussed in the course of this article.

The Deuteron—
Nucleus of the Atom of Heavy Hydrogen

We now consider in succession the 5 newly discovered particles which appear among the 8 at the head of the list; and we begin with the "deuteron" (this name is proposed to supersede the earlier "deuton" and "diplon") which is the nucleus of the hydrogen atom of mass number 2, the second isotope of hydrogen which bears the name of "deuterium," is sometimes called "heavy hydrogen," and is sometimes denoted for convenience by the symbol D or ${}_1D^2$ instead of the natural ${}_1H^2$.

Heavy hydrogen, discovered in the autumn of 1931 and first reported to the world in the closing days of that year, proved itself so great an addition to the materials and the resources of chemist and of physicist alike (not to speak of the biologists) that in 3 years precisely it won for its discoverer the Nobel prize. It was not stumbled upon, it did not appear by some happy accident in the course of a research planned for other ends, as so often happens; it was deliberately sought after by Urey, who suspected it to be a scanty constituent of ordinary hydrogen, thought out a physicochemical method for concentrating it, applied the method with the aid of collaborators, and with them observed in the spectrum of the concentrated mixture a spectrum line distinctive of the new isotope. In ordinary hydrogen, there are more than 10,000 of the "light" atoms H^1 to every one of the heavy variety; yet by the spring of 1933, methods had been developed for concentrating the mixture—or, better expressed, for separating the heavy from the common isotope of hydrogen—so potent and efficient that samples of hydrogen, or of water or of other hydrogen compounds, in which the heavy atoms are more than a thousand times as abundant as the light ones, are frequently made and constantly used in laboratories. Indeed, it is asserted that samples of water have been made in which 99.99 per cent of the molecules are H^2H^2O instead of H^1H^1O, though there is now some doubt as to whether the criteria for estimating the relative amounts of the atoms H^1 and H^2 are as accurate as was thought. Such questions, however, do not affect us, and the voluminous knowledge of the chemical and physical properties of deuterium—already in 3 years and a half grown to the size of a small encyclopedia—does not concern us, so long as we are interesting ourselves in only the nucleus of the deuterium atom.

Table of the Lighter Elementary Particles

Arranged in order of increasing mass up to and including the 3 types of oxygen nuclei, and excluding certain unstable nuclei as well as corpuscles of light. The masses printed opposite nuclei are those of the corresponding atoms; the last significant figure quoted is almost certainly correct or at worst in error by not more than one unit

Atomic Number	Mass Number	Mass	Name
−1	0	0.000548	negative electron
+1	0	(cf. p. 815)	positive electron
0	1	1.008	neutron
1	1	1.008	proton
1	2	2.014	deuteron
1	3	3.016	H^3 nucleus
2	3	3.017	He^3 nucleus
2	4	4.003	alpha particle
3	6	6.016	Li^6 nucleus
3	7	7.017	Li^7 nucleus
4	9	9.014	Be^9 nucleus
5	10	10.01	B^{10} nucleus
5	11	11.01	B^{11} nucleus
6	12	12.00	C^{12} nucleus
6	13	13.01	C^{13} nucleus
7	14	14.01	N^{14} nucleus
7	15	15.01	N^{15} nucleus
8	16	16.00	O^{16} nucleus
8	17	17.00	O^{17} nucleus
8	18	18.01	O^{18} nucleus

Chemical symbols: H hydrogen, He helium, Li lithium, Be beryllium, B boron, C carbon, N nitrogen, O oxygen.

The Deuteron in Nuclear Chemistry; The Neutron

The charge of the deuteron is $+e$, since it is the nucleus of an atom which is an isotope of hydrogen. Its mass, determined as early as the spring of 1933, is 2.014. It plays a part in several very striking and important reactions of transmutation or of "nuclear chemistry," which I will presently describe, but not until after making some inferences from the mass and the charge of the deuteron.

The mass by itself would suggest that the deuteron is a pair of protons linked together. Such a combination however would not have the right charge; it must be completed by a negative electron—not, of course, an unwelcome supplement, since it might

supply the want of something to hold the protons together. Such a model was once the customary one, or at any rate would have been, had the deuteron been discovered sooner. Let us, however, make the hypothesis that the deuteron is made of a proton and a neutral particle, the latter of mass about equal to the difference (2.014 − 1.008) of deuteron mass and proton mass, about equal therefore to unity (the reader may expect me to say, *exactly* equal to the difference 1.006, but this would be wrong, for a reason later to be mentioned). Let us call this hypothetical particle the "neutron"; and let us inquire how the so-defined neutron might conceivably be observed.

First, it is conceivable that if a deuteron were to be projected with great energy against a massive obstacle—which would be, necessarily, a massive nucleus—it would break into a proton and a neutron, and the 2 would go separate ways. If a beam of fast deuterons were to be directed against a plate of, for example, lead, then protons and neutrons might be detected bounding back from the plate. Nothing of the sort has been observed, so far as I know, and so we will spend no more time over this possibility. It has, however, been observed that an impact of a deuteron against a corpuscle of light may lead to a separation of the 2 components; of this I will speak later.

Second, it is conceivable that if a deuteron were to be projected against another nucleus the neutron might stick to this nucleus, the proton go on by itself; and third, it is conceivable that in the same circumstances, the proton might stick and the neutron go on. Now, processes of both these kinds *have* been observed and can be produced at will. I describe some in detail.

Bombardment of Lithium by Deuterons Produces Heavy Lithium

A process of the second kind—the neutron sticking to the struck nucleus, the proton going on—would result in an elevation of the mass of the struck nucleus by about one unit, without any change in its charge. In other words, this process would transform the struck atom into an atom belonging to a different isotope of the original element, of mass number higher by unity than that of the original isotope. Here is an outstanding and thoroughly studied example. Lithium has 2 isotopes, Li^6 and Li^7 (their nuclei figure in our table), and after long labor it has been made possible to produce films of sufficient thickness (only a few atom layers are required) for the experiment, consisting almost exclusively of either isotope by itself. When a film of Li^6 is bombarded by a beam of fast moving deuterons, protons spring from the film: There is occurring the process,

$$_3Li^6 + {}_1H^2 \longrightarrow {}_3Li^7 + {}_1H^1 \qquad (1)$$

Deuterons are leaving their neutrons behind in the nuclei of the light isotope of lithium, which thus are becoming nuclei of the heavy isotope, while the protons originally attached to the neutrons go on by themselves.

If the arrow in equation 1 is replaced by the equals sign, we have what resembles an equation of ordinary chemistry, though it would have been unintelligible to the chemists of 25 years ago and incredible to those of 15 years ago: It is in fact an *equation of nuclear chemistry*. Considered as an algebraic equation, it balances in the atomic numbers (subscripts) and the mass number (superscripts). I shall be quoting several more, and yet they form only a minute fraction of the hundreds describing "nuclear reactions" which are already known.

One might expect to observe such a process whenever deuterons are used to bombard—as the term is—elements having 2 (or more) isotopes differing from one another by one unit in mass number. Additional instances of such elements in our table are boron, carbon, nitrogen, oxygen. Protons in fact are observed to spring from these elements whenever they are bombarded by energetic deuterons. It has not yet been possible to separate the isotopes of these elements so as to get "pure" films, and yet in the cases of carbon, nitrogen, and oxygen the lightest isotope is so greatly more abundant than the other or others, as to make it almost (not quite) safe to regard them for these purposes as consisting entirely of C^{12} and O^{16}. Another circumstance, later to be reviewed, stiffens the presumption that in all these cases the lightest isotope is being converted into the next lightest by absorbing neutrons from the bombarding deuterons: B^{10} into B^{11}, C^{12} into C^{13}, N^{14} into N^{15}, O^{16} into O^{17}. One of the most remarkable of these processes I postpone for the moment, and turn to the processes of the third kind, in which the proton sticks to the struck nucleus and the neutron goes onward.

Bombardment of Heavy Lithium by Deuterons Produces Helium

If the nucleus incorporates the proton into itself, both its mass number and its atomic number must ascend by one unit; it becomes not another isotope merely, but another element. We should be inclined to look for this to happen when adjoining elements (Z differing by one) have adjoining isotopes (A differing by one); boron of mass number 11 might readily—or so at least it seems—get transformed into carbon of mass number 12. As a matter of fact, neutrons have been observed emerging from boron bombarded by deuterons. But take a case like that of lithium, where the adjoining element ($_4Be$) has no adjoining isotope; if the heaviest nucleus of lithium ($_3Li^7$) were to absorb a proton, it would be converted into a nucleus which could be denoted only as $_4Be^8$, and it happens that in spite of very arduous and thorough searching, no isotope of beryllium of mass number 8 has ever been certainly proved to exist. Yet, the nucleus of the atom $_3Li^7$ can absorb a proton out of a deuteron, the neutron going on by itself; and what happens then, and in a number of similar cases, is very remarkable.

What happens in this particular case is described by the equation,

$$_3Li^7 + {}_1H^2 \longrightarrow {}_2He^4 + {}_2He^4 + {}_0n^1 \qquad (2)$$

Two nuclei of helium spring from the scene of the transmutation! (As also does the escaping neutron, here denoted by a symbol implying that its charge is zero and its mass is nearly unity.) It is as if the lithium nucleus, having absorbed a proton out of the impinging deuteron, had then and there exploded into a pair of identical fragments. It would have been a Be^8 nucleus had it been able to hold itself together, but it could not; it was essentially unstable, as the absence of Be^8 from the chemistry of the earth suggests.

Is there actually a nucleus of Be^8 which is created and enjoys a brief existence before it explodes into the pair of helium nuclei? All that can be said is, that if such a one there be its lifetime is too short to have been detected up to now. A more satisfactory answer can be given in several cases, of which here is a much studied and fairly well known example: the reaction, or rather the pair of consecutive reactions,

$$_6C^{12} + {}_1H^2 \longrightarrow {}_7N^{13} + {}_0n^1 \qquad (3a)$$

$$_7N^{13} \longrightarrow {}_6C^{13} + {}_1e^0 \qquad (3b)$$

The deuteron impinges upon the carbon nucleus, which lets the neutron escape but captures the proton, and becomes thus a nitrogen nucleus of mass number 13—not, however, a stable nucleus, for on the one hand no isotope N^{13} of nitrogen has ever been detected in nature except under circumstances such as these, and on the other hand these particular nuclei are positively known to be unstable and to break down of themselves, because the nitrogen resulting from this transmutation is *radioactive*. The N^{13} nuclei mostly survive for an appreciable time before the breakdown; their lives are not all equal, but are distributed according to the law of chance about a mean value; the mean life is several minutes. The eventual breakdown is described by equation 3b, in which occurs a symbol standing for a particle of atomic number 1 and mass number 0, therefore of charge $+e$ and mass nearly zero. This is a "positive electron," one of the newly discovered elementary particles of our table; here I make only a casual reference to it, leaving it to be properly introduced later on.

Very Heavy Hydrogen and Light Helium

It would be justifiable to make a list of all the unstable nuclei discovered in such experiments—including very many produced by bombarding various atoms with protons, with alpha particles, and above all with neutrons—and add them to the list of the elementary particles; but this would take much too long, and indeed this article would practically never end if I were to let myself stray *ad libitum* among the wonders of transmutation. It will be wisest to conclude this part with the reactions which generate 2 more of the elementary particles of our table, the third and fourth lightest of all atom nuclei and the 2 lightest discovered by transmutation. Suppose *deuterons projected* with great force *against deuterons* (the target might be hydrogen gas or water or any other hydrogen compound containing a multitude of H^2 atoms). Conceivably there might be a process in which a proton went off free while its neutron stayed with the other deuteron; or conceivably there might be a process in which a neutron went off free, leaving its proton with the other deuteron. The new particle would consist of 2 neutrons and a proton in the one case, 2 protons and a neutron in the other. The processes occur and the particles are observed. Here are the equations:

$$_1H^2 + {}_1H^2 \longrightarrow {}_1H^3 + {}_1H^1 \qquad (4)$$

$$_1H^2 + {}_1H^2 \longrightarrow {}_2He^3 + {}_0n^1 \qquad (5)$$

The particles are denoted by self-explanatory symbols. The atoms of which they are the nuclei may well be styled "very heavy hydrogen" and "light helium," respectively. They share the mass number 3, but actually their masses differ by just a little, an amount on the verge of the detectable; the best estimates are 3.016 for $_1H^3$ and 3.017 for $_2He^3$.

Nothing as yet has been said here about the experiments from which all these so definite and confident statements are derived; and while an even partway adequate description of the methods would take an article of great length, they must not be entirely omitted.

Detection of Fast-Flying Charged Particles

Almost the whole of our knowledge of subatomic and elementary particles—including our knowledge of radioactivity, of transmutation, and of cosmic rays—is based on the fact that *we can detect fast-flying charged elementary particles through various of their effects, especially the ionization which they cause in traversing a gas*. For the sake of completeness I mention that these particles may be detected by the flashes which they set off when hitting a fluorescent screen, or the imprints which they make upon a photographic film. It is, however, their effect of ionizing a gas which is most often observed.

When a sufficiently fast-moving particle of any of the kinds appearing in our table (*the neutron alone excepted!*) is projected across a chamber full of air or any other gas, it ionizes the gas by detaching negative electrons from some of the molecules near or through which it passes, thus leaving along the path which it followed a trail of freed electrons and of positively charged molecules—the "ions." The number of ions, or rather ion-pairs (a pair being one liberated electron and the molecule from which it was liberated) per unit length of the path, in air of ordinary density, depends somewhat on the speed of the particle but chiefly upon its nature: An alpha particle will produce some 30,000 in a centimeter, an electron only a few score, while the other elementary particles have each their characteristic value of ionization per unit length of path or "density of track." The detachment of each electron or formation of each ion-pair costs energy, which is paid out of the kinetic energy of the fast-flying particle; hence the particle moves ever more and more slowly as it drives ahead, and if the gas is deep enough its traceable path comes rather suddenly to an end. The length of the path—which in air of ordinary density is called the "range"—depends on the nature

of the particle and on the kinetic energy which this had when it started into the gas, and may be used to tell the latter if the former is known. Also the energy may be learned by applying a magnetic field to the region which the particle is traversing, and measuring the curvature which the field imprints upon its path. The latter is the direct way, and serves for calibrating the other; very accurate measurements are made upon the kinetic energy of (say) alpha particles of various carefully measured ranges, and out of these an energy-versus-range curve is plotted which enables future observers to learn all they need about energies from simply observing ranges.

Of the various ways for detecting this ionization, the most spectacular is the wonderful scheme of the Wilson expansion chamber or cloud chamber, in which droplets of water large enough to be seen are condensed upon the individual ions, converting the hitherto invisible paths of the fast-flying particles into visible trails of mist. The term "mist" may suggest that the trails are hazy or vague, but actually under good conditions they are sharp and fine, as though a gleaming thin wire had suddenly been stretched taut across the chamber of gas. The length of such a trail from beginning to end may be measured quite closely. A mere inspection of the trail often suffices to show to the practiced eye what the nature of the particle was; if not, this may be learned by repeating the experiment with some electrometric device which measures the total charge of all the electrons liberated along the path, therefore the total number and the number per unit length of path of the ions which the particle formed as it flew along. These observations jointly establish what the nature and the energy of the particle were. In such a way as this, the protons figuring on the right-hand side of equation 1 and the alpha particles on the right-hand side of equation 2 and the newly discovered particles on the right-hand sides of equations 4 and 5 were detected and were identified.

Not so, however, for the neutrons! The quality of being able to leave behind a trail of ions in a gas is confined to elementary particles which are *charged*. Positive corpuscles attract the negative electrons of the molecules near or through which they pass, negative corpuscles repel them; in either case it happens, with an oftenness indicated by the figures which I gave before, that the interaction results in a total expulsion of the electron from the molecular structure which was its home. Neutrons exert neither the one kind of force nor the other, and fly through meters of air without ever setting a single electron free. Not only the Wilson cloud chamber, but all the other methods for detecting the passage of a charged elementary particle, are completely futile.

How the Neutron Was Discovered

A totally uncharged particle of subatomic size is indeed a strangely evasive and surreptitious being; it has no optical, no electrical, no photographic effects; and neutrons would still in all probability be quite unknown as independent particles, were it not that when a stream of them is pouring through a solid or across a gas, a very few of them will strike so squarely against the nuclei of a very few atoms, that these nuclei take over a large share of their kinetic energy in an elastic recoil, and voyage onward themselves as fast-flying *charged* particles capable of producing all the effects of which I have been speaking. This occurs particularly well in hydrogen, for H^1 nuclei or protons have very nearly the same mass as a neutron, and by a well-known theorem of mechanics the exchange of energy between 2 elastic colliding particles is greatest when their masses are equal. Indeed, a perfectly central impact of a neutron against a proton entails the total transfer of the kinetic energy of the former to the latter, if the impact is perfectly central: One has thus only to select the proton-paths which are directed straight away from the neutron source, estimate from them the energy of the protons and identify it with that of the neutrons. The experiment may be performed by admitting the neutrons to a Wilson chamber containing hydrogen instead of air; best of all is to send them through a windowpane made of paraffin or some other solid material rich in hydrogen, for then they have ample opportunities to make such collisions, and great numbers of protons will leap out of the paraffin.

In this manner the neutron was discovered. The source, or what was later to be recognized as the source, was set close to an ionization chamber, i. e., a thin walled capsule filled with gas and equipped with a device for detecting and measuring the ionization in the gas; and it was observed that when a sheet of paraffin was slipped between the chamber and the source, the amount of the ionization in the chamber increased immensely. This observation was made by Joliot and Madame Curie-Joliot; the mysterious rays had earlier been detected by Bothe and Becker who had interpreted them as gamma rays—which is to say, as high frequency light—and this interpretation lingered on even after the Joliots had discerned the effect of paraffin, until it was supplanted with the proper one by Chadwick. The honor of discovering the neutron is thus to be divided among 3 nations and 5 physicists. Incidentally, the source in these experiments was a piece of beryllium which was being bombarded by alpha particles, in which consequently the following process was going on:

$$ {}_4Be^9 + {}_2He^4 \longrightarrow {}_6C^{12} + {}_0n^1 \qquad (6) $$

This was the first to be discovered of the nuclear reactions generating free neutrons, and is still ranked among the most prolific.

Nuclear Mass and Kinetic Energy

Something must now be said about mass and kinetic energy, since these 2 are closely interrelated in a way which confirms Einstein's great principle of the equivalence of mass and energy, which enables us to evaluate nuclear masses with a precision exceeding the 4 significant figures which are all that I am quoting, and which serves as a good preparation for what I shall say about the positive electron.

To introduce this subject I bring out the last of the reactions involving the neutron which is to appear in this article:

$$\phi + {}_1H^2 \longrightarrow {}_1H^1 + {}_0n^1 \qquad (7)$$

Here ϕ stands for a photon or corpuscle of light. The reaction occurs when deuterium is bombarded, or irradiated, with light of extremely high frequency—gamma radiation from radioactive bodies. Under these circumstances, Chadwick and Goldhaber have found that protons spring from the deuterium. The deuterons or H^2 nuclei are dissociated by the gamma rays. As I said before, we cannot (as yet) affirm that the deuteron can be broken apart by hammering it against a hard material wall; but we may affirm that it *can* be broken in 2 by hammering it with a corpuscle of light.

We now attempt to convert equation 7 into an actual equation for the masses. The first problem arising is, what mass to assign to the photon? One is not accustomed to speaking of the mass of a corpuscle of light; but the energy of such a corpuscle is well known—it is $h\nu$, where ν stands for the frequency of the light (which is ascertainable) and h for a known fundamental constant of Nature, Planck's constant. Now according to Einstein's principle already mentioned, energy E is always linked with mass E/c^2; here ν stands for another fundamental constant of Nature, the speed of light in vacuo. We therefore set $h\nu/c^2$ for the first term of our equation. Next come the masses of the nuclei ${}_1H^2$ and ${}_1H^1$. One would naturally take them from such a table as appears in this article; but *all the values given in such a table refer to particles at rest or moving relatively slowly, whereas the particles resulting from a reaction of transmutation are often shot off with enormous speeds!* The reason why this matters is, that according to the relativity theory and to experiment alike, the mass of a material particle increases with its speed. It is the augmented mass of the high speed nucleus, not the lesser mass of the same nucleus while at rest, which ought to be put for (say) ${}_1H^1$ in our equation. Another way of saying the same thing is, that whenever a nucleus or any other material body is in motion, it is carrying not only its rest mass but also the mass of its kinetic energy; denoting by T this energy, we have T/c^2 for the extra mass. Taking into account these extra masses of the newborn proton and neutron, but disregarding that of the deuteron on the ground that this particle is nearly standing still (its speed of thermal agitation being inconsiderable from this viewpoint) when the photon strikes it, we write the following equation of masses:

$$h\nu/c^2 + {}_1H^2 = {}_1H^1 + {}_0n^1 + T_H/c^2 + T_n/c^2 \qquad (8)$$

where now the symbols for the various nuclei stand definitely for the rest masses taken from the table, while T_H and T_n stand for the kinetic energies of proton and neutron, respectively. T_H is ascertainable, because the protons resulting from the reaction have a measurable range; T_n may be set equal to T_H, because we know that the masses of proton and neutron are almost the same, and therefore the momenta and therefore the kinetic energies with which they spring apart must be nearly the same in order to conform with the principle of the conservation of momentum.

If all the masses appearing in equation 8 were known with sufficient accuracy, we could use the equation to test Einstein's principle. Actually, all of them are known with sufficient accuracy, excepting the term ${}_0n^1$; it is therefore customary to *solve equation 8 for the rest mass of the neutron*, taking Einstein's principle for granted. The value thus obtained, quoted to 4 significant figures is 1.008—the same to 1 part in 1,000 as the mass of the proton.

To test Einstein's principle it is necessary to use some nuclear reaction in which all the rest masses are known with sufficient accuracy and all the kinetic energies are measurable. Two excellent examples are the following:

$${}_1H^1 + {}_3Li^7 \longrightarrow {}_2He^4 + {}_2He^4 \qquad (9)$$

$${}_1H^1 + {}_3Li^6 \longrightarrow {}_2He^4 + {}_2He^4 \qquad (10)$$

These reactions resemble equation 2, but are not identical with it: In one case a light hydrogen nucleus is captured by a heavy lithium nucleus; in the other case a heavy hydrogen nucleus is captured by a light lithium nucleus; and in both cases we obtain not a single consolidated particle (which would be a nucleus of ${}_4Be^8$) but a pair of identical fragments flying off in opposite or nearly opposite directions.

If now we treat expressions 9 and 10 as equations, and replace the symbol of each nucleus by the corresponding rest mass, we meet trouble at once: The left-hand member of expression 9 is equal to 8.023, the left-hand member of expression 10 to 8.028, and the right-hand members of both are equal to 8.004. (Note that these figures, being derived from the table, include in each case the mass of 4 electrons, which cancels out.) The unbalances are far in excess of the limit of possible error. They are, however, converted into excellent balances, when the extra masses due to the kinetic energies of the helium nuclei (those of the particles on the left-hand sides of the equations are negligibly small) are inserted on the right. There are other such cases which fortify Einstein's principle, and still others (the reaction 2 is one of these) which supply additional estimates of the neutron mass when the principle is accepted; while several of the mass values appearing in our table—those of ${}_1H^3$ and ${}_2H^3$ among them—are obtained by applying the principle to reactions of transmutation from which the particles in question spring.

Binding Energy an Index of Stability

Some readers perhaps may recall that originally I defined the "neutron" as a hypothetical neutral particle existing in combination with a proton to form a deuteron; that the difference between the masses of deuteron and proton (which are 2.014 and 1.008, respectively) is 1.006; and that the mass of the newly discovered free particle called by the name of neutron is not 1.006 but 1.008. This discrepancy is not unwelcome, but the contrary. Let

us suppose that the neutron and the proton attract one another strongly when they are very close together—as indeed they must, for otherwise the deuteron could not exist. Energy will then be required to pull them apart: When a photon effects the reaction expressed in equation 7, part of its energy must be used for this purpose, and only the remainder will become kinetic energy of neutron and proton. In other language, out of the initial energy $h\nu$ of the photon, a portion B is spent in "breaking the bond" between the constituent parts of the deuteron, the remainder $(h\nu - B)$ in giving to these the kinetic energies T_H and T_n. We may apply the name of "binding energy" to B. Remembering that energy has mass, and referring back to equation 8, we learn:

$$({}_1H^2 - {}_1H^1) + B = {}_0n^1 \qquad (11)$$

The rest mass of the free neutron exceeds the difference between the rest masses of deuteron and proton by an amount which is the binding energy of the deuteron. The whole (the deuteron) seems to be smaller than the sum of its parts (proton and neutron)! This however is not so, for we have to add something (*viz.*, the binding energy) to the "whole" in order to get the parts. Reversely, if the "whole" is made by bringing the parts together, the binding energy must be released and take its departure; we may imagine it as going away in the form of a photon of energy B and mass B/c^2, though there are other possibilities.

The difference 0.002 between the masses 1.006 and 1.008 is therefore nothing to be worried about; on the contrary, it is a measure of the energy which must be imparted to the deuteron in order to dissociate it, and thus an indication of the *stability* of the deuteron. Such estimates of stability are made whenever the data permit. Thus if we suppose the alpha particle to be made up of 2 protons and 2 neutrons, the sum of the rest masses of its presumed constituents is greater by 0.030 than the rest mass of the particle itself; this is a tremendous difference as such things go, and amply sufficient to explain why no one has succeeded in breaking up the alpha particle by bombarding it with photons, for no photons of anywhere nearly so great an energy can be generated by any apparatus yet developed. The corresponding argument applied to ${}_1H^3$ and ${}_2He^3$ gives much smaller margins of stability, and yet they are greater than the margin for the deuteron.

As I have just been implying without actually saying, the present day custom is to suppose every nucleus to consist of protons and neutrons in sufficient number to account for the actual atomic number and mass number of that nucleus: to wit, Z protons and $(A - Z)$ neutrons. This idea was actually suggested a number of years ago, but never met with general acceptance until the neutron was discovered "on the loose," so to speak, as a free particle freely wandering in space. Till then it was the custom to suppose each nucleus to consist of A protons and $(A - Z)$ negative electrons. One cannot say, however, that this idea is extinct, for in the first place there are certain radioactive nuclei which eject negative electrons, and in the second place there is a great desire to interpret the neutron as a combination of a proton and a negative electron. On the other hand there are also radioactive nuclei which eject positive electrons (I have already given an example in equation 3*b*) and there is a desire to interpret the proton as a combination of a neutron and a negative electron. It is clear at all events that we might reduce the 4 lightest elementary particles of the table to 3 "ultimates," if we could prove either that the proton is a neutron plus a positive electron, or that the neutron is a proton plus a negative electron. Now, the argument about stability seems to offer at least a partial test: If the rest mass of the proton were inferior to the sum of the rest masses of neutron and electron, this would speak in favor of the first alternative; if the rest mass of the neutron were inferior to the sum of the rest masses of proton and electron, it would speak in favor of the second. But the rest masses of proton and neutron seem to be equal as far as the fourth significant figure, and the immediate question at issue cannot be resolved without certain knowledge of the fifth, so that it is as yet an unsettled question.

"Spin" of the Nucleus an Important Feature

Reverting, for a paragraph, to the nuclei which are known to be composite, and in particular to those of our table which are the simplest known structures: The values of their binding energies are among the most important of their characteristics, and one of those on which we must rely for guidance and test in contriving the theory of these constructions. Another important feature is the "spin" or angular momentum of the nucleus, for protons, deuterons, and most other nuclei, as well as electrons, are *whirling* bodies. There is a unit of nuclear spin, as inconceivably small by comparison with the angular momenta of ordinary wheels as are nuclear masses by comparison with the masses of ordinary tangible objects. The spin of the proton amounts to one of these units, the spin of the deuteron to 2; we infer that the spin of the neutron (which unluckily is inaccessible to measurement) is also one unit, and that neutron and proton set themselves end to end with their spins pointing in the same direction and compounding themselves into a single spin of double value. (This statement requires a minor modification to be in harmony with quantum mechanics, but we need not enter so far into detail.) The spin of the alpha particle is zero, as if the protons and the neutrons set themselves end to end with their spins opposing and therefore counteracting one another; so are those of the nuclei ${}_6C^{12}$ and ${}_8O^{16}$. The spins of the nuclei ${}_3Li^7$ and ${}_7N^{14}$ are 3 and 2 of these units, respectively. These items also must be explained by any competent theory of the way in which nuclei are constructed, and it can only be hoped that the severity of the requirements which they set will be matched by the value of the hints which they give. It is unfortunately to be added that the spins of the other nuclei figuring in our table are not known (though those of many yet heavier nuclei have been ascertained) and some perhaps never will be.

The Positive Electron

The positive electron has already made its entrance into this article by way of the transmutation described by equation 3*b*. There is, however, a much simpler and more startling way of bringing it into being, than that or any other process which involves a nucleus. This is one of the primordial processes. Its equation is as follows:

$$\phi \longrightarrow {}_{-1}e + {}_{+1}e \tag{12}$$

A corpuscle of light transmutes itself into a pair of electrons, one negative, the other positive.

Incredible as this reaction seems to any physicist who has been reared in the belief of the permanence and the immutability of electricity, it conforms with all the major principles of conservation but one, and with this one it may be made to conform by a plausible addition. Conservation of *net* charge is sustained because equal and opposite charges are created: The addition of $+e$ and $-e$ to the electrification of the universe makes no alteration on balance. As to conservation of mass: Rewrite equation 12 as an equation of masses,

$$h\nu/c^2 = {}_{-1}e + {}_{+1}e + T/c^2 \tag{13}$$

where T stands for the sum of the kinetic energies of the 2 newborn electrons. It is then evident that the law of the conservation of mass will be maintained, if T is found by experiment to be equal to the difference between the energy of the photon and the energy equivalent of twice the rest mass of an electron. Experiment does yield this result, so far as the conditions permit: which is to say that when sheets of matter are bombarded by gamma radiation, pairs of electrons of opposite sign are occasionally observed to spring from a single point, and the sum of their kinetic energies may attain but never exceeds the difference between the energy $h\nu$ of a gamma ray photon and the energy equivalent of the doubled rest mass of an electron. (It often falls below, but this is readily explicable on the ground that most of the electrons lose a good deal of their energy in escaping from the solid sheet of matter into the gas where they first become observable.) Conservation of mass is therefore verified, and so, automatically, is conservation of energy. There remains the conservation of momentum, and this at first glance makes the situation serious, for the process described in equation 12 is one in which the momenta of the resultant particles cannot possibly equal that of the photon. It is, however, a fact that the creation of electron pairs out of light has never been observed in empty space, but only in the midst of matter, and especially of massive atoms; when diverse substances are irradiated by gamma rays, the process happens oftenest in lead, much more seldom in aluminium or carbon, while in gases only a few examples have been seen. We may now assume that the transmutation depicted in equation 12 occurs only in the immediate vicinity of an atom nucleus, and that this nucleus, without itself undergoing any change, is set into motion with just enough momentum to balance the momentum budget. Of course it must also possess some kinetic energy likewise derived from the photon, which strictly should be entered on the right of equation 13; but the amount of this turns out to be negligibly small by comparison with the other terms already entered there. The idea may seem somewhat artificial, but it is fully borne out by the successfulness of the quantum mechanical theory of the process. Charge and mass and energy and momentum are therefore all preserved intact when photons are converted into electrons, and no violence is done to anything excepting our inbred idea that electricity and light are somehow different and noninterchangeable in nature, which we are now obliged to abandon.

Positive Electrons Produced in Several Ways

I have acquainted the reader with 2 ways in which positive electrons are produced; there are yet others. Every now and then, in the solid objects which surround us here on the surface of the earth, and probably in the atmosphere as well, there occur terrific atomic explosions in which dozens, scores, or even hundreds of charged particles are fired in all directions. Many if not all of these particles are electrons; some are negative, and some are positive. It is presumed that these explosions are provoked by photons of colossal energy falling upon the earth from outer space, but this is a question into which I should not enter here. The electrons may be created in pairs out of the energy of the photon, but this cannot at present be proved. Occasionally one sees (in the Wilson chamber) the tracks of a single electron pair, and it seems almost indubitable that such a one must have been produced by the process of equation 12. Occasionally one sees the tracks of an electron pair leaping out of a lead plate just where an immensely fast electron has shot through the plate, and theory confirms the inference that the 2 new electrons have been created out of a portion of the kinetic energy of the old one. The very first positive electron ever recognized was wandering by itself inside a Wilson chamber in Pasadena, Calif., when C. D. Anderson by a happy chance condensed the water vapor on its track and so obtained a photograph thereof. All these, I hardly need say, are phenomena of the cosmic rays.

(It may have been noticed that I have assumed throughout that the mass and charge of the positive electron are equal in magnitude to those of its negative counterpart. This expresses our faith, rather than the result of accurate experiments. Measurements on the mass, or rather upon the charge-to-mass ratio, of the positive electron have already been commenced, but as yet they fall far short of the accuracy attained with the negative electron. They make it certain, however, that this ratio has the same value within a few per cent in both cases.)

Turning the arrow around in equation 12, we find ourselves confronted with the description, or rather the partial description of the converse process: 2 electrons meet and are converted together into light. If they become a single photon, conservation of momentum requires as before that the nucleus of some atom should participate in the process to the extent of taking some momentum and

a small quantity of energy, and this energy should strictly figure in the equation corresponding to equation 13 but may be disregarded so long as we remember that properly it should be there. (It is conceivable also that the 2 electrons might be converted into 2 photons sharing the available energy, and in such a case the participation of a nucleus is not required.) Now it is actually observed that when a stream of positive electrons is projected into a stratum of dense matter, photons of high energy shoot forth. Something of the sort is indeed observed when the infalling electrons are negative; but the positives produce a greater number of photons, and these extra ones have just the energy which equation 13 suggests. One would expect the positive electron to be more likely to unite with a negative electron after it has come nearly to rest than while it is still plunging forward at high speed into the stratum; in this case there would be little kinetic energy figuring on the right of the equation, and the energy of the newborn photon would be about the same as twice the rest mass of an electron. Well, this *is* a feature of the extra radiation stimulated by positive electrons driving into matter, as nearly as the very difficult experiments can tell. It appears that the positives retain their identity while they retain their high speed, but either they never come down to the relatively low speeds characteristic of the "conduction" electrons roving through the matter (if it be a conductor) and the "bound electrons" attached to the atoms, or if they do slow down to these speeds it is not for long: Each presently meets with a negative in such a fashion that the encounter is fatal to them both.

It seems as though in speaking of the positive electron I had for the first time introduced a mortal particle, in contradistinction to the presumptively immortal atom nuclei and negative electrons of the remainder of the list. The negative electron is, however, no less mortal than the positive, inasmuch as the 2 of them vanish together into light; and so far as the atom nuclei are concerned, if any one of them should ever meet a particle identical with it except in sign, the presumption is that the 2 could effect just such a merger as electrons can. It happens however that the electron is as yet the only particle of which there are known to be 2 varieties, antagonistic in sign and apparently alike in every other way. If either kind of electron were altogether missing we should suppose the other to be immortal, as we so long supposed the negative to be; if both were equally common the world would be unlivable, the interchange of substance between the form of electricity and the form of light being so abundant and incessant; it is because one kind is so very much rarer than the other and yet not entirely absent, that it is obviously ephemeral while the other gives the impression of durability.

Practical Applications of Insulation Research

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By applying the results of insulation research to factory equipment and procedures, manufacturers of oil-impregnated paper-insulated cables for electric power transmission and distribution have been able to effect marked improvements in their products. By following and taking advantage of these improvements as they develop, users of cable have been able not only to obtain more satisfactory operating results, but also to effect substantial savings. Some of the more recent achievements in insulation research and their practical applications are outlined briefly in this paper.

IN a previous paper[1] the author gave some test data and conclusions derived from accelerated aging tests of 69 kv cables. Those tests consisted of the application of from 1.5 to 3 times normal voltage and daily load cycles reaching a maximum of 84 cycles. As was shown in figure 9 of that paper, the lead sheaths of the cable samples were insulated from ground and from each other. Test leads were provided so that the sheath of each section of cable could be connected separately through a Schering bridge apparatus to ground. Measurements then were made on the insulation in that one section. Changes in the cable with age in these tests were determined at intervals by power factor measurements and by examinations of the insulation before and after the test.

A new series of accelerated aging tests on 19 samples of 69-kv single-conductor cable is now in progress at the high voltage laboratory of the Commonwealth Edison Company, Chicago, Ill. The

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1. For all numbered references see list at end of paper.

cables set up ready for test are shown in figure 1. All methods of testing and examining the insulation followed in the previous tests will be utilized, and, in addition, use will be made of several new tests that have been devised in the meantime.

Radial Power Factor Tests

One of the most interesting of the new tests is the radial power factor test of impregnated paper insulation described by Wyatt, Spring, and Fellows.[2] In this test, power factor measurements are made on the impregnated paper tapes, one at a time, and the results are shown graphically for a radial path through the insulation. During the past year in which results of the tests from similar apparatus in the laboratories of the Commonwealth Edison Company have been available, several such radial power factor tests have been made, not only on the 69 kv cable included in the present accelerated aging tests, but also on several other cables. By comparisons and analyses of the results of the tests, some familiarity with this new tool has been developed so that it can be used to advantage in connection with the accelerated aging tests.

Figures 2 and 3 show the results of the radial power factor tests on most of the samples included in the present accelerated aging test. The results of these tests appear to show a sufficiently wide range in the value of the power factor and in the shape of the curves to make it possible to determine the importance of these factors on the quality of the insulation. Some of these curves have the shape of an unsymmetrical letter "U," that is, they show marked upturns near the conductor and the sheath. Several of the curves show some irregular variations from the U shape, the causes of which are not immediately apparent but might become apparent through consideration of other information.

The cable from which curve *B* in figure 3 was obtained included several different grades of paper. Such radial power factor curves should be helpful to the manufacturer in determining the most suitable grade for the purpose.

Figure 4 shows that a material improvement has been made in the radial power factor curves for cable made in one factory during a period of several years. Similar improvement has been made by other manufacturers. However, no single curve combines the 2 most desirable qualities, namely, a low power factor

Fig. 1 (above). Interior of laboratory with 19 samples of 66-kv cable ready for aging tests

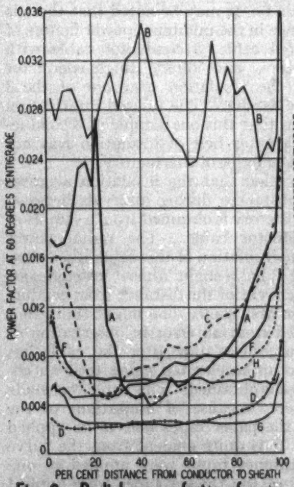


Fig. 2. Radial power factor of new 69-kv single-conductor cable of different makes

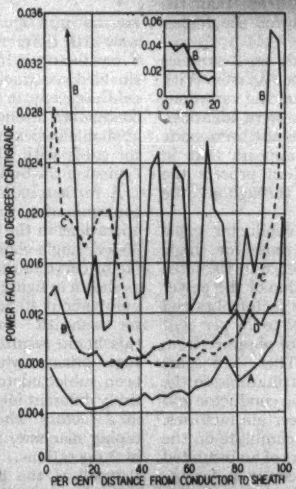


Fig. 3. Radial power factor of used 69-kv single-conductor cable of different makes

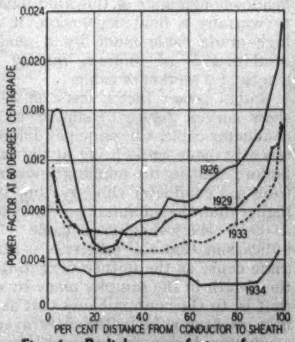


Fig. 4. Radial power factor of new 69-kv cable of make C showing marked improvement achieved between years 1926 and 1934

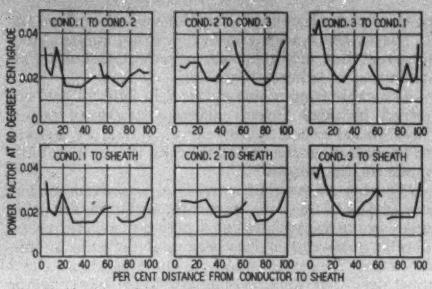


Fig. 5. Radial power factor of used 13-kv 3-conductor cable of make B

and a horizontal straight line without upturns near the conductor and sheath. One manufacturer has explained that the slight upturn next to the sheath resulted from the use of manila paper for the outer layer of paper tapes; but this explanation covers only 1 or 2 tapes, while the upturns in the curves usually involve many tapes.

The apparatus used for measuring radial power factor has electrodes $^1/_2$ inch in diameter and is arranged so that these electrodes are used also as a micrometer. Accordingly, measurements of the thickness of each tape as well as the power factor are included in the reports. For one cable it was noted that 3 thicknesses of tape were used, nominally 5, 6, and 8 mils, and, disregarding the upturns near the conductor and sheath, that the power factor of the tapes improved as the thickness increased. The thinner tapes appeared to be more dense than the thicker ones, which might account for the higher power factors.

In one instance, tests were made on 2 samples from the same piece of cable 140 feet apart. With allowance for errors in observation and the variations in commercial paper, the 2 curves were identical. While enough tests of this kind have not been made to warrant a final conclusion, it appears that in high grade cable made by a modern process the insulation is of uniform quality throughout the length of a section of cable.

Radial power factor tests on 3 conductor cable show curves (figure 5) similar to those for single conductor cable, the principal difference in the most recently made cable being in the value of the power factor; that is, the minimum power factor obtained from a 3 conductor cable is from 10 to 75 per cent higher than the minimum power factor obtained from a 69-kv single-conductor cable. There are some indications that this difference is attributable to the same cause as the upturn next to the conductor and the sheath in the samples made by certain factories, that is, to the contaminants that accumulate on the bare conductor and on the outer layers of an insulated conductor during the interval between manufacturing operations. This point was brought to the attention of one manufacturer, and radial power factor tests were made before and after the manufacturer made some slight changes in his equipment and/or processes in the factory. The results of these tests showed that the upturns in the curves near the conductor and sheath were eliminated by the manufacturer's changes, except for the slight upturn resulting from the use of manila paper for the outer layer. The elimination of the upturns in power factor near the conductor and near the sheath thus is shown to be entirely within the control of the manufacturer. Radial power factor curves for cables manufactured after such changes had been made

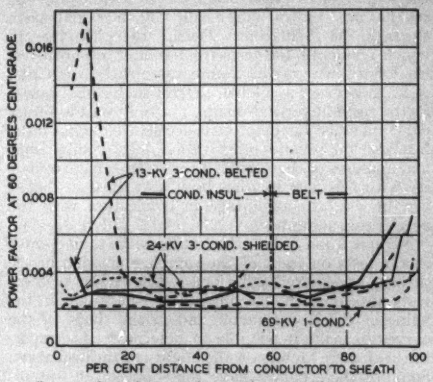


Fig. 6. Radial power factor of new cable made in 1934 by one manufacturer

are shown in figure 6. It may be noted that there is very little difference in the minimum power factors of 3 conductor belted cable, 3 conductor cable with shielded conductors, and 69-kv single-conductor cable, except in the insulation near one of the 3 conductors of one sample. The limited information available indicates that this one sample of 3 conductor cable with an outer belt of insulation was not typical of the best practice of this factory.

A further indication that the insulation acquires contaminating substances during intervals between operations in the factory is obtained from a sample of 69-kv single-conductor cable. The radial power factor curve of the insulation of this cable when new, as shown in figure 7, has a slight, almost insignificant, hump about 40 per cent of the distance from conductor to sheath. On first glance, one might think that this hump resulted from an error in observation or some other trivial cause; but after the cable has been subjected to an accelerated aging test, an entirely different idea is obtained. This cable was made in a factory where, because of limitations of the taping machine, the paper tapes had to be applied in 2 operations. It is quite evident from the curve that all of the thinner tapes were applied in one operation and all of the thicker tapes were applied in the second operation. During the interval between the 2 operations, the partly insulated conductor

stood on reels in the room where the taping machines are located.

Apparently the upturn in power factor near the conductor is attributable either to fine solid particles of dust and condensed vapors deposited on the conductor while standing around the factory before the paper tapes were applied or to copper soaps

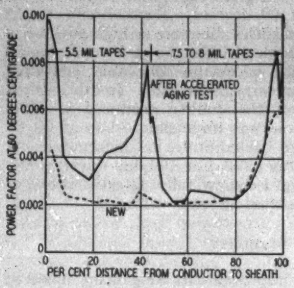


Fig. 7. Radial power factor of 69-kv cable made in 1931 before and after aging test

Peaks near the middle of the curves show the result of applying the paper tape to the conductor in 2 operations

formed by chemical action with the oil. The upturn at the 40 per cent point is attributable to the solid particles collecting on the outer layers of paper of the partly insulated conductor, and perhaps also to vapors absorbed by these outer layers of paper, while standing in the factory before the remaining paper tapes were applied. The upturn in the curve of new cable next to the sheath probably is ascribable, in part, to the same causes and, in part, to oxidation

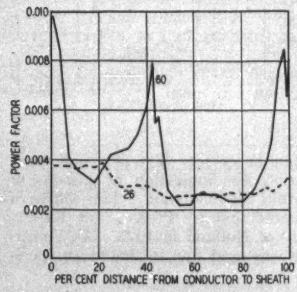


Fig. 8. Comparison of radial power factor at 26 and 60 degrees centigrade of 69-kv cable made in 1931

of the oil as it is exposed in the factory after the removal of the cable from the impregnating tank and before application of the lead sheath.

This cable was of excellent quality, as shown by the accelerated aging test. Even at the summit of the peak near the center of the insulation, the power factor is not much higher than that of the product of some other factories when new; but the curve, taken in connection with other curves, indicates that more careful "housekeeping" in some of the factories would be of assistance in producing impregnated paper insulation of the highest quality. Information obtained from the radial power factor tests has been found by cable manufacturers to be so interesting that several of them have equipped their laboratories with apparatus for making such tests.

In figure 8 the curves of power factor at 26 degrees centigrade and at 60 degrees centigrade for the 69 kv cable that has been subjected to an accelerated aging test show that comparatively little information is obtained from tests at the lower temperature and that the curves obtained at 60 degrees are far more informative and useful.

Breakdown Voltage Tests

A further point regarding the present status of research on impregnated paper insulation becomes more apparent by first considering briefly the improvements in impregnated paper insulation in the past 15 years.

In 1919 the Commonwealth Edison Company prepared specifications for 3 conductor cable to be operated at 12 kv which required breakdown voltage tests on short samples, and this requirement was included in specifications issued by the National Electric Light Association in the following year. In 1924 the Association of Edison Illuminating Companies prepared cable specifications, mainly for high voltage cable with some new requirements. Based largely upon a series of life tests made by the Commonwealth Edison Company, these specifications required much higher short-time breakdown strengths and a long-time test. These and subsequent changes in cable specifications are shown graphically in figure 9.

Breakdown strengths of 3 conductor cable for operation at 12 kv are shown in figure 10. For simplicity, the data are for one make of cable furnished to the Commonwealth Edison Company, but these results are quite typical of improvements made by practically all American manufacturers in this period. The short-time breakdown strength has increased by more than 200 per cent although during the same period the insulation thickness has been

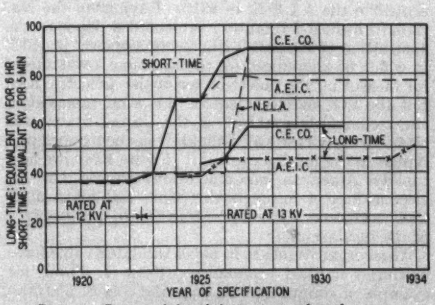


Fig. 9. Required breakdown strengths of 3-conductor cable for 12-kv operation

Equivalent voltages were determined by use of the relation between voltage and time given by F. M. Farmer[3]

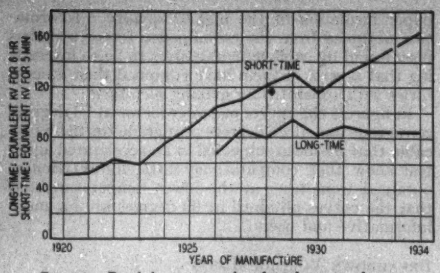


Fig. 10. Breakdown strengths of 13-kv 3-conductor cable on short- and long-time tests, depicting the steady improvement of the insulation

Equivalent voltages were determined by use of the relation between voltage and time given by F. M. Farmer[3]

reduced about 25 per cent. With due allowance for this difference in thickness of insulation, the present-day insulation will withstand a high voltage test about 4.4 times as severe as the same thickness of insulation would withstand in 1920. The service record shown in figure 11, of the 13-kv 3-conductor cable made in 1924 shows only one burnout resulting from defective insulation per 300 miles of cable per year, a very satisfactory service record. The breakdown strength of this cable for 5 minutes' duration was 6 times normal operating voltage. Since 1924 this figure has increased to 12 times normal operating voltage, as indicated in figure 10, showing that so far as this property of the insulation is concerned a considerable reduction in the present thickness of insulation, which is the same as that used in 1924, would be warranted.

Dielectric Loss

Dielectric loss was a troublesome factor in the earlier days and was the cause of many hundreds of cable failures in the United States. Bang and Louis[4] showed the importance of this factor in a paper presented to the A.I.E.E. in 1916. Rayner[5] of the National Physical Laboratory presented a paper to the Institution of Electrical Engineers, London, in 1912, in which he announced for the first time a wattmeter for measuring the power factor of the dielectric loss, but the first measurement of this kind reported in the technical laboratories of the United States was reported by Clark and Shanklin[6] in their paper presented to the A.I.E.E. in 1917. Figure 12 shows how rapidly American manufacturers reduced the dielectric loss of impregnated paper insulation after their customers learned how to measure this property of the insulation.

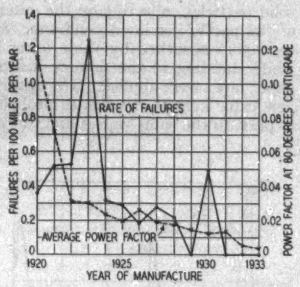
These improvements in paper insulated cable have produced marked economies. Table I shows, for example, a comparison between the cost of 500,000-circular mil 3-conductor cable for operation at 12 kv of the quality made in 1920 with that made recently. If such cable of the quality furnished in 1920 were used now, the cost per kilovolt-ampere of capacity would be about 27 per cent higher than the present cost.

The lower allowable operating temperature for the old cable was necessitated largely by the high loss in the insulation which is shown in figure 12 in terms of power factor. If the 1918 standardization rules of the A.I.E.E. were in use today, the maximum allowable operating temperature for 69 kv cable would be 45 degrees centigrade instead of the present value of 60 degrees. Furthermore, if the dielectric losses in such cable were as high as those of the 12 kv cable made in 1920, the 69 kv cable would be heated to its maximum allowable operating temperature when carrying no load. In other words with insulation of the quality produced in 1920, use of 69 kv cable was impossible. Use of 69 kv cable began in the United States in Cleveland during 1924 and in Chicago and Philadelphia during 1926. Its operating record is now fully as satisfactory as that of cables operated at lower voltages.

Ionization and Stability

While marked improvements were being made in the initial properties of the insulation, attention also was focused on the deterioration that occurred in the

Fig. 11. Operating record of 1,085 miles of 13-kv 3-conductor cable showing decrease of rate of insulation failures and of average power factor of cable insulation



insulation with time in service. The principal cause of this deterioration was ionization of gaseous or vacuous voids within the insulation. This source of trouble was exploited first by Proos, Smit Kleine, and van Staveren[7] of Holland in 1923. An ionization factor clause was used first in American speci-

Table I—Comparison of 500,000-Circular Mil 3-Conductor 12-Kv Cable Made in 1920 With That Made in 1934

Year Made	1920	1934
Thickness of insulation, 64ths of an inch		
On each conductor	12	9
Over all 3 insulated conductors	8	5
Maximum allowable operating temperature, degrees centigrade	73	77
Power factor of dielectric at maximum allowable temperature	0.18	0.01
Carrying capacity in summer, kilovolt-amperes	6,680	7,610
Cost per mile of line under present conditions	$11,350	$10,190
Cost per mile per kilovolt-ampere	$ 1.70	$ 1.34
Estimated annual cost of dielectric losses per mile	$ 37.00	$ 7.64

fications in 1924. Figure 12 shows that the American manufacturers improved this property of the insulation rapidly after they learned how to measure it by a comparatively simple test that could be applied to each reel of cable in the factory. Before this test was devised, the only method of determining whether the insulation was subject to deterioration from this cause was to submit the cable to a long-time test and to note the visual changes in the insulation after the test.

At present, the stability of the insulation can be measured only by placing the cable in service and noting the results over a long period of years, or by an accelerated aging test, a very expensive test requiring several weeks or perhaps months in order to secure the desired results. The improvements in dielectric loss and in ionization following the development of suitable means of measuring these properties by a comparatively simple test, as depicted in figure 12, indicate that the manufacturers would make a similar rapid improvement in the stability of the insulation following the discovery of some method of measuring the stability by means of a laboratory test comparable in simplicity with methods of measuring dielectric loss and ionization factor.

Reduction in Thickness of Insulation

If the stability of the insulation could be insured so that the initial properties of the insulation could be maintained over a long period of years, then the thickness of the insulation for the higher voltage cables could be reduced radically, thus resulting in further reductions in the cost of the cable. The extent to which further reductions in the thickness of insulation may be carried is indicated by the action of one English manufacturer who has furnished for a 66 kv line in England cable having 15 per cent less insulation than any 66 kv cable now in operation in the United States. If this manufacturer can find sufficient warrant from the present rather crude methods of measuring the stability of insulation to reduce the thickness by 15 per cent, it would appear that a further reduction of about the same amount might follow in a few years the development of a laboratory method of measuring the stability of impregnated paper insulation.

Recent carefully made estimates indicate that in the past 13 years the Commonwealth Edison Company has saved about $2,000,000 by using on its lead covered cables less insulation than other companies operating at the voltages now being used on the various transmission and distribution systems of the company. Distribution of the saving by years and voltage class is shown in figure 13. A liberal estimate of the cost of the investigations that made possible this saving is $300,000. The results of these investigations have been beneficial also in connection with other cables. This saving is probably greater than the gain that can reasonably be expected during the next 13 year period. It shows, however, what can be done by means of such tests in following and taking advantage of improvements in quality as they develop.

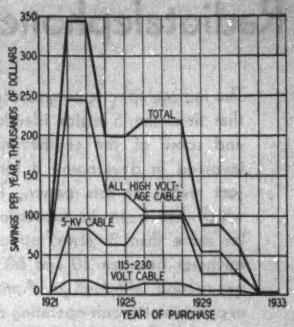


Fig. 13. Savings effected by Commonwealth Edison Company by using on its cables less insulation than was used by other companies for operation at comparable voltages

While some further reductions in insulation thickness probably will be made from the information obtained by the tests used at present, the indications are that larger reductions will follow a new test for stability.

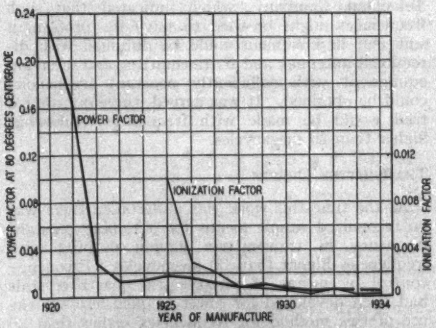


Fig. 12. Average power factor and ionization factor of 13-kv 3-conductor cable of one make

Note sharp reduction immediately following the development of suitable means of measuring these properties

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The Hawaiian Radiotelephone System

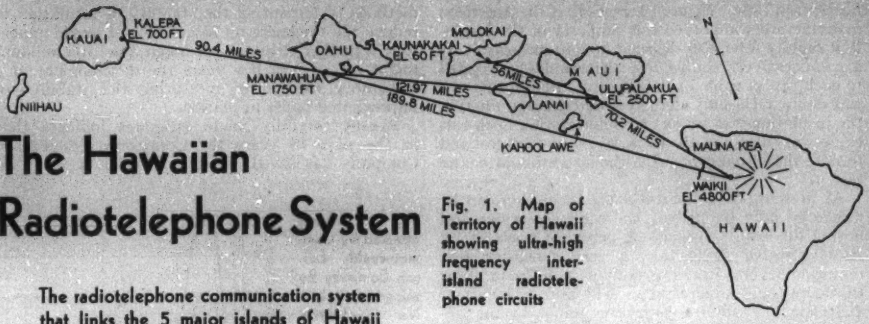

Fig. 1. Map of Territory of Hawaii showing ultra-high frequency inter-island radiotelephone circuits

The radiotelephone communication system that links the 5 major islands of Hawaii and some of the engineering problems involved in developing it form the subject matter of this paper. This system, which has been in successful operation for more than 3 years, operates on frequencies between 30 and 60 megacycles per second, although in April 1935, an experimental circuit operating on 220/230 megacycles was placed in service. The successful operation of this system has shown that ultra-high frequencies are well suited to short quasi-optical ranges and that reliable semi-nonattended radiotelephone services are practicable.

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FOR many years there had been a need of joining the islands of Hawaii with telephone circuits, and the Mutual Telephone Company of Honolulu had been seeking a practical means of accomplishing this end. The presence of coral reefs, the depth and configuration of the ocean bottom, and the constant pounding of the waves made undersea cables impracticable. Consequently the company turned to radio to find a solution of the problem, but for many years even radio was not capable of providing circuits at a cost that the service could afford. Surveys were made with frequencies lower than 3 megacycles per second, but atmospheric disturbances and selective fading on these frequencies were too great to permit establishing a service. A solution finally was found by the application of frequencies higher than 30 megacycles.

Since 1924 the Radio Corporation of America has engaged in a continuous development program for the purpose of providing equipment to operate at higher and higher frequencies and of utilizing this equipment in determining the propagation characteristics and potential usefulness of these higher frequencies. By 1928 this work had progressed sufficiently to indicate that frequencies between 30 and 100 megacycles per second would reach considerable distances beyond the optical range and that, by placing transmitters and receivers at elevated points, distances of from 100 to 200 miles could be reached. At the same time it had been demonstrated that, unlike frequencies between 2 and 30 megacycles, signals transmitted at frequencies of 30 to 100 megacycles would neither be heard nor produce interference at great distances.[1]

On July 13, 1928, the Mutual Telephone Company instigated negotiations with the Radio Corporation of America which led to a joint investigation of the possibilities for setting up interisland radiotelephone circuits. Some experiments with very high frequencies already had been made by the Mutual Telephone Company, which indicated that such frequencies might be used to solve the problem if sufficient improvement could be obtained with directional antennas and if transmitting and receiving equipment with sufficiently constant frequencies could be obtained. It was agreed, therefore, that a trial would be made with frequencies somewhat higher than 30 megacycles.

Transmitter Design

At the time this work was undertaken there was no recognized simple means for obtaining constant frequency in transmitters having outputs with frequencies higher than 30 megacycles. Frequency control by means of piezoelectric quartz crystals had been developed for lower frequencies, but the use of this method for frequencies higher than 30 megacycles would have involved an excessive number of frequency multipliers and amplifiers, which would have resulted in greater expense and less reliability,

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1. For all numbered references see list at end of paper.

and would have required more expert operating personnel.

In attempting to provide simple semiportable equipment for the surveys in Hawaii, 2 transmitters were constructed, at the transmitter research and development laboratory of the Radio Corporation (Rocky Point, N. Y.) having their frequencies stabilized by means of a portion of 2-conductor radio-frequency transmission line. A simplified schematic diagram of the transmitter is shown in figure 2, and a photograph in figure 3.

In this arrangement 2 type 852 tubes were used in a balanced or push-pull circuit. Regeneration was obtained by the coupling between output and input circuits through the anode to grid capacitances of the tubes. During oscillation the output coil and the line each acted as effective inductances of such a combined value as to balance the anode to grid capacitances. Under these conditions the radio frequency anode and grid voltages of each tube are opposite in phase, with respect to the cathode, which is the well known condition required for oscillation. The regeneration was adjusted by varying the output coil and the length of line in such a way as to produce equal and opposite changes in inductance and no change in frequency. The oscillatory energy in the line was adjusted by varying the length of line until substantially minimum frequency modulation from a-c cathode heating and a-c components of anode supply current was obtained. The line passed through equal values of effective inductance at lengths differing by a half wave or multiples of a half wave. For survey work an open wire line of number 6 copper wires, spaced a few inches, was used. This type of line has a power factor of about 0.0005 to 0.0007, depending upon the frequency, in the band between 30 and 60 megacycles.

As a result of its low power factor, the line formed a sharply resonant or highly selective grid circuit for the oscillator and was found to be quite effective in reducing undesired frequency modulation and variations in mean frequency. It permitted the use of alternating current cathode heating and reduced the transmitter circuits to the simplest possible arrangement. Subsequent developments of line control, starting with these transmitters, have provided one of the most promising means of frequency control for very high frequency transmitters.[2,3]

Receiver Design

Receivers used for field surveys were of the superheterodyne type constructed in 2 units. Figure 4 shows the first unit of one of the receivers. The unit contained 2 stages of tuned radio frequency amplification followed by a heterodyne detector. The radio frequency amplifiers utilized special screen grid tubes designed for operation at frequencies higher than 30 megacycles. With the aid of these tubes and careful shielding and arrangement it was possible to obtain considerable amplification, which would have been impossible with any arrangement of standard tubes then available.

The second unit consisted of a modified aircraft beacon receiver. The high gain and high working frequency (270 to 500 kilocycles) of this receiver made it particularly suitable for use as an intermediate frequency amplifier, detector, and audio amplifier. The circuits in the receiver consisted of 3 stages of tuned intermediate frequency amplification utilizing screen grid tubes, oscillating detector, and 2 stages of high quality audio amplification.

Directional Antennas

At the time the survey equipment was provided there had been developed recently a new type of directional antenna consisting of 4 wires, each several wave lengths long, arranged in one vertical plane and interconnected in such a way as to produce a substantially unidirectional beam of radiation. Figure 5 is a diagram showing the arrangement of this antenna.[4]

As usually constructed this type of antenna produces radiation in the direction of the beam about 16 times greater in intensity than would be produced by the same amount of total power radiated from a simple antenna. When used for receiving the antenna gives an equivalent power gain. The overall gain obtained by using these antennas at both transmitter and receiver is about 250 to 1. Proportionally larger gains may be obtained by paralleling or broadsiding more than one of these antennas into one highly directional system.

Antennas of this type were used in connection with field surveys and later for setting up commercial circuits.

Field Surveys

In August 1929, 2 transmitters, 2 receivers, and a gasoline engine driven generator to supply power at isolated survey points were taken to the islands. Tests were begun in September with a transmitter located on a knoll on the southern slope of Puu Manawahua, Oahu, at an elevation of about 1,700 feet. The results of these tests already have been described.[1]

Frequencies in the neighborhood of 37.5 megacycles were selected as best for the Oahu-Hawaii circuit, the longest in the desired interisland system. There was no doubt in the minds of all the observers that, with the aid of directional antennas, thoroughly

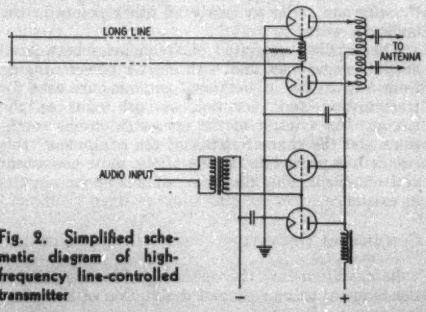

Fig. 2. Simplified schematic diagram of high-frequency line-controlled transmitter

commercial interisland radiotelephone circuits could be established. Accordingly, a 2 way radiotelephone circuit was set up between Puu Manawahua, Oahu, and Waikii, Hawaii, using directional antennas. An extended period of 2 way testing then demonstrated the commercial feasibility of the circuit.

Additional tests were made over the other proposed circuits which confirmed the conclusion that commercial circuits were practicable. At sea level on Kaui it was possible to receive the Hawaii transmitter over a record distance of 280 miles. This result was attributed to the use of directional antennas and to favorable conditions.

Successful performance of the interisland circuits having been assured, arrangements were made to obtain commercial equipment. This equipment followed the general design of the survey equipment fairly closely. Significant changes in design included the selection of a completely shielded frequency control line for the transmitter and a band width of 50,000 cycles for the receiver. The broad receiver band width made frequent attention to correct for transmitter and receiver frequency drift unnecessary and was essential for economical operation.

By careful design and selection of frequencies it was possible to operate both transmitters and receivers at each terminal in the same building. This greatly simplified operation and maintenance.

Honolulu to San Francisco Circuit

Within a few weeks after the interisland radiotelephone system was placed in operation a radio telephone circuit was opened between Honolulu and San Francisco, Calif., through the facilities of R. C. A. Communications, Inc., in Hawaii, and the facilities of the American Telephone and Telegraph Company in California. The transmitter for the Hawaiian end of this circuit is located in the transocean station at Kahuku and the receiver is located at Koko Head. They are joined through wire connections to the central telephone system of the Mutual Telephone Company in Honolulu.

On the California end of the circuit the transmitter is located at Dixon and the receiver at Point Reyes, from which points wire line connections extend to San Francisco. From San Francisco wire connections can be made to any point in the United States and by wire and radio to nearly all other points in the civilized world.

The circuit is operated on frequencies between 5 and 20 megacycles and with carrier power ranging from 5 to 20 kw. Directional antennas are used for transmission and reception at both ends of the circuit. As a result of the favorable circuit conditions and the characteristics of the equipment, this circuit has proved to be one of the most consistent and reliable of long distance radiotelephone circuits in existence.

Commercial Operation

Before discussing the operating characteristics of the System, a brief general description of the plant as a whole will be given. Reference to a map of the Territory of Hawaii, figure 1, will show that the group consists principally of 5 major islands: Oahu, Hawaii, Maui, Molokai, and Kauai. The Mutal Telephone Company owns and operates telephone systems upon these 5 islands and, in considering methods of interconnecting the 5 systems, was faced with several problems. It may be seen from the map that the islands are ideally situated for quasi-optical circuits, and some of the problems involving selection of station sites, frequencies, etc., and the design of suitable apparatus and antenna systems, have been described previously.

After it had been demonstrated to be technically feasible to establish the desired circuits utilizing ultra-high frequencies, there remained for consideration the requirements of economic operation, which in themselves presented several technical problems. In figure 6 is shown a block diagram of the system, on which are indicated the circuit frequencies and the number of telephones on the various islands to be connected. It may be readily understood that the system to be economically practicable, with this comparatively small number of subscribers, must be capable of operation at a minimum of expense. This requirement is emphasized by the rather large capital investment required to erect stations at the isolated mountain sites necessitated by altitude and optical path considerations.

Some of the technical problems presented thus were: The transmitters and receivers must be capable of operation in one building, to reduc eoperating and maintenance personnel; antenna systems must

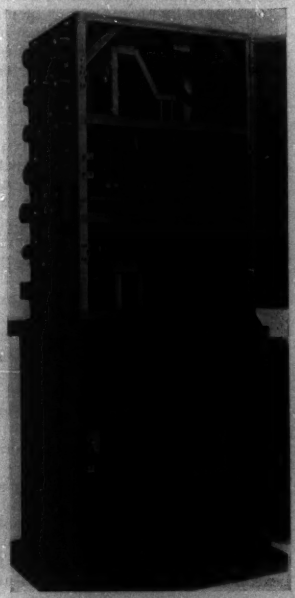

Fig. 3. High frequency survey transmitter

Fig. 4. High frequency unit of survey receiver

be adapted to the same type of operation; transmitters and receivers must have a degree of frequency stability and ruggedness sufficient to permit semi-nonattended operation; received signal levels should permit the use of automatic volume control and preclude, in so far as possible, the necessity for constant manual gain control. Some of these problems were worked out in the design and installation of the equipment and antenna systems, but others could be met and solved only in the light of operating experience.

A few weeks of operation were sufficient to show that the over-all frequency stability of the circuits would permit the use of remote control and semi-nonattended service, which was highly desirable from the standpoint of operating economy. Accordingly, a method was devised whereby the telephone operators at the various exchanges might have control of the transmitters at the associated radio stations. As the system now is operated, the plate supply circuits of the transmitters are shut down between calls during the day, and at night the entire transmitter is so controlled.

When making the installation of this equipment, it was desired to keep the technical personnel at the minimum consistent with good service. Therefore, technical monitoring of calls is not attempted. The input transformers, or hybrid coils, necessary to a 2 wire circuit were installed at the radio stations, and 2-wire channels were extended to the control telephone exchanges; from there the calls are distributed throughout the lines of the company's system. This arrangement cuts the number of lines required to a minimum, but has the disadvantage that technical monitoring, if required, would have to be accomplished at the radio station; this, however, has not been found necessary. Transmitter input and receiver output are adjusted to the optimum value for average calls, and further adjustments for individual calls are not made except that 2-way repeaters are installed in the Honolulu and Hilo exchanges, and monitoring operators may increase the speech frequency volume 6 decibels when required. Pads also are installed at the control exchanges in order that volume may be reduced when connecting local subscribers.

While this method is a compromise in favor of reduced personnel it is working quite satisfactorily in the present system where there are no extremely long lines or subscriber's loops, and where the general speech volume is at a fairly constant average level. Should future developments warrant or require the addition of constant monitoring of calls, it could be accomplished by extending 4-wire circuits to the control telephone exchanges and providing there means of regulating transmitter input and receiver output. This method would not necessitate increasing the technical personnel at the radio stations, which are necessarily in isolated locations where the maintenance of large staffs would be expensive.

At present, each station is staffed with one skilled technical and maintenance man and one student-assistant, who is capable of taking over the station for short periods and doing routine maintenance work. For the most part, the circuits operate without constant supervision, and the station staff is free to carry on the general maintenance work during circuit hours.

That this system of semi-nonattended operation is satisfactory from the subscribers point of view is indicated by a study of the general quality of calls. For this purpose, all calls are classified by the supervising operator into 4 groups:

A. Good talk; no repetitions necessitated by circuit faults; no noticeable noise.

B. Conversation satisfactory; very few repetitions; slight noise or low level transmission.

C. Fair talk; some time deductions for repetition; circuit noisy or level low.

D. Poor; noisy or weak, necessitating large time deductions or reconnection.

During the past 3 years of commercial operation approximately 45,000 paid calls were handled over the system, and of this number 96.5 per cent were rated "A," and 98.3 per cent fell within the "A" and "B" classification.

Privacy

At the present time no inverters or other "scrambling" devices are used on the circuits. All stations are located on mountain sides, well remote from centers of population, and the sharply directional beams from the directional antennas pass well over any such centers. Efforts at interception with carefully constructed receivers were made, with entire lack of success. No instances of interception by unauthorized parties, of any interisland radiotelephone calls have come to the authors' attention, and no reports or rumors of such an occurrence have been circulated. It is felt that this record, covering a period of over 3 years' operation, may be accepted as proving definitely that the inherent qualities of the system offer complete privacy of calls. The absence of any technical activity in the ultra-high frequencies in the Territory tends to assist this condition.

Receiver Plate Supply System

As originally installed, the receiver plate supply consisted of a double-bank 250-volt lead-acid battery

at each station, but the maintenance and replacement expense on this large number of small cells, especially when operated on a charge and discharge basis, led to experiments with various plate supply systems in the hope of obviating this large expense. This problem was made difficult by the fact that the receiver frequency stability requirements necessi-

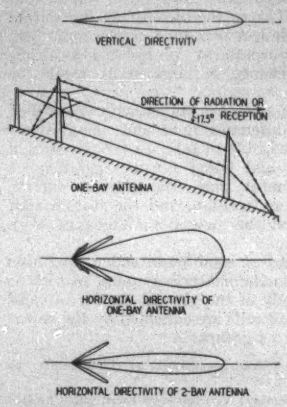

Fig. 5. Schematic diagram of directional antenna and directive characteristics

tated a plate supply having extremely good regulation. Recent developments in rectifier tubes and electrolytic condensers, however, made possible the construction of heavy duty a-c power supplies, which have been giving satisfactory service for the past 18 months.

Interference

Interference problems on this system have been very few because of the isolated location of the stations, the directional characteristics of the receiving antennas, and the fact that the more common types of interference do not affect the ultra-high frequencies to the same extent as the lower frequencies. One notable exception has been the interference experienced from nonshielded air-plane engines which at times has reached fairly serious proportions. Tests on this type of interference have shown that the sensitive receiving arrays used are capable of picking up noise from this source over a distance of 10 miles. The gradual replacement of the nonshielded type of plane, to-gether with the co-operation of the army and navy air services in restricting their flying in the affected areas, however, has kept this type of interference at a minimum.

Interference from natural electrical disturbances seems to have little effect on the frequencies in use. Instances have been noted when severe electrical storms have originated near the stations without causing noticeable interference. In one instance the disturbance was so severe as practically to paralyze radio communication throughout the Territory on all frequencies lower than 30 megacycles; yet the ultra-high frequency radiotelephone scarcely was affected at all.

Fading

Data on fading characteristics on these circuits necessarily is limited by the use of remote control and nonattended operation, but such information as is available indicates that the frequency and severity of fading is directly proportional to the amount of intervention of earth surface between transmitter and receiver. Fading is most noticeable on the Oahu-Hawaii circuit over a distance of 190 miles, with approximately 70 miles of intervention, and practically nonexistent on the Oahu-Maui circuit with 13 miles of intervention in 122 miles. On the Oahu-Kauai circuit over 90 miles, with approximately 35 miles of intervention, the fading is less prevalent than on the Oahu-Hawaii circuit but more frequent than on the longer Oahu-Maui circuit.

Such fading as has been noted has been practically all of the same nature and usually of 3 or 4 minutes' duration, accompanying a period of general instability lasting from 15 minutes to an hour. Uusually, the automatic volume control is able to compensate for fading, and such periods are characterized only by a relatively high noise level on the circuit affected; occasionally, however, the fading is sufficiently severe to interrupt service for a short time. It has been impossible to determine any diurnal relationship to this fading because of limited data, but all observations indicate that it may occur at any time during the day or night. It is noted frequently that one circuit may be subject to erratic fading conditions, while other circuits are not affected at all; at other times, all circuits are affected simultaneously.

An entirely different fading characteristic has been observed on the circuit between Hawaii and Maui. This circuit is 70 miles long and enjoys a complete optical path. The fading periods were comparatively rapid in recurrence and maintained a fairly definite time interval—the signal swinging in and out at a rate of approximately 20 times per minute, frequently over a period of an hour or more. Investigation showed that this condition was caused by a twist in polarity of the wave front, and the phenomenon was exaggerated at the receiver by the strongly vertical characteristics of the directional receiving antenna. Experiments with a portable doublet antenna showed that while the wave might be polarized horizontally at the directional antenna, it would return to a vertical position a few hundred feet further along the wave path. The condition finally was corrected by the use of a very long harmonic wire receiving antenna.

Connections to Transpacific Radiotelephone

On December 23, 1931, the Mutual Telephone Company system was connected with the American Telephone and Telegraph Company system through the radiotelephone circuit between Honolulu and San Francisco, Calif. From San Francisco the service is extended through the American Telephone

and Telegraph Company's facilities to the North American Continent, and through other radiotelephone circuits, to many foreign countries. On the Hawaiian end, the service is extended through the ultra-high frequency system to the other islands of the group. As a result of the excellent transmission characteristics of the 2 systems, interconnections have been very successful. During the past 3 years about 700 commercial calls have been transferred from the interisland system to the mainland and to foreign countries, and they have enjoyed a very high transmission rating. For these connections, a straight 2 wire patch is made at the Honolulu control board.

Program Transmission and Relaying

There has been some call for use of the interisland circuits in handling broadcast programs originating on the outlying islands; and while neither the apparatus nor the telephone lines involved are designed for high quality program transmission, some quite successful connections have been made. Notable among these was the recent broadcast of the ceremonies attending the opening of the new highway to the summit of Haleakala Crater on the Island of Maui. In this instance the program originated at the top of Haleakala and was transmitted to Honolulu over the ultra-high frequency circuit, and there bridged to a local broadcasting station and to the R.C.A. short wave station at Kahuku, Oahu. The signal from Kahuku was picked up at San Francisco and transferred to the network of the National Broadcasting Company. The broadcasting company gave the program a rating of 95, which is considered excellent.

The circuit between the islands of Maui and Hawaii frequently is used to provide an additional circuit from Oahu to Hawaii, via Maui, or to Maui via Hawaii. This forms a valuable adjunct to the service as a whole not only in handling overflow traffic during rush hours, but as an emergency circuit in the event of failure of a direct circuit. This relay has proved quite satisfactory, and the general quality of conversations compares favorably with those over a single circuit. In the original set-up, the circuits were patched together at the telephone exchange controlling the Maui radio station; but since this 2 wire patch left 2 possible singing paths in the circuit, it was considered desirable to effect a 4 wire patch at the radio station. From personnel considerations it is not practicable to call upon the station staff to perform this patching operation; so an automatic patching device was designed, utilizing a series of relays actuated by an automatic telephone selector switch. With this device the telephone operator, by dialing different numbers, may set up either circuit individually or patch the 2 together at the radio station. Since one singing path is eliminated by this method, it is possible to operate the 2 circuits at a higher level, and considerable improvement in quality is effected.

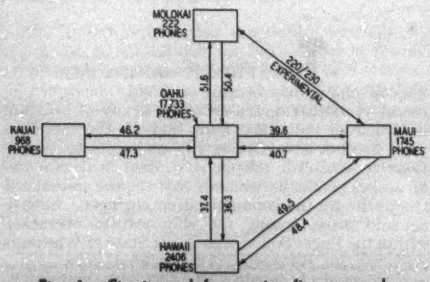

Fig. 6. Circuits and frequencies (in megacycles per second) used for Hawaiian interisland circuits

New 220/230 Megacycle Circuit

On April 22, 1935 the Mutual Telephone Company placed into operation an experimental circuit between the islands of Molokai and Maui operating on frequencies of 220 and 230 megacycles. This circuit now is operating on a commercial basis through special permission granted by the Federal Communications Commission; it is hoped, by this means, to accumulate valuable data on the transmission characteristics of these frequencies. The Maui end of the circuit is located at the interisland ultra-high frequency station at an altitude of 2,500 feet, and the Molokai end at the company's wireless telegraph station at Kaunakakai, which is at sea level. An optical path 56 miles in length exists between the 2 points.

Technical considerations that influenced the selection of frequencies in the neighborhood of 230 megacycles for this circuit were those of automobile ignition interference, directional antennas and their cost, interference between transmitter and receiver operated in the same building, and interference from the wireless telegraph plant.

The Molokai end of this circuit was placed at the present wireless station to effect a desirable economy in personnel and plant property. This site is on a well traveled country highway and several interference problems were presented. Experiments developed the fact that frequencies in the range of 150 to 400 megacycles are relatively unaffected by automobile ignition interference, and it was found possible to eliminate noise from this source entirely with directive antennas elevated 30 or 40 feet. No interference is experienced from the wireless telegraph transmitter, operating on 5,750 kilocycles, and located about 100 feet from the receiving antenna.

The transmitting antennas consist of half wave doublets located at the focus of quarter wave parabolas. These parabolas are supported on towers 50 feet from the ground and are fed through 240 ohm transmission lines. The transmitters are of the modulated oscillator type, utilizing 2 type 800 tubes in a push-pull arrangement, with approximately 50 watts input. Long resonant grid lines are used for frequency control and have proved highly satisfactory at these frequencies.

Several types of receivers are being tested, in-

cluding superregenerative and superheterodyne arrangements. A superregenerative affair utilizing the new type 955 tube has proved most satisfactory to date. The field laid down by the transmitter is so great that extremely sensitive receivers are not required, and more attention is being given to stability and noise suppression than to sensitivity.

Frequencies are checked by harmonic methods, from the standard frequency transmission of the U.S. Bureau of Standards. An electron coupled oscillator set at 10,000 kilocycles is used to generate harmonics, which are amplified and beat against the transmitters in a carefully shielded receiver. The frequencies were selected purposely at 10,000 kilocycle harmonics to facilitate these measurements. At the present time no attempt at constant frequency monitoring is made, but the weekly checks so far have shown that the control method used should be entirely adequate.

Economic Considerations

Since so many of the engineering problems presented in establishing a communication system are created by economic necessity, it might be of interest to outline briefly some of the commercial features of the system under discussion.

At the time the interisland radiotelephone circuits were placed in commission, the Mutual Telephone Company was operating an interisland wireless telegraph system linking the islands of Hawaii, Maui, Kauai, Molokai, and Lanai, to Oahu, and the new radio telephone circuits entered into active competition with this existing system. At this time, the wireless telegraph department offered service from 7:30 a.m. until midnight daily, employing 2 licensed wireless operators at each station. With the radiotelephone department offering 24 hour service at rates comparable to the amount required for a telegraph message and an answer thereto, it was to be expected that the wireless telegraph system would sustain a considerable loss in traffic. To offset this expected loss, the night operators were replaced with lower salaried clerks who accept telegraph traffic and effect delivery by means of the radiotelephone. Operating under this arrangement, the telephone system has carried an average of 7,000 messages per year in addition to its subscriber load of approximately 15,000 calls.

The entire population of the Territory of Hawaii is 378,948, of which number 207,000 reside in Oahu. The number of paid calls since the circuits were opened has averaged 15,000 per year, and average gross revenue per year has been $50,000. The total capital investment of the system is approximately $332,000. From these figures it may readily be seen that an attempt to produce adequate return from such a system must present some unique engineering problems, not necessarily encountered elsewhere.

The 3 years of operation of this system have shown that the ultra-high frequencies are well suited to short quasi-optical ranges, and that reliable seminonattended radio telephone services are practicable. It is believed that the practical demonstration of these possibilities may help to advance the application of these frequencies.

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Ship-to-Shore Radio in Puget Sound Area

Telephone communication to and from harbor craft in the Puget Sound area in the State of Washington is accomplished by means of low powered radiotelephone channels from each boat to a single land station from which connections can be made to any telephone; the equipment used for this purpose is described here. A 400 watt transmitter is used in the land station and a 50 watt transmitter on each boat. Frequencies used are 2,522 kilocycles for the shore-to-ship direction, and 2,126 kilocycles for the ship-to-shore direction.

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TELEPHONE communication in its various phases has become so highly developed in recent years that regardless of the degree of isolation in which an individual finds himself, the commonplace habit of always being able under normal conditions to establish telephone contact with anyone he desires results in demands that require specialized treatment by the communication engineer. Such a demand arose among the ship owners operating within the Puget Sound area in the State of Washing-

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ton. This large inland body of salt water extends in the United States about 150 miles from the international boundary on the north to its southern end at Olympia. Its average width is approximately 50 miles with outlets to the Pacific Ocean through the Strait of Juan de Fuca and Georgia Strait. Hundreds of islands are within the confines of the sound, ranging in size from mere rock juttings to an island (Whidby) that is the second largest in the United States.

Puget Sound serves a large area the principal resources of which are lumber and fishing. Movement of the raw products to points where the manufacturing and processing is carried on comprises a major part of the short haul shipping in the Puget Sound area. Large lumber and pulp mills have been established permanently at locations where deep sea shipping and rail facilities are readily available. Logs in the form of large booms are towed to the mills from the sources of supply which extend throughout the area drained by Puget Sound. The average haul of each boom is about 75 miles and consumes several days. Because of the relatively long time a tug is isolated in each operation, it is evident that some economical means of dispatching and directing the activities of the tow boats from the land headquarters is desirable. In fishing, there is an even greater need than in log towing for close contact between boat and land, in order that both the fishing and cannery activities may be co-ordinated so as to prevent wastage of fish during large runs.

From the foregoing, it seems clear that some means of communication between harbor craft and land stations would be useful. A preliminary view of the problem indicated that low-powered radiotelephone channels from each of these boats to a single land station from which connections could be made over land wires to any telephone appeared to be the most economical and practical means from the standpoint of the ship owners. Furthermore, the government regulations covering the issuance of operators' licenses for radiotelephone transmitters of 50 watts or less power are such that the average member of a ship's crew can qualify after a few hours instruction, thus making it unnecessary for vessels employing this equipment to carry a special radio operator.

Selection of Land Station Site

After it was decided that this service was feasible and should be established, the initial order of procedure was the selection of the site for the land station. This involved consideration of the following primary factors: radio transmission or coverage, freedom from interfering noise, proximity to other radio stations, power supply, telephone wire connections, availability of land and housing facilities, and, of course, the cost of each of these items.

Radio Transmission

The radio transmission requirements for the land transmitter are of prime importance, as it is essential to locate the transmitter so as to provide adequate signal strength to the area that must be covered. For the distances involved in the harbor area it is advantageous to make use of a frequency that will permit covering the entire area with the direct or "ground" wave. The frequency assigned by the Federal Communications Commission for the Puget Sound shore-to-ship transmission is 2,522 kilocycles, and for transmission in the ship-to-shore direction 2,126 kilocycles. When it can be used alone, the ground wave is usually superior from the standpoint of quality and freedom from fading. The signal strengths obtained with ground wave transmission, however, are affected considerably by the terrain in the transmission path. For example, the daytime range of a 50 watt transmitter may be 150 miles over water while over land it may be less than 15 miles. Furthermore, because of the characteristics of overland transmission in which the attenuation in the first mile or 2 is much greater than in succeeding miles, the location of the shore station a mile back from the shore reduces the over-water range to 50 miles. The first requirement, therefore, was that the shore station be located as close to the water as possible. Calculated field strength distribution patterns were made for various tentative locations of the radio station. These predictions, however, were checked by an actual field strength survey.

At the locations that appeared from the theoretical

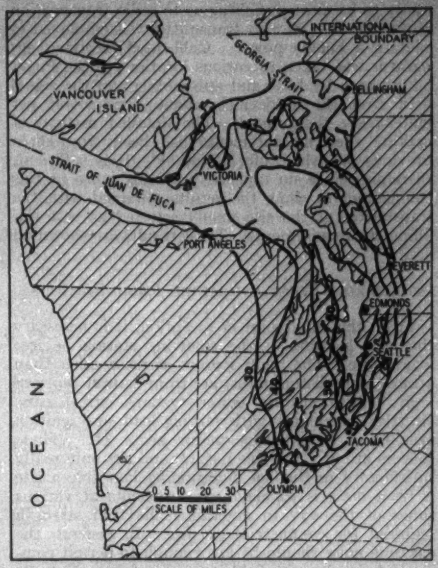

Fig. 1. Field strength contour map of Puget Sound and vicinity

Measurements made with 50 watt transmitter at the Point Edwards (near Edmonds) site. Figures on contour lines indicate field strength in decibels above one microvolt per meter

study to be most promising as to radio transmission performance, a 50 watt transmitter was employed to radiate a known power. Calibrated receiving apparatus was taken to various locations in the Puget Sound area by boat and automobile and the signal field strengths in decibels above 1 microvolt per meter were determined. The detailed method of making such measurements has been covered in previous published information.[1,2,3] It is sufficient, therefore, since no unusual problems arose in this connection, to show the results obtained with the transmitter at the site finally selected as best fulfilling the requirements. These results are shown on figure 1.

Interfering Noise and Other Radio Stations

From the standpoint of reception, it is necessary that the location of the receiving station be free from noise. The main sources of noise other than atmospheric disturbances, are from certain types of high voltage electric power systems, street cars, electrical machinery with varying load, and ignition systems of automobiles, motor boats, etc. These sources are of a variable nature, and the only really satisfactory method of determining how free a site is from noise is to make measurements at various times of the day to determine the field strength required for commercial circuits. In general, the daytime noise should be low enough to permit commercial circuits with field strengths of from 15 to 30 decibels above one microvolt per meter, depending, of course, upon the coverage desired. It was found generally that the receiving antenna should be at least 300 feet from automobile highways and $^1/_4$ mile or more from high voltage power transmission lines. Measurements of noise and of interference from other radio stations were made, and the site selected was found to be extremely free from all sources of interference.

The site selected as fulfilling the foregoing requirements in addition to having power supply and telephone wire connection available is on Point Edwards about one mile south of Edmonds, Wash. The plot contains about 13 acres of tide and harbor land and has a shore line of approximately 1,300 feet. While the land is flooded to a depth of several feet during high tides, about half of it may be utilized in the future for antenna construction without excessive cost.

Housing and Antenna System

The building housing the transmitter and receiver is of wood frame construction erected on treated piling.

The transmitting antenna is of the simple vertical type, 80 feet high and supported by a single pole 110 feet high. This pole also is supported by piling and is adjacent to the building. The receiving antenna is of the vertical type, 40 feet high and located 200 feet from the transmitting antenna; it also is supported by piling. A tuning unit is mounted in a weather-proofed box on the receiving antenna pole.

1. For all numbered references see list at end of paper.

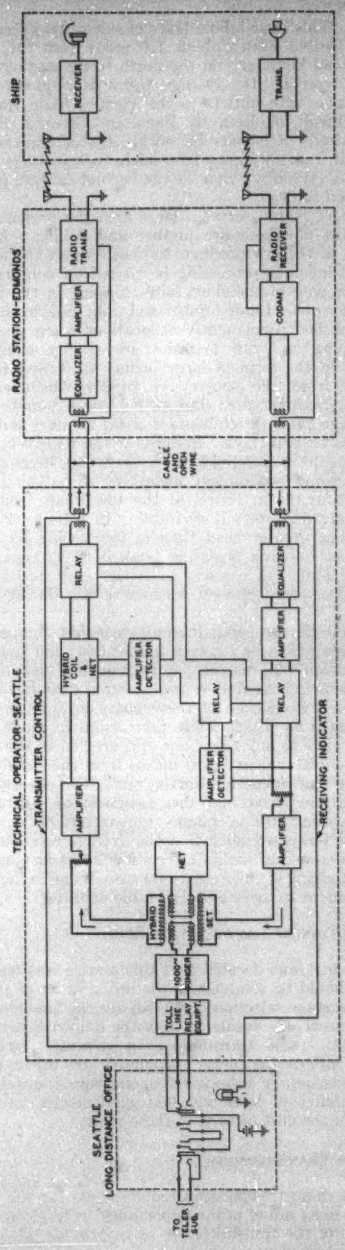

Fig. 2. Schematic diagram of Puget Sound harbor-craft ship-to-shore radiotelephone circuit

The transmission line from the receiving antenna to the receiver in the radio equipment building is a special armored and lead covered concentric conductor type.

Equipment

Equipment at the land stations consists of a 400 watt transmitter with a rectifier unit for power supply similar to the type generally used for aviation service. Frequency stability is obtained by the use of a quartz crystal frequency control which will maintain its frequency to better than 0.025 per cent. It is designed for substantially complete modulation of the carrier, and under this condition little distortion occurs to the speech frequencies. A tuning unit for tuning the transmitting antenna to resonance also is housed in the building. The radio receiver is of a superheterodyne type having a high degree of sensitivity and selectivity and was designed primarily for use in marine radio telephone service with small boats. Associated with the receiver is a "codan" (carrier operated device anti-noise) which serves to cut off the output of the receiver when no carrier signal is being received from a ship station. During such periods, the automatic gain control permits the receiver gain to increase to its maximum value, and if the "codan" were not used this would result in high noise being delivered to the receiving circuit; this not only is annoying to the operator or shore subscriber, but also distinctly affects the operating adjustments of the voice frequency equipment. These comprise the main items of apparatus in the radio building.

As shown on the block diagram, figure 2, a 4-wire circuit is used to the Seattle office. In the Seattle office, equipment is provided for combining the transmitting and receiving channels to form a 2-wire circuit capable of being switched over wire circuits of the telephone plant. The equipment, known as "*B*-1 control terminal," includes means for regulating speech volumes; outgoing, so as always to load the ratio transmitter properly; and incoming, so as to give the shore subscriber the best received volume. A voice operated device known as the "vodas" provides means for suppressing echoes and singing. This device is essentially the same in principle and in its operation as those used in intercontinental radio telephone service which have been described in detail in previous publications. In addition to the foregoing units, apparatus for monitoring and testing is provided.

The 2-wire circuit is terminated in the Seattle toll switchboard where it appears as any other long distance circuit. Since the harbor station is arranged for remote control operation, equipment is provided so that the transmitter is turned on automatically when the operator inserts a plug in the "harbor circuit" jack.

Operation

As already noted, the land radio transmitter and receiver at Point Edwards is operated remotely from Seattle, a distance of about 15 miles, where the licensed radio operators assigned to operate the station are located. The transmitter is monitored continuously by means of an auxiliary radio receiver in Seattle tuned to the transmitter frequency. In addition, the 2-way portion of the voice frequency circuit is monitored by means of an amplifier and loud speaker bridged across the circuit through a high impedance coil. This, of course, indicates to the attendant the general status of each connection as to transmission in both directions. Monitoring by means of a headset is also available and usually is resorted to when conditions require close attention to the adjustment of the apparatus to insure a satisfactory connection.

When a call originates on land, the toll operator connects the land line from the shore subscriber to the radio circuit, designated "harbor," by means of a regular toll cord circuit. This operation, which requires the insertion of a plug in the jack of the radio circuit, automatically starts the transmitter at Point Edwards. It also indicates to the radio attendant, by means of an alarm, that a connection is being made and that his attention is required to ascertain whether any adjustments under his control are necessary for proper operation of the circuit. The switchboard operator then rings with a 1,000 cycle signal which registers as an attention call to all ships that have their receivers operated. The particular vessel to which a connection is to be made is called by name and station letter. This ship then starts its transmitter and reports, and the 2 way connection is established.

On calls originating from a ship, the boat's transmitter is energized and its carrier operates the "codan" circuit associated with the land station receiver. An auxiliary circuit actuated by the "codan" functions to signal the Seattle long distance operator by means of the regular toll line lamp signal. It also signals the radio attendant to stand by in the manner just described. The switchboard operator in responding to the signal inserts the answering plug of a cord circuit in the "harbor" jack which energizes the land transmitter. Two way telephone contact then is established with the ship and from this point on, the regular traffic operating procedure is followed in connecting the ship with the desired telephone station.

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Regulation Beyond the Distribution Substation

Nonuniform load growth, which sometimes results in excessive voltage drops in various parts of an electric power distribution system, caused engineers to consider extending the installation of voltage regulating devices to portions of the system beyond the station. As a result, several supplementary devices have been developed for use in distribution circuits between station and load. These devices and their applications are discussed in this paper.

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THE PROVED economy of using induction regulators together with proper feeder design to compensate for rather than eliminate voltage drop in an electric power distribution system has led to a consideration of extending this principle by installing devices to compensate for or reduce voltage drops in certain individual parts of a feeder in the load area. Experimental installations have been made and have proved so successful that considerable interest has been created in the various types of devices involved. This paper presents a review of the fundamental considerations applying to voltage drop and regulation in distribution systems and a discussion of the factors involved in the economic application of the various supplementary devices, together with a brief mention of the developments that made possible the production of small capacity regulators at reasonable cost.

Regulation and Voltage Drop

Regulation, which is one of the 2 fundamental measures of electric service, is defined as the ratio of the difference between no load and full load voltage to normal voltage. The amount of voltage regulation and the limit of permissible voltage variations have been specified by the public service commissions of many states. In 20 states these limits for cities having populations of more than 2,500 vary from plus or minus 3 per cent to plus or minus 6 per cent and average approximately plus $4^3/_4$ per cent to minus $4^1/_2$ per cent for the lighting period. In discussing certain specific examples in this paper, limits of plus or minus 4 per cent are assumed.

If the substation bus voltage be constant, the regulation of a distributed load consisting of individual customers is determined by the voltage drop from the substation bus to the farthest customer, whereas the regulation of a distributed load on a regulated feeder is determined only by the drop from the nearest to the farthest customer in the load area, as shown by figure 1. This voltage drop in the load area, which determines the regulation, consists of primary, distribution transformer, and secondary drops.

The primary drop may be considered as being divided into 2 parts—3 phase and single phase. For reasons of loss and regulation, 3 phase circuits are desirable for large loads where such loads are balanced and where the full benefit of the 3 phase circuit can be obtained. Assuming equal distances, wire sizes, and conductor spacings, the drop resulting from 3 single-phase 2,400-volt loads wye-connected on a 4,160-volt 3-phase 4-wire circuit is just $^1/_8$ the drop resulting from the same 3 single-phase 2,400-volt loads all connected to the same 2,400-volt single-phase circuit. Ordinarily the circuits constituting the final subdivision of the primary system are loaded so lightly and have such a small voltage drop that 3 phase construction is uneconomical. Also, in the usual types of urban layouts, these circuits serve only a few transformers and so an effective 3 phase balance is not possible. The small voltage drop in a typical single phase lateral circuit, as they conventionally are called, is indicated by the fact that a single-phase 2,400-volt lateral circuit consisting of number 6 (B. & S. gauge) copper conductor and having a 10-kva 0.95-power factor load taken off every 750 feet has a drop of only 1.12 per cent in 3,000 feet. The drops in lateral circuits are maintained at low values when a uniform increase in load occurs by breaking them up with additional 3 phase branches.

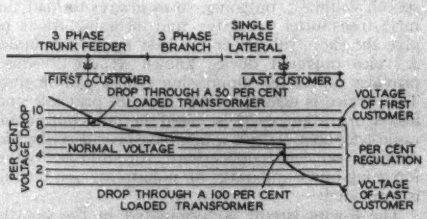

Fig. 1. Distribution feeder regulation

On a regulated feeder, the voltage drop between the first and last customers determines the regulation for the area considered

For instance, doubling the number of 3 phase branches with the corresponding halving of the lengths of the lateral circuits will decrease the voltage drops in the lateral circuits to $^1/_4$ of the original values. The drops in the 3 phase branches and in the 3 phase trunk feeder comprise the rest and usually the major part of the primary voltage drop. The general shape

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of the load area determines the proportioning of the 3 phase drop between the trunk feeder and the 3 phase branches.

The average voltage drop in distribution transformers can be compensated for so the only way distribution transformers affect regulation is in the variation of their individual voltage drops from the average. If distribution transformers be applied so that their loads when installed are 50 per cent of rating and when removed 100 per cent of rating, the voltage drops through average sized (15 kva) transformers will vary between approximately 1.25 and 2.50 per cent or 1.25 per cent. This same variation would occur to increase the regulation if transformers were loaded from 75 to 125 per cent or from 100 to 150 per cent. Obviously the variation could be reduced by narrowing the loading limits.

The secondary voltage drop depends on the sizes and lengths of secondary circuits. For ordinary overhead construction, numerous studies have pointed consistently to the economy of controlling this drop in average residential areas by varying the length of secondary circuit rather than by changing the size of conductor. The following example will serve to illustrate this point: A number 1/0 conductor would be required to make a 50 per cent reduction in the voltage drop resulting from a 0.95 power factor current in a secondary circuit of number 4 wire; considering investment alone, if the additional investment required for the larger conductor were applied to decreasing the average secondary circuit length from 500 to 250 feet by doubling the number and decreasing the size of distribution transformers from 15 to $7^1/_2$ kva, the drop would be reduced 75 per cent.

As shown by figure 1 the regulation specified determines the sum total of the primary, transformer, and secondary voltage drops. It is possible by careful economic analysis to proportion correctly the total drop between these various parts. For example, figure 2 shows the rate at which the total

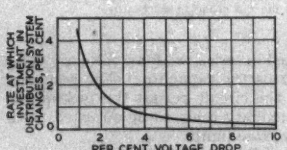

Fig. 2. Effect of secondary voltage drop on distribution system investment

This curve applies to a system in which the investment in distribution transformers and secondary copper is 23 per cent of the total investment in distribution facilities, excluding the substation, when the secondary drop is 3 per cent

investment in distribution facilities changes at each value of secondary voltage drop. Referring to this curve, it may be seen that the total investment changes at the rate of 1 per cent per per cent change in secondary drop when the secondary drop is 3 per cent and at the rate of 0.7 per cent when the secondary drop is 4 per cent. Therefore, if the secondary voltage drop be increased from 3 to 4 per cent, the total investment in distribution facilities will decrease 0.8 per cent (average rate between 3 and 4 per cent secondary drops). This particular curve applies to an average urban distribution system in which the maximum loading of distribution transformers is

This curve applies to the same system as figure 2. When the primary voltage drop is $3^1/_2$ per cent, the investment in 2,400/4,160 volt primary copper is 9 per cent of the total investment in distribution facilities

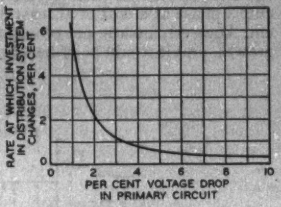

Fig. 3. Effect of primary voltage drop on distribution system investment

from 100 to 150 per cent of their rated capacities and the investment in distribution transformers and secondary circuit copper is 23 per cent of the total investment in distribution facilities from the substation to and including the customers' meters. Figure 3 shows the rate at which the total investment in distribution facilities changes at each value of primary voltage drop in the same hypothetical system. The investment in primary circuit copper in this particular 2,400/4,160 volt primary system is about 9 per cent of the total investment in distribution facilities, not including the substation. Having plotted these curves (figures 2 and 3) the proportioning of the voltage drops in primary and secondary circuits is obviously a matter of determining the primary and secondary drops at which the rates of change of the total investment are equal. For instance, if the total voltage drop in the primary and secondary circuits be $6^1/_2$ per cent, 3 per cent should be allocated to the secondary circuit and $3^1/_2$ per cent to the primary circuit, because the rate at which the total investment in distribution facilities changes is the same (1 per cent) in each case.

Need for Supplementary Regulating Devices

Having thus reviewed the fundamental considerations applying to voltage drop and regulation for ordinary conditions of load density and growth, the extraordinary conditions or exceptions to the rule will be studied. Unfortunately load does not develop over every area as uniformly as might be desired to make economic a generally uniform expansion of primary distribution facilities. This is particularly true in "fringe" areas which only partly are built up. Usually there is a tendency in such areas for certain streets to build up more rapidly than others in the immediate vicinity, which makes the load rather spotty. The primary lateral circuits supplying these streets become loaded and cannot be broken up economically if this requires running in a long 3 phase branch to relieve only 1 or 2 lateral circuits. Several conditions of this nature are indi-

cated in figure 4. The voltage of the last customer served by the 2,400-volt single-phase lateral circuit AB is 6 per cent below the rated voltage, or 2 per cent below the allowable minus 4 per cent. The voltage drop in the lateral circuit itself is $2^1/_2$ per cent. The voltage of the last customer could be brought within the allowable lower limit by making the lateral circuit 3 phase at a cost of at least $250. This expedient, however, makes no provision for future load growth, and it would be of benefit for perhaps only a

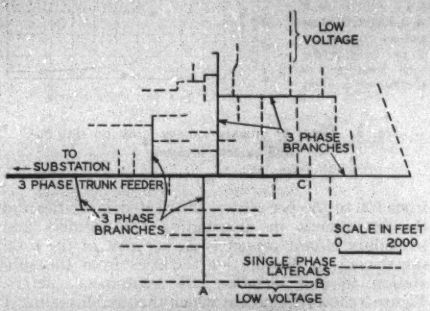

Fig. 4. Urban feeder having several overloaded single phase branches

The low voltage condition on lateral AB can be relieved economically by installing a branch feeder step regulator at A

year or 2 until the construction of a 3 phase branch from C to B was necessary. The other possible alternatives are: (1) the immediate construction of a 3-phase 4-wire branch from C to B, and (2) the installation of a supplementary regulating device at A.

Allowing for the reduction in losses, the yearly carrying charges on a new 3 phase branch would amount to at least $200, whereas the carrying charges on a suitable branch feeder step regulator would be only about $100; the latter would make possible a saving of approximately $100 a year until a more uniform development of load made the construction of the 3 phase branch desirable. The installation of this regulator would result in a considerable improvement in voltage, in addition to the yearly saving mentioned, because the line drop compensator would make it possible to hold an average voltage several per cent higher than would be obtained even by the construction of a new 3 phase branch. An even larger yearly saving (approximately $150) could be obtained by installing a single-step booster. As this device is not equipped with a line drop compensator and, in this case, would change the voltage in a single 5 per cent step, it would not be possible to hold as uniform a voltage as with the step voltage regulator.

These savings would not have been possible several years ago, because it is only very recently that new developments in tap changing mechanism and control have made the construction of a small capacity regulator feasible from the standpoint of cost. Probably the most important factor in reducing the cost of the tap changing mechanism in the step regulator is the thyrite by-pass shown in the diagram, figure 5, which permits the omission of the heavy and bulky preventive reactor and allows the use of a single movable contact arm. ("Thyrite" is a trade name of the General Electric Company and is used to designate a resistance material that is practically nonconductive at voltages lower than a certain predetermined value.) The oscillogram reproduced in figure 6 shows how the thyrite by-pass carries the load current for $1^1/_2$ cycles when the movable contact is between the stationary contacts during a tap change.

In the single-step booster, an appreciable saving was made possible by taking advantage of the fact that it was a one-step device and substituting a simple resonant relay[1] for the customary contact making voltmeter. The basis of this relay is a nonlinear circuit consisting of a resistor, a reactor, and a

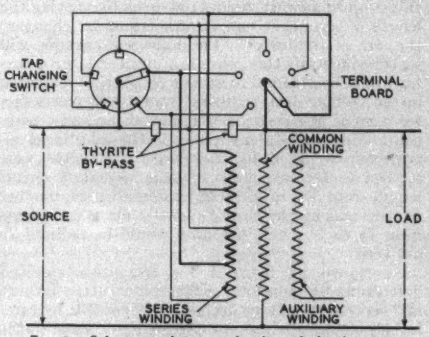

Fig. 5. Schematic diagram of a branch feeder step regulator

The use of the thyrite by-pass greatly increases the simplicity of the tap changing mechanism

capacitor connected in series, with an auxiliary relay coil connected across the capacitor. The nonlinear characteristics of the circuit permit the pickup and drop-out of the auxiliary relay to be adjusted accurately within very close limits.

The prevalence of lateral circuits having excessive voltage drops is shown by table I, which lists data for actual single-phase, 2,300-volt branch circuits taken from circuit maps of 4 different operating companies. In calculating the per cent voltage drop, it was assumed that the distribution transformers were 50 per cent loaded.

In some instances, the economy anticipated from the construction of large capacity feeders (number 3/0 or 4/0 conductor) has resulted in the use of circuits with current ratings too high for the load density of the area served. This naturally results in feeders that are too long and have too high a voltage drop in the load area. When loads were

1. For all numbered references see list at end of paper.

increasing steadily, it was customary to gamble on the future and take care of excessive voltage drops in 3 phase circuits by running in new feeders, or, if feeder positions were not available, by building new substations. Sometimes the expected load growth has not materialized[2] and uneconomical underloading of feeders and substations has resulted. When a condition of this type exists and the feeder load is limited by regulation rather than by its capacity, the careful consideration of supplementary regulators is recommended. The loading of a feeder with a uniformly distributed load can be increased 50 per cent by installing a bank of supplementary regulators to compensate for the 3 phase drop in the load area. When compared with the alternative of running in a new feeder, the regulator installation would only have to show an advantage in yearly carrying charges over 50 per cent of those for a new feeder.

The proper location of such a bank of regulators is where the trunk feeder drop is $^1/_2$ of its maximum value in the load area. On a feeder having a uniformly distributed load, the location would be $^1/_3$ of the distance into the load area. The current at this point would be $^2/_3$ of its total value and so a regulator rating equal to the present value of the feeder load current would provide for the 50 per cent increased loading that such an installation would make possible. The maximum compensation possible is equal to the voltage drop in the trunk feeder in the load area, unless a special construction such as a back feed is used. An idea of the amount of this voltage drop may be obtained from figure 1.

Conditions most favorable to an installation of this type is a feeder with 2 distinct load centers, but with negligible load between. Consider, for example, a 4,800-volt delta-connected circuit feeding through one small community to another 4 miles distant. Assuming a 6 or 7 per cent voltage drop between the towns, it obviously would be necessary to use a feed back or its equivalent to maintain a reasonable voltage at each of the towns. It is estimated that the cost of 2 miles of circuit for a feed back would be at least 50 per cent more than the cost of 2 4,800-volt branch feeder induction regulators connected open delta. The induction type of regulator would be especially desirable for such an application because of its reliability, low maintenance requirement, and instantaneous response.

Table I—Voltage Drops in Typical Single-Phase 2,300-Volt 2-Wire Lateral Circuits of 4 Typical Distribution Systems

System	Length of Circuit, Feet	Wire Size, B. & S. Gauge	Transformer Kva	Assumed Load, Amperes	Per Cent Voltage Drop
A	3,950	4 & 6	.357	77.5	4.8
	2,600	6	.188	41.0	2.0
	3,300	4	.340	74.0	3.1
	6,400	4	.385	83.5	6.6
B	2,100	6	.200	43.5	1.7
	3,700	6	.165	35.9	2.5
	3,700	1/0	.196	42.5	1.0
	2,000	6	.107	23.5	0.9
	10,900	6	.96	20.9	4.3
C	10,500	6	.114	24.8	4.8
	3,240	4	.159	34.6	1.4
	5,100	4	.130	28.3	1.8
	5,000	6	.95	20.5	1.9
D	6,150	6	.218	47.5	5.4
	6,600	6	.167	36.5	4.5
	4,100	6	.230	50.0	3.8

Instantaneous Regulation Causing Light Flicker

So far this discussion has been confined to regulation caused by steady loads. Of increasing importance is instantaneous voltage drop which causes light flicker. The majority of lamp flicker complaints involve only one particular secondary circuit and individually may not amount to very much. In the aggregate, however, they may be rather serious.

The 2 general methods of reducing the instantaneous drop in secondary circuits are: first, by design, and second, by the addition of supplementary devices. In regard to design, there is, of course, the possibility of reinforcing the circuit either by using a larger conductor, or by interspacing transformers, or both. For a 12 inch spacing the resistance and reactance of a number 1/0 copper conductor are approximately the same; therefore, as the size of wire approaches and exceeds that size, the benefit obtained by increasing wire size decreases rapidly because, although the resistance decreases, the reactance remains approximately the same, and for low power factor current the largest part of the voltage drop in the heavier conductors is due to the circuit reactance. Some thought has been given also to decreasing the conductor spacing. The larger the conductor the more effective this becomes. For instance, decreasing the spacing from 12 inches to 1 inch will reduce the voltage drop caused by a 0.50 power factor current 21.5 per cent in a number 4 conductor, and 38.5 per cent in a number 2/0 conductor.

Assuming the same total transformer capacity, a slight improvement may be obtained by decreasing the length of secondary circuit. Specifically decreasing the size of transformers from 15 to 10 kva with a resultant decrease in spacing from 1,000 feet to 666 feet decreases the voltage drop caused by the 0.50 power factor starting current of a motor in number 2, 4, and 6 secondary conductors by ap-

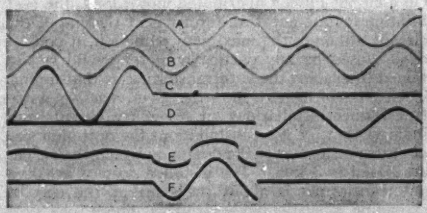

Fig. 6. Current and voltage relations in regulator of figure 5 during a tap change

A. Load voltage
B. Load current in line
C. Current in high tap
D. Current in low tap
E. Thyrite switching by-pass voltage
F. Current in thyrite by-pass

During the tap change the load current flows through the thyrite by-pass

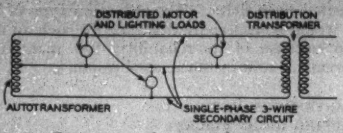

Fig. 7. Connection of autotransformer in secondary circuit for reducing instantaneous voltage fluctuations

The best location of the autotransformer is at the end of the secondary circuit if the motor loads are distributed

proximately 19.5, 22.5, and 25 per cent, respectively. The larger the transformer, the larger will be the reduction experienced. For instance, decreasing the transformer size from 25 kva to a hypothetical $16^2/_3$ kva with the resultant decrease in spacing from 1,000 feet to 666 feet will decrease the voltage drop caused by the 0.50 power factor current in a number 2 secondary conductor by approximately 24.5 per cent.

The problem of reducing instantaneous voltage drop causing light flicker has given added impetus to the practice of banking or interconnecting transformer secondary circuits. It can readily be seen that the interconnection of similar secondary circuits will reduce the maximum voltage drop (at the midpoint between transformers) by 50 per cent.

The Secondary Autotransformer

Instantaneous voltage fluctuations on secondary circuits usually are caused by the starting of motors connected from line to neutral. Obviously if such motors were for line-to-line connection the voltage drop would be only $^1/_4$ of the drop for the line-to-neutral connection for the same starting kilovolt-amperes (neglecting voltage drop in transformer). A large part of this possible improvement can be obtained by installing an autotransformer in the secondary circuit,[3] as shown by figure 7. Its function is to transform the motor starting current at line-to-neutral voltage to line-to-line voltage and thus cause it to be transmitted at line-to-line voltage rather than at line-to-neutral voltage, with the consequent 75 per cent reduction in voltage drop. On a circuit having distributed motor load, the best location for the autotransformer is at the end of the circuit, although the maximum reduction in voltage drop caused by any particular motor would be obtained by placing the autotransformer at that motor. The curves of figure 8 show the effectiveness of autotransformer installations on secondary circuits and indicate that for most installations the optimum size of autotransformer of the design on which the curves are based is 3 kva. The installed cost of a 3 kva autotransformer is about the same as the cost of extending a single phase primary circuit one pole span where such an extension requires setting a new pole. The application of autotransformers has been found to be very attractive for temporarily relieving bad voltage situations until the extension of primary facilities is desirable. In one case of underground primary construction, saving the carrying charges of a primary extension for only a few months more than paid for the complete installation of an autotransformer.

Primary Series Capacitor

Ordinarily the voltage fluctuations reflected in the primary circuit are not sufficiently large to cause lamp flicker. However, when such a situation does occur, it is quite serious, first, because of the large number of customers affected, and second, because of the large expenditure usually required to correct it.

Occasionally, normal allowable starting currents of motors near the end of a long primary circuit cause objectionable voltage fluctuations. In several situations of this kind, it was possible to bring about the necessary reduction in instantaneous voltage drop by neutralizing the inductive reactance of the circuit by installing a series capacitor. In one of these situations the series capacitor installation cost only about $^1/_3$ as much as the cheapest alternative.[4]

By overneutralizing the inductive reactance it is possible to obtain a reduction in instantaneous voltage drop caused by current of a low power factor in a circuit, the impedance of which is predominantly resistive. Considerable caution must be used in this connection, however, because the amount of correction obtained depends largely on the power factor of the current.

For economic reasons it is desirable that the capacitive reactance (X_c) and correspondingly the capacitor voltage drop be as high as possible. This is because capacitive reactance is inversely proportional to the capacitance ($X_c = 1/[2\pi fc]$) and the capacitance has a direct bearing on capacitor cost.

In general, the successful application of the series capacitor depends on 4 factors:

1. Instantaneous regulation required on account of light flicker.
2. Line reactance a large part of the total impedance.
3. Compensation not restricted by loads tapped off at close intervals along the feeder.
4. The rating of the capacitor economically feasible.

The enthusiasm for the various supplementary regulating devices shown by engineers who have

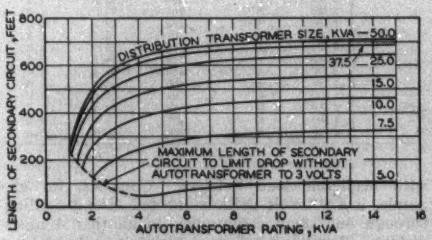

Fig. 8. Autotransformer capacity required to reduce secondary voltage dip to 3 volts

The 3 volt dip, which includes the voltage drop in the distribution transformer, is caused by the 25-ampere 0.50-power factor starting current of a $^1/_2$ horsepower motor. These curves apply to a secondary circuit of number 4 copper wire having an average conductor spacing of 12 inches

applied them successfully is excellent evidence that such devices have a place in distribution system design. Believing that it would be of real benefit to the industry, this paper has attempted to bring about a more general appreciation of how, in certain instances, applications of supplementary devices make it possible to save carrying charges by deferring major system additions, to eliminate line rebuilding in which the original investment in copper largely is lost, and to supplement existing facilities as conditions require so as to approach the ideal of making system additions on the basis of existing rather than anticipated loads.

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Lightning Currents in Field and Laboratory

A review of available data on the magnitude and effects of lightning stroke currents, supplemented by laboratory experiments to check these effects, is presented herewith. Maximum currents of 150,000 to 200,000 amperes having durations of from 40 to 100 microseconds are indicated.

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LIGHTNING stroke currents were produced in the laboratory[1] early in 1933. Since then, physical effects associated with natural lightning have been compared directly with similar results obtained in the laboratory. This has been an effective method in determining the currents involved in the lightning stroke.

The more common field experiences with lightning current phenomena hereto recorded by or reported to the author have been associated largely with the following effects: (1) fusion of conductors, (2) crushing of parallel conductors and of tubes, (3) surface burning of conductors, (4) explosive and shattering effects, (5) magnetic and magnetizing effects, (6) characteristics of lightning arc proper, and (7) miscellaneous effects. Accordingly, the laboratory data on lightning currents presented here are confined to these corresponding field experiences. Furthermore, because of the continually accumulating field information the present paper will be limited largely to factual data. However, the author has made use in part of analyses already available to compare the field experiences with the laboratory measurements. Rapid progress has been made lately toward a quantitative understanding of lightning phenomena. The mechanism of the lightning stroke formation has been revealed most effectively by means of the "rapid" camera.[2] New and improved methods for determining lightning currents have been applied in the field. After a trial period both here[3] and abroad[4] the magnetic link has been found particularly suitable to measure lightning stroke currents on transmission lines.[5,6,7] Another device found adapted to measure lightning currents consists simply of 2 metal discs separated with thin paper insulation;[8] this device has been employed to measure the lightning currents in the ground wires of lightning arresters. By these 2 methods some valuable data on lightning currents have been procured in the past 2 or 3 years. These data are summarized here briefly for the purpose of comparison with the data recorded by the method described in this paper.

For practical purposes the various methods now available for recording the characteristics of lightning stroke currents may be sufficient; but from a scientific standpoint it is suggested and urged that eventually direct measurements of the lightning stroke with the cathode ray oscillograph be made as a final

Fig. 1. Oscillograms of 140,000 ampere discharge from lightning stroke current generator

Period ≅ 45 microseconds. Duration to half crest value = 190 microseconds

1. For all numbered references see list at end of paper.

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The author acknowledges the assistance received from many sources in securing part of the field data recorded in this paper, and particularly of the following: W. J. Humphreys (U. S. Weather Bureau) and D. D. Clarke (Kansas City Power and Light Company) who made available, respectively, the crushed lightning rod and the crushed-parallel conductors; A. H. Schirmer (Bell Telephone Laboratories) who submitted extensive data on the fusion of conductors; J. K. Hodnette (Westinghouse Electric and Manufacturing Company) who secured valuable field data in conjunction with his development of the deion gap for distribution transformers; and W. L. Teague (Westinghouse Electric and Manufacturing Company) who assisted in the laboratory investigation and analysis of data.

confirmation. In all events, field experience undoubtedly will continue to remain a most valuable source of information, well worth recording and analyzing. In fact, field experience alone can be the ultimate confirmation of the adequacy of protective equipment and devices employed in electric circuits and with apparatus, and also of other schemes and devices, such as the lightning rod, used to safeguard property, animal stock, and human life.

Fusion of Conductors

The current of a single lightning discharge that would fuse a conductor is given by the expression[1]

$$I^2T = (kA)^2 \qquad (1)$$

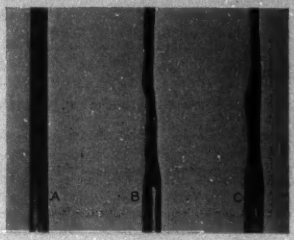
where

A = area of conductor in square millimeters
I = crest value of current in amperes
T = duration of current in microseconds, measured from start to the half-crest value on the tail of the wave
k = a numerical constant which is a function of the conductor material and of the wave form of the current

For the exponential current $i = I\epsilon^{-0.693\, t/T}$, the constant k equals 320,000 for copper and 200,000 for aluminum. From limited tests on bronze and steel wires having cross-sectional areas between 1.0 and 3.0 square millimeters, k = 200,000 and 220,000, respectively. For a multiple stroke of current discharges I_1, I_2, I_3, etc., of corresponding durations T_1, T_2, T_3, etc., the sum of the products I^2T would be added in equation 1, provided all the heat generated in the conductor is retained during the total duration of the stroke.

Field investigations with the cathode ray oscillograph show a duration of the waves produced on transmission lines by lightning of from 15 to 100 microseconds. Measurements by B. F. J. Schonland (South Africa) of the duration of luminosity in the main channel and of the time required for the main discharge to progress from earth to cloud would indicate an average duration of the discharge in the order of 50 microseconds. His measurements also reveal that the wave form is characterized by a sustained peak on the crest which endures a fractional part of the duration of the wave. More remains to be known of the wave form and duration of the lightning stroke current, but a duration of 40 to 100 microseconds on the basis of an equivalent exponential wave seems reasonable to assume at the present.

Another consideration pertains to the repetitive nature of the stroke. Some strokes are single discharges; others are multiple discharges, only a few involving more than 4. The first discharge is apparently the most intense and severe, while the successive ones appear to be reduced in intensity. It is important, however, to note that actually 80 per cent of the strokes to lines comprise a single discharge,[4,9] while the remaining 20 per cent are multiple discharges rarely exceeding 4. Field observations seem to indicate that multiple discharges of lightning actually may strike the ground at places apart. All these considerations will be given proper weight in deducing the lightning stroke currents from the fusion of conductors.



A—Original tube
B—After 3 successive discharges of 140,000 amperes
C—After 4 successive discharges of 135,000 amperes

Fig. 3. Copper tubes crushed by lightning currents in laboratory (tubes had 14.3 millimeter inside diameter and 0.406 millimeter wall thickness)

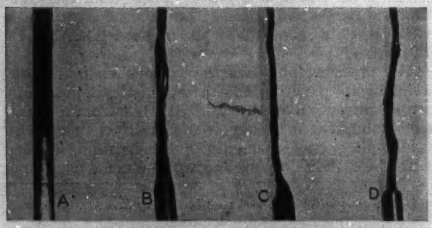


Fig. 2. Copper tubes crushed by lightning currents in laboratory (tubes had 14.3 millimeter inside diameter and 0.254 millimeter wall thickness)

A—Original tube
B—After single discharge of 140,000 amperes
C—After 2 successive discharges of 140,000 amperes
D—After 3 successive discharges of 140,000 amperes

Hundreds of instances virtually are known where 2.05 square millimeter bronze conductors (used in telephone circuits) have been fused by lightning. Hundreds of 2.08 square millimeter (number 14) copper conductors (employed on antennas, for house wiring, for grounding, etc.) also have been reported to have been fused by lightning. An instance has been recorded where lightning vaporized a 3.34 square millimeter (number 12) copper conductor.[10] Another instance is known where a 5.25 square millimeter (number 10) conductor was beaded at the point of contact with the stroke, but not fused.[1] Experiments conducted by E. C. Starr (Oregon State College, Corvallis) have shown that the current in a direct lightning stroke can be expected to fuse 2.08 square millimeter copper wires and smaller, but that larger conductors ordinarily will conduct the current successfully to ground.

Several instances are known where overhead copper telephone wires of 5.50 and 8.32 square millimeter cross section were parted at the point where lightning struck, presumably because the lightning discharge caused the wire to lose its tensile strength at the point hit. One source relates unconfirmed reports of copper conductors up to and including

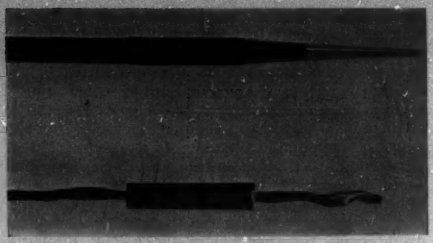


Fig. 4. Lightning rod crushed in the field by lightning stroke discharge[16] (rod had a 14.65 millimeter inside diameter and 0.675 millimeter wall thickness; original rod is shown at top)

13.45 square millimeters that apparently have been fused, while another source states that in no instance was 13.45 square millimeter copper wire fused. From a reliable source it is known where several thousands of 20.9 square millimeter steel ground wires have been installed now for a few years. These ground wires protect a corresponding number of wood poles, which otherwise would frequently be shattered. To date none of these ground wires have been found fused. It is also worth noting that about 30 square millimeter copper and 60 square millimeter steel conductors are prescribed for lightning rods[11, 12, 13, 14] as experience has proved these conductors are fully adequate to discharge the lightning strokes.

From the numerically predominant instances of 2.05 square millimeter bronze and 2.08 square millimeter copper conductors that have been fused by lightning, the present conclusions are justified. On the basis established that the bulk of these fusions were produced by a single discharge or possibly by a heavy single discharge followed by a weak discharge, then from equation 1 and on the basis of 40 microsecond duration the great majority of the severe lightning strokes would involve a current in the order of 100,000 amperes. On the basis of 100 microsecond duration, the current would be in the order of 65,000 amperes. On the assumption of a single discharge fusing the 3.34 square millimeter copper conductor, the lightning current would be 170,000 and 110,000 amperes for durations of 40 and 100 microseconds, respectively. The limited number of reports where copper conductors of cross sections greater than 5.00 square millimeters were fused by lightning are unconfirmed in part or dubious and partly contradicted by reports from other sources. A few investigators have observed copper conductors of 30 square millimeters and larger that have been heated by the lightning stroke to high temperatures, near to the point of fusion[15,16]. There are indications in such instances (also discussed later) pointing to the probability of multiple strokes as having fused the larger conductors.

From the data on the fusion of conductors, hereto reported, one concludes that the probability of lightning stroke currents exceeding considerably 100,000 amperes is rare, though there are indications from these data that lightning currents may attain 150,000 to 200,000 amperes at the most.

Crushing of Conductors

When 2 conductors d centimeters apart each carry a current of I amperes for an average duration of T seconds, each conductor acquires per centimeter length a momentum

$$mv = FT = \frac{2I^2T}{100d} \text{ dyne-seconds} \qquad (2)$$

where

F = attractive force in dynes
m = mass of each conductor per centimeter length, ingrams
v = velocity of each conductor at end of time T

The force action of lightning currents producing the crushing of parallel conductors and tubes is accounted for quantitatively by this fundamental relation.

In one case reported by W. J. Humphreys,[16] figure 4, a hollow copper tube having an inside diameter of 14.65 millimeters and a wall thickness of 0.675 millimeters (32.5 square millimeter section) was crushed by lightning. From the incipient fusion indicated in several places it would seem that this tube was raised to a high temperature. On the assumption of a 100,000 ampere discharge, a force of 400 pounds per square inch of tube surface would be calculated.

Experiment shows that in addition to the current magnitude, the duration and repetitive discharges of the stroke also would influence the crushing of conductors. Copper tubes having an inside diameter of 14.3 millimeters and wall thicknesses 0.127, 0.254, and 0.406 millimeters, each securely brazed along the square-joint seam, were tested. Figure 1 shows typical oscillograms of the currents discharged through the tubes. The 0.127 millimeter tube collapsed partially on a single 80,000 ampere discharge; it was crushed on a single 95,000 ampere discharge; a single 135,000 ampere discharge completely crumpled the tube. The thicker tubes collapsed and

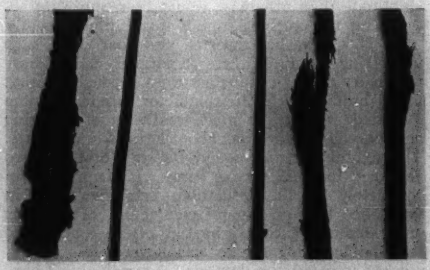


Fig. 5. Parallel conductors crushed together by: (left) direct stroke of lightning in field,[17] and (right) 4 successive discharges of 140,000 amperes each in the laboratory

Fig. 6. Lightning currents recorded in field (bottom group) compared with those produced in laboratory (top group) from the extent and amount of surface burning appearing on the face of the deionizing gap plugs

Left—Discharge of about 25,000 amperes
Center—Discharge of about 50,000 amperes
Right—Discharge of about 100,000 amperes

were crushed on repeated discharges. These repeated discharges were applied about one minute apart, the time required to charge the lightning current generator[23] fully, and therefore some of the heat produced was dissipated between discharges. The amount of crushing produced by 1 to 4 successive discharges, each of 140,000 amperes, can be seen in figures 2 and 3. On the basis of a single discharge, it would appear that lightning strokes unusually severe, in either the amount of current or duration, or both, would be required to crush the rather thick tubes reported; apparently from the laboratory tests, lightning currents in the order of and greater than 200,000 amperes would be required. It seems likely, from this and other evidence, that the lightning strokes that produced crushing of the tubes reported were in the nature of multiple strokes, each discharge being of relatively more moderate current amplitude than otherwise would be required to account for the crushing from a single discharge.

D. D. Clarke has reported and analyzed a very interesting instance where 2 parallel, 8.32 square millimeter copper conductors were crushed together by lightning.[17] Each conductor originally was insulated with triple-braid weatherproof covering and spaced from the other about 10 to 15 centimeters. The lightning stroke found its way down a tree and then to the 2 service wires. It stripped them completely of the insulation, crushing them in semblance into one round conductor. There was no evidence of excessive heating of the conductors, but the lightning stroke was nevertheless severe, judging from all the damage. Accordingly, 2 conductors identical to those employed in service were properly arranged and spaced for test. It was found that the first discharge at 140,000 amperes (figure 1) would strip the rather tough (new) insulation, while the successive discharges would crush the 2 conductors together more and more until after the fourth discharge they resembled closely in appearance the field specimen, as can be seen from figure 5.

From equation 1 a 100,000 ampere discharge of 100 microsecond average duration produces a force of about 350 pounds on each conductor per foot of length. Each conductor assumes a speed of 22 feet per second. With double this current the force and speed are each quadrupled. From data on multiple lightning discharges, the interval between discharges is relatively large so that the 2 conductors would come together before the second discharge took place. The impact energy required to have crushed the 2 conductors observed in the field can be accounted for with no great difficulty on the basis of a severe multiple lightning stroke of about 4 or 5 discharges. Theoretically, a single discharge of rather high current likewise would produce the crushing.

From the field data on the crushing of tubes and conductors reported hereto, it appears that a single lightning discharge would have to attain a current magnitude of 200,000 amperes or more in order to produce such effects. What is more probable is that multiple discharges of more moderate currents have occurred; several of these discharges readily could have produced the crushing.

Surface Burning of Conductors

Field records of lightning strokes near and at distribution transformers protected with deionizing gaps have furnished valuable data. The electrodes of the deionizing gaps discharging the lightning current are marked with a surface figure which, when compared with similar figures on deionizing gaps tested in the laboratory with known lightning cur-

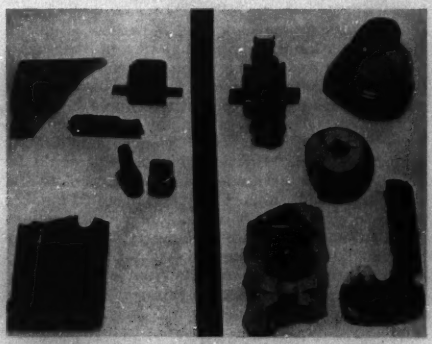


Fig. 7. Shattering effects produced by lightning currents

Right—Shattering of line and guy-wire insulators, fuse cutouts, etc., produced by lightning stroke discharge to distribution line
Left—Similar effects produced with known lightning currents in the laboratory

rents, enables evaluating the lightning current discharged through the deionizing gaps in service. Such a comparison of lightning currents recorded in the field and in the laboratory may be seen in figure 6.

A record of lightning strokes near and at distribution transformers during 1932–33, mounted in suburban or rural areas, is shown by curve *A* in figure 8. A direct stroke at the terminals of a transformer recorded in 1934 indicated a current somewhat greater than 100,000 amperes. The dash-dot extension to 150,000 amperes is intended to represent the maximum current in a stroke recorded to date from this field experience; however, this maximum value does not preclude the rare possibility of 200,000 amperes.

Explosive and Shattering Effects

Direct strokes at distribution transformers also have shattered line and guy-wire insulators, fuse cutouts, and similar apparatus. Such results were produced by the severe stroke cited in the preceding section of this paper, can be seen in figure 7. As the figure shows, similar effects can be produced in the laboratory, in which event the lightning currents required are known.

Lightning strokes to guy wires have blasted the rock, cement, etc., in which the wire was embedded. Shattering of wood poles and trees is a familiar occurrence. Metal pipes have been cracked and even broken open by lightning. The parts of shattered bodies have been projected distances of 100 feet and more. Large holes have been dug a few feet deep into the ground. It is not possible to compare all these and other field experiences with direct laboratory tests, but the forces involved will become apparent from some of the laboratory results.

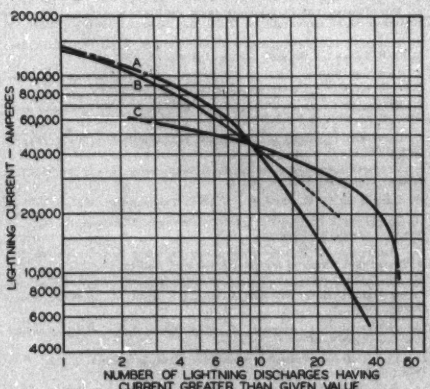


Fig. 8. Comparison of magnitude of lightning currents as ascertained from 3 different sources

A—Direct or near-direct strokes of lightning at distribution transformers during 1932–33, mounted in suburban or rural areas. Transformer years = 4,000

B—Direct strokes of lightning to transmission lines[7]

C—Direct strokes of lightning to transmission lines[4]

Fig. 9. Appearance of lightning stroke discharge of 140,000 amperes produced in laboratory (see oscillograms in figure 1 for duration)

Laboratory tests with fiber tubes indicate that a current discharge, such as in figure 1 when confined to a bore having a diameter substantially less than 2 centimeters gives rise to internal pressures in the order of 10,000 to 20,000 pounds per square inch and perhaps more. These experiments on fiber tubes indicate that when the lightning arc is restricted to a section substantially less than 2 centimeters in diameter high pressures are developed which have a bearing on the dimension of the "core" section of the lightning stroke channel, as will be discussed later. In short, from a consideration of the explosive forces that can be produced by lightning currents in the laboratory, it should not be difficult to account for the destructive effects encountered from natural lightning.

Magnetizing Effect

The practical method now commonly used to measure the lightning currents discharged through the steel towers of transmission lines depends simply on the magnetization of magnetic links and their ability to retain the magnetization produced. Each link consists of a bundle of small magnetic elements so that the magnetization produced is proportional to the amplitude of the current, independently of the wave form. With modern facilities for calibrating these links, apparently dependable data on lightning currents have become available in the past few years.

Many investigators have reported the magnitudes of lightning currents discharged through the towers.[2,5,6] Sporn and Gross also have calculated the currents of the lightning stroke from the currents recorded in the towers.[7] Likewise Grünewald was able to estimate the lightning stroke currents[4] from the currents recorded in the towers and in the ground wires. These data on lightning stroke currents are plotted in figure 8 (curves *B* and *C*). It can be seen that the magnitude of the lightning stroke currents reported to date, as determined from the

Fig. 10. Surface burning produced by 140,000 ampere discharge in laboratory which indicates the "core" diameter of the lightning stroke to be 1.5 centimeters

various methods discussed, are substantially of the same order.

Characteristics of Lightning Arc

The lightning discharge in the laboratory is similar to the lightning stoke in nature. The light produced by the laboratory discharge is intensely brilliant and blinding. The sound produced by the discharge, although the arc is only about 4 feet long, is uncomfortable and even painful to the ear. If one were taken unaware by a laboratory discharge occurring a few feet away, the deafening noise and the blinding light quite likely would produce a stunning effect, much the same as natural lightning does. The diameter of the 140,000 ampere discharge of figure 1, as recorded by the camera at 10 feet from the arc, is about 10 centimeters (figure 9). With the camera removed to a greater distance from the arc, the diameter on the photograph appears still larger (about 20 or 25 centimeters).

The true diameter of the "core" of the arc becomes evident only from certain experimental observations. The fiber tube experiments mentioned previously would indicate the "core" to be about 1 to 2 centimeters in diameter. Another experiment comprised of discharging the arc with a fine copper wire (0.08 millimeter in diameter) to the center of a thick polished copper plate (0.5 by 12 by 12 centimeters). A very small hole was bored at the center of the plate just large enough to carry the fine wire straight through. The 140,000 ampere discharge (figure 1) would produce a uniformly burned surface in the form of a circle about 1.5 centimeters in diameter, as shown in figure 10. The amount of surface burning diminished with a decrease in the discharge current. These experimental data thus demonstrate that the "core" of the lightning stroke channel is in the order of 1 to 2 centimeters in diameter, perhaps 1.5 centimeters representing a severe stroke. From recent theoretical analysis[15] of the characteristics of the stroke channel the deductions conform substantially to the laboratory observations.

Summary

1. From the available substantial data on the fusion of conductors, lightning stroke currents infrequently exceed considerably 100,000 amperes (on the basis of 40 to 100 microsecond duration to half crest value on the tail of the wave). These data indicate that lightning currents may attain maximum values of 150,000 to 200,000 amperes. Similarly, limited instances of severe crushing of tubes and conductors would indicate that on the basis of a single stroke the current would have to attain an amplitude of 200,000 amperes and somewhat more to produce such effects. It is more probable that multiple strokes, consisting of several successive discharges, each discharge involving a relatively smaller current, account for the fusion of the heavier conductors and for the few instances of severe crushing of conductors recorded.

2. Lightning current distribution curves (figure 8) established from lightning data on transmission and distribution circuits and based upon different methods of measurement indicate a substantially similar trend. The current amplitudes from these sources range from about 10,000 amperes to a maximum in the order of 150,000 amperes. These current values are in general agreement with those deduced from the data on the fusion and crushing of conductors.

3. From a comparison of the pressures giving rise to the explosive and shattering effects observed in the field and in the laboratory, it is confirmed still further that the lightning currents generated in the laboratory simulate those in lightning strokes. Pressures are developed from the restricting or confining of the lightning current arc, which are of the order of 10,000 to 20,000 pounds per square inch and perhaps more.

4. Physical characteristics of the lightning arc (light, sound, current density, etc.) have been investigated in the laboratory, establishing also in this respect that the field and laboratory phenomena are essentially of the same nature. From tests of lightning current discharges confined in fiber tubes, and from other tests of surface burning of polished metal plates, the "core" of the lightning stroke channel has been established experimentally as having a diameter of 1 to 2 centimeters, approximately 1.5 centimeter diameter representing a severe stroke.

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Recent Research in Radio Communication

A review of the literature describing research investigations in the field of radio communication, published in the United States and other countries during the past year and more, indicates the progress being made in this field. For each of the 5 principal classifications into which radio communication research is found to be divided, a summary of recent progress is included as part of this article, and a bibliography totaling 104 items gives reference to the principal articles in these 5 divisions.

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A REVIEW of research in radio communication during the past year indicates that research efforts in this field may be divided broadly into 5 general classifications as follows: (1) studies of electromagnetic wave propagation; (2) ultra-short-wave investigations; (3) research in television; (4) studies of the properties of antennas; and (5) investigations of high fidelity. The order of listing indicates the extent of interest of the particular classification as evidenced by the quantity of material published. Each of these divisions of research will be summarized briefly and a bibliography appended.

Especially prepared for ELECTRICAL ENGINEERING under the auspices of the A.I.E.E. committee on research; submitted for publication April 3, 1935, subsequently brought up to date as of July 1, 1935.

1. All numbered references in each section refer to bibliography under the corresponding section.

STUDIES OF ELECTROMAGNETIC WAVE PROPAGATION

The research investigations in this field can be subdivided into 3 parts: (1) direct investigation of the properties of the ionosphere (Kennelly-Heaviside layer); (2) studies of propagation between fixed points on the earth's surface; and (3) development of apparatus and methods to improve the conditions of study of wave propagation.

The attack on the ionosphere is universal. Investigations of its properties have been reported from such widely separated points as Washington, D. C.; Australia; Moormansk, U.S.S.R.; Peru; Calcutta; Bangalore, South India; Sydney, Nova Scotia; and others. The principal method of attack has in most cases been the pulse method of Breit and Tuve[1] with modifications, or the frequency change method of Appleton and Barnett.[2]

The general results of these investigations may be briefly summarized. A number of layers have been evident; the major daytime layers are the E layer at 100–120 kilometers virtual height, the F_1 layer at about 180 kilometers virtual height and the F_2 layer at about 240 kilometers virtual height. The relative electron densities of these layers have been measured. The critical frequencies of the various layers (the lowest frequency at which a wave passes through the layer) have also been measured together with their diurnal and seasonal variations. Typical of the practical potential use of the information now being gathered and aside from the importance of the data as improving our knowledge of the fundamental properties of the ionosphere is the indicated correlation between the results of the ionosphere studies and actual transmission studies as mentioned by Kirby, Berkner, and Stuart.[3] Their observations indicate a relation between the highest critical frequency of the F_2 layer and the highest frequency at which waves can be received over great distances. They found that the maximum frequency at which waves are reflected from the F_2 layer was very much less in summer than in winter. This checks with the results of Burrows[4] who showed that during trans-Atlantic transmission in 1928–29 the highest frequency at which waves could be transmitted across the Atlantic was 22 megacycles in summer and 28 megacycles in winter. As the information concerning the ionosphere continues to accumulate from all over the world, it is certain that knowledge of the earth's ionized atmospheric regions will be considerably enhanced and with it the ability to provide satisfactory radio communication at all times. The bibliography on this subject which follows makes no pretentions to completeness, but it is hoped that the more important studies on this subject, reported during the past year, have been listed. The paper by Kirby, Berkner, and Stuart[3] gives an historical summary of the published studies on the ionosphere together with the report of the U.S. Bureau of Standards observations from September 1930 to April 1933.

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Ultra-Short-Wave Investigations

In this branch of radio research the principal line of attack has been the design and development of satisfactory oscillators for frequencies above 100 megacycles. As is well known, oscillators of the conventional negative grid type are, in general, unsatisfactory for frequencies much above this limit and resource has been had to positive grid and magnetron oscillators. During the year one of the developments has been the design of tubes of small dimensions that can be used successfully as negative grid oscillators above 100 megacycles. Typical of this development is the so-called "acorn" tube described by Thompson and Rose,[1] and by Salzberg.[2] Various types of positive grid oscillators using special triodes or other tubes have been described by Kamio,[3] Thompson and Zottu,[4] Okabe,[5] Hamburger,[6] and others. Studies of special types of magnetron oscillators have been reported by deFassi and Salom[7]; Slutzkin; Leljakow; Kopilowitsch; Wyschiniski and Usikow;[8] and Wolff, Linder, and Braden.[9]

The most recent publication on this topic is the paper of Fay and Samuel[10] describing 2 special triodes for negative grid oscillations and 2 special triodes for positive grid oscillations. For the 2 negative grid oscillators they report the following: one tube capable of producing 0.9 and 8.5 watts at 700 and 200 megacycles with an efficiency of 3 per cent and 29 per cent, respectively; the other produces 12 and 55 watts at 100 and 300 megacycles with an efficiency of 17 per cent and 50 per cent. For the 2 negative grid oscillators they show for one tube a power output of 4.5 and 8 watts at 500 and 600 megacycles with 6 per cent and 5 per cent efficiency, and for the other tube an output of 0.4 and 5.5 watts at 2,000 and 700 megacycles and an efficiency of about 1 per cent.

A number of other investigations have been reported dealing with other phases of ultra-short-wave radio communications, as can be seen from the bibliography. The papers of Hollman,[11] Kelly and Samuel,[12] and that of Scheibe[13] give summaries of the various phases of the subject of ultra-short-wave communication.

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Research in Television

Television research has brought about remarkable developments. The principal investigators have departed from the old mechanical scanning method and its inherent difficulties and have introduced electronic scanning. A complete description of an experimental television system using electronic scanning at the transmitter and a cathode ray tube at the receiver is given by Engstrom[1] and his associates, featuring the iconoscope of Zworykin.[2]

A second television system also using electronic scanning is described by Farnsworth.[3] Both of these systems have reached the point in development where satisfactory images can be received using as subjects for transmission outdoor scenes as well as studio performances and motion picture film. The theory of scanning has received further treatment by Maloff[4] and by Mertz and Gray.[5]

Another field of investigation with application to television has been the development of special wire transmission lines to accommodate the wide frequency bands needed for television. Schelkunoff[6,7] and Espenschied and Strieby[8] have reported along these lines.

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11. Principles and Problems of Television, E. Hudec. *Naturwiss*, v. 22, Nov. 9, 1934, p. 740.

12. Symposium, An Experimental Television System. *I.R.E. Proc.*, v. 21, Dec. 1933, p. 1631, 1652, 1655, 1674, 1692.

13. Survey of Present Systems—Television. *Electronics*, v. 7, Oct. 1934, p. 300.

14. An Electron Multiplier. *Electronics*, v. 7, Aug. 1934, p. 242.

Studies of the Properties of Antennas

Further studies of the properties of antennas have been conducted particularly with a view of controlling the radiation pattern of the antenna. Several methods for accomplishing this have been reported—the tuning method of Nickle, Dome, and Brown[1] and a somewhat similar method by Reinartz.[2]

Investigations have also been carried out on methods of maintaining the directivity of antenna arrays, a most important problem in aircraft beacon work, for example. Two methods have been reported—one by Roder,[3] and the other by Kear.[4]

Other investigations include those of the properties of special types of antennas, such as the rectangular short-wave frame aerial of Palmer and Taylor[5] and the horizontal rhombic antennas of Bruce, Beck, and Lowry.[6] A most interesting investigation of the possibility of the use of high frequency models in antenna studies has been made by Brown and King.[7]

Following are the principal references in this field:

1. Control of Radiating Properties of Antennas, C. A. Nickle, R. B. Dome, and W. W. Brown. *I.R.E. Proc.*, v. 22, Dec. 1934, p. 1362.

2. A New Antenna System for Operating Control of Radiation, J. L. Reinartz. *Q.S.T.*, v. 19, Feb. 1935, p. 9.

3. Elimination of Phase Shifts Between The Currents in Two Antennas, Hans Roder. *I.R.E. Proc.*, v. 22, Mar. 1934, p. 374.

4. Maintaining the Directivity of Antenna Arrays, F. G. Kear. *I.R.E. Proc.*, v. 22, July 1934, p. 847.

5. Rectangular Short Wave Frame Aerials for Reception and Transmission, L. S. Palmer and D. Taylor. *I.R.E. Proc.*, v. 22, Jan. 1934, p. 93.

6. Horizontal Rhombic Antennas, E. Bruce, A. C. Beck, and L. R. Lowry. *I. R. E. Proc.*, v. 23, Jan. 1935, p. 24.

7. High-Frequency Models in Antenna Investigations, G. H. Brown and Ronold King. *I.R.E. Proc.*, v. 22, April 1934, p. 457.

8. Tower Antennas, E. A. Laport. *Electronics*, v. 7, Aug. 1934, p. 238.

Investigations of High Fidelity

Considerable interest has been evidenced in the improvement of the quality and fidelity of broadcast transmissions. Several critical studies of this subject have been published, among them the reports of Ballantine[1] and Goldsmith.[2] In addition, several papers on the improvement of the component parts of a complete transmitter have appeared such as the papers of Olson[3] and Seabert.[4] Much remains to be accomplished in this field.

Following are the principal references in this field:

1. High Quality Radio Broadcast Transmission and Reception, Stuart Ballantine. *I.R.E. Proc.*, v. 22, May 1934, p. 564.

2. Conditions Necessary for an Increase in Usable Receiver Fidelity, Alfred N. Goldsmith. *I.R.E., Proc.*, v. 22, Jan. 1934, p. 9.

3. A New Cone Loud Speaker for High Fidelity Sound Reproduction, Harry F. Olson. *I.R.E. Proc.*, v. 22, Jan. 1934, p. 33.

4. Electrodynamic Speaker Design Considerations, J. D. Seabert. *I.R.E., Proc.*, v. 22, June 1934, p. 738.

5. High Fidelity Broadcast Transmitter Performance, E. A. Laport. *Electronics*, v. 7, May 1934, p. 144.

6. Some Notes on Adjacent Channel Interference, I. J. Kaar. *I.R.E. Proc.*, v. 22, Mar. 1934, p. 295.

Corona Losses at 230 Kv With One Conductor Grounded

Tests have been made to determine the increase in corona losses on a high voltage transmission line, due to the grounding of one of the conductors. The corona losses under this condition of operation, which may occur on a transmission system not having the neutral solidly grounded, are shown to be considerably increased over the more usual operation with all 3 conductors at the same voltage. This corona loss may increase the in-phase component of current, with a consequent effect on the operation of Petersen coils. The conductors of the line used in these tests were hollow copper conductors composed of interlocking segments.

By
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THE increase in corona losses due to the grounding of one conductor of a high voltage transmission line having the neutral not solidly grounded, may affect the operation of other equipment, such as Petersen coils. A Petersen coil, or other form of reactor, has often been placed between the neutral and ground. The purpose is, of course, to neutralize the charging current by the lagging current flowing through the grounding reactor, if an intermittent ground is placed on a conductor, thereby reducing the current to a low value so that the arc will extinguish itself. For theoretically perfect operation, the 2 currents should be equal and should have no in-phase component. As a practical matter, satisfactory operation has been obtained without complete theoretical perfection of conditions, but cases have been reported where unduly high corona losses have caused such a shift in the phase of the charging current as to cause less satisfactory performance.

The authors are not aware of any measured values of corona losses on a transmission line with one phase grounded; corona losses have usually been made with balanced 3 phase voltage. For instance, under normal conditions in a 230 kv line, there would be voltages of 230 kv, respectively between the conductors, and a voltage of 133 kv between each conductor and ground. If one conductor should become grounded (with an ungrounded neutral or a neutral grounded through a reactor) the same voltage will exist as before between conductors, but the voltage to ground of 2 conductors will be 230 kv, with zero voltage to ground on the other conductor. It would be expected that this would change the corona

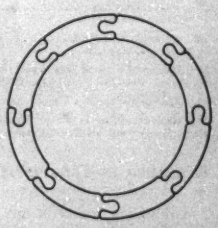

Fig. 1. 1.10 inch, 500,000 circular mil segmental hollow copper conductor

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losses, but the only way to make such a determination is by actual measurements.

The authors, therefore, arranged to make some actual measurements at the Ryan High Voltage Laboratory of Stanford University. The test set-up is described in full in "Corona Losses From Conductors of 1.4 Inch Diameter" by J. S. Carroll, Bradley Cozzens, and T. M. Blakeslee (ELECTRICAL ENGINEERING, December 1933, pages 854–60) except that in this case, the spacing between conductors was reduced to 22 feet.

The cable measured was a hollow conductor composed of interlocking segments having a total cross sectional area of 500,000 circular mils, and with an outside diameter of 1.1 inch. Figure 1 shows the cross section of the cable.

When this conductor was erected initially it was prepared for the test as described in the paper previously referred to; that is, it was thoroughly washed inside and out with gasoline; then washed outside with soap and water, and with clear water. The curves shown in this paper were taken after the cable had weathered for approximately one month, during which time there had been some rain. Except for the weathering, nothing had been done to the cable since the original washing.

To obtain the proper phase relation of voltages, only 2 of the transformers described in the previous work were used. One side of the high voltage winding of each transformer was grounded. The high voltage side of one transformer was connected through the wattmeter to one of the conductors of the test line; the high voltage side of the other transformer was connected through a wattmeter to the second conductor; the third conductor was grounded. The

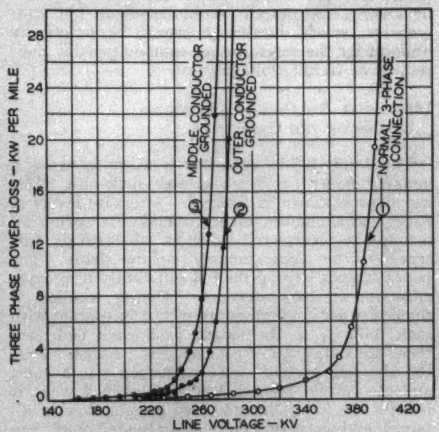

Fig. 2. Three phase corona loss curves for 1.1 inch segmental hollow copper conductor

Curve No.	Date	Condition	Barom. In. Hg.	% Rel. Humid.	Temp. Deg F Air	Temp. Deg F Cable
1	11-28-34	After gasoline, soap and water washing	30.16	46	60.5	68.0
2	12-10-34	After 1.25 in. rain	30.20	62	61.8	70.0
3	12-19-34	After 1.25 in. rain	30.20	60	61.0	68.0

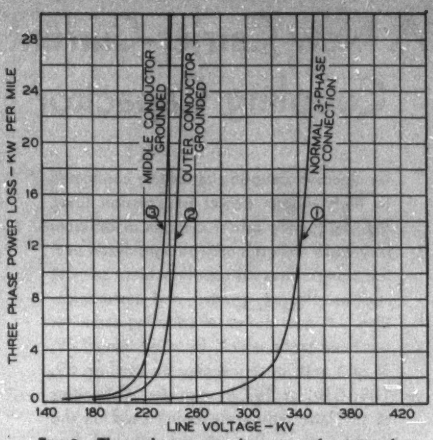

Fig. 3. Three phase corona loss curves for 1.1 inch segmental hollow copper conductor at 4,000 feet elevation

These curves computed from measured values of figure 2

primaries of these transformers were connected to the 3 phase generator in such a manner that the phase angle between the voltage of one of the conductors to ground and the voltage of the other conductor to ground was 60 degrees. This arrangement gave an equivalent 3 phase system with one of the conductors grounded.

Figure 2 shows the results obtained, both when an outer conductor was grounded and when the middle conductor was grounded, and also for normal 3 phase voltage. The increase in loss under the grounded condition is very great, especially with the middle conductor grounded. Since these measurements were made at practically sea level, and since transmission lines often go to much higher levels, it was thought that it might be of interest to compute the values for 4,000 feet elevation. These curves are shown in figure 3, and at this elevation the losses become very significant.

It is realized that in order to draw a definite conclusion in a given case, such measurements should be made for any given size and type of conductor under consideration for a transmission line. These curves will, however, at least give an indication of the order of the magnitude of the change in corona. It should be pointed out also that with this smooth surfaced segmental cable, the losses are very much lower than with a cable with round wires on the surface. The loss curves as shown in this paper are for the 1.1 inch diameter segmental cable only. However, when these data are plotted with other published results reduced to similar conditions, the diameter of an ordinary stranded cable for the same normal loss is found to be approximately 1.3 inches; presumably a similar ratio would hold for the grounded condition.

A New Carrier-Current Coupling Capacitor

By means of coupling capacitors connected to high voltage power transmission lines, high frequency carrier currents in different frequency channels may be transmitted over the power lines for supplementary services such as relaying, control, and communication. A new design of coupling capacitor has been made which, by combining 1, 2, 3, or 4 units in series, may be used on 69, 138, 230, or 287 kv circuits. Capacitors of the latter rating are being used on the Boulder Dam line of the city of Los Angeles.

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THE Boulder Dam power transmission system of the City of Los Angeles (Calif.) bureau of power and light, which employs a higher line voltage than has been used previously in this country, will utilize high frequency carrier-current channels for several distinct purposes; these include relaying, supervisory control of switching stations, telephone communication between stations, and telephone communication with patrolmen's automobiles in the vicinity of the line.

The foregoing factors demanded carrier-current coupling capacitors for connection to the high voltage line, having characteristics considerably superior to any previously considered. Adequate insulation, compactness, light weight, ease of installation, flexibility of mounting, and economy had to be combined with ample capacitance for carrier-current coupling for the several channels and at the same time for obtaining potential for the various relays and instruments.

Adequate insulation and coupling capacitance could have been provided by the use of a series-multiple combination of coupling capacitor units of existing types, but the resulting assembly would have been prohibitive from the standpoint of size and cost. Therefore, the development of an entirely new type was undertaken, as described in this paper.

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Selection of Capacitor Type, Voltage Rating, and Capacitance

Several obvious advantages, and others apparent from detailed studies, favored small series connected units in contrast with a single large unit capacitor for this voltage. Ease and economy of manufacture, simplicity of testing, lighter weight, economy in packing and shipping, and facility of handling and installing were all in support of this conclusion. Replacement of units in case of damage was not overlooked. The application of the small-unit type to lower voltage circuits would be advantageous to both manufacturer and operator.

A survey of existing operating voltages showed the prominence of 69, 138, and 230 kv circuits, suggesting division of the 287 kv capacitor into 4 units, each rated 69 kv. From a review of the 60 cycle and impulse characteristics of apparatus and line insulation for these 4 circuit voltages, it was found that a 69 kv capacitor unit, in series combinations of 2, 3, and 4 units, respectively, would co-ordinate satisfactorily with the insulation requirements of 138, 230, and 287 kv circuits. This was confirmed later by actual tests.

Since these capacitors were intended to serve the double purpose of carrier-current coupling and potential coupling, it was necessary to consider the output demanded by both classes of service. It was desirable to avoid multiple strings of units at the higher voltages. It was found that the carrier-current demand for the 287,500 volt circuit would be provided for by a capacitance of 0.00075 microfarad. Thus, with 4 units in series, the unit capacitance would be 0.003 microfarad. This capacitance would also provide adequate output for potential devices. (This output would be about 150 volt-amperes, which, incidently, would be practically uniform for the several other combinations at their respective circuit voltages.)

Individual Rolls and Assembled Stacks of the Capacitor

The 2-unit 138-kv capacitor is shown in figure 1, and the paper foil stack of the single-unit 69-kv capacitor is shown in figure 2. Alternate layers of paper and aluminum foil are wound on a cylindrical mandrel to form a roll which is subsequently flattened to an approximately square shape. The paper extends beyond the foil sufficiently to provide adequate creepage distance. During winding, 2 tinned copper connectors are placed in contact with each foil, $^1/_4$ of the length from each end, and these are subsequently connected in parallel. Thus the charging current divides between the 2 leads, and the current in each lead divides in 2 when it reaches the foil. Noninductive current flow is obtained, and no current flows along the foil more than $^1/_4$ of its length.

The rolls are assembled into stacks and connected in series. The ends of the stack are connected respectively to the cap and to the base. The connection at the bottom is made permanently at assembly of the rolls upon the base, while connection at the top

is made by a tinned copper braid of sufficient length to permit attachment to the interior of the cap before the latter is assembled to the enclosing porcelain shell.

The base plate of the assembled stack illustrated in figure 2 forms the bottom end of the completed unit, and serves as the foundation for the assembly. The rolls are divided into 4 groups by circular herkolite (molded insulation) separators, and similar plates are placed at the bottom and top of the stack. Clamping of the rolls is accomplished by means of 4 insulating rods passing through holes in the herkolite plates, and located midway of the 4 flat faces of the stack. The bottom ends of the 4 rods are threaded into the base plate and the upper ends are fitted with clamping nuts. Between the separator plates, the insulating rods pass through herkolite tubes which provide exact and equal spacing for each quarter of the stack. A nickel plated steel clamping member at the top of the stack transmits the pressure of the clamping nuts on the upper ends of the rods. Under these nuts, cam-shaped insulating washers are located, which provide a means of centering and locking the upper end of the stack in rigid position inside the shell.

The top clamping plate, which is held in fixed relation to the base of the unit by the 4 clamping rods, is provided with 2 upwardly projecting wings welded to the plate. Through holes in their upper ends a transversely assembled steel rod engages recesses on the interior of the cap. This feature provides an emergency support for the unit in case of accidental breakage of the porcelain shell.

Porcelain Housing and End Castings

The housing consists of a one-piece cylindrical porcelain shell, having a smooth unglazed interior and a deeply petticoated exterior finished in standard chocolate glaze. This porcelain has a wall thickness of $1^1/_8$ inches, except at the ends which are outwardly tapered and roughened for holding the portland cement mortar. The inside diameter of the porcelain shell is $5^1/_4$ inches and its over-all length is $24^1/_2$ inches. The string length arcing distance between clamping rings is $21^3/_4$ inches, and the external creepage distance is 57 inches. The cross-sectional area of the cylindrical body between petticoats is $22^1/_2$ square inches indicating a tensile strength exceeding 60,000 pounds.

Both ends of the porcelain are smoothly ground to fit tightly against the gaskets which form the seal between the porcelain and the machined castings. A grinding tolerance of plus or minus $^1/_4$ inch assures that the finished length of each unit will not depart more than this amount from the average.

To both ends of the porcelain shell there are cemented nickel-plated aluminum alloy clamping rings, each having tapped holes for 8 $^1/_2$ inch galvanized steel cap screws for applying pressure to the gasket. By reason of the tapered ends of the porcelain, the mortar between porcelain and clamping ring is placed under compression as well as shear when clamping pressure is applied. The inner surfaces of clamping rings are deeply grooved to receive mortar.

The cap and base castings are made of special aluminum alloy, developed for this particular application to secure both oil tightness and gas tightness. During the process of manufacture both castings receive several high pressure air tests under water to insure their complete soundness and freedom from porosity. Both of these castings are formed with 4 bolt bosses, drilled on the same bolt circle, by means of which the cap of one unit may be bolted to the base of another to form a rigid axial connection for either base or suspension mounting.

The cap forms an expansion chamber to contain the inert gas which serves as a cushion to prevent excessive pressure in the oil at elevated temperatures. There is but one opening into this gas chamber from the outside, through which the treating and filling is carried on, after which this opening is sealed with a large-headed plug under-cut to contain a gasket which is completely enclosed when compressed. The plug is locked in final position by means of a wire cable and lead seal.

The interior of the unit is filled with mineral oil

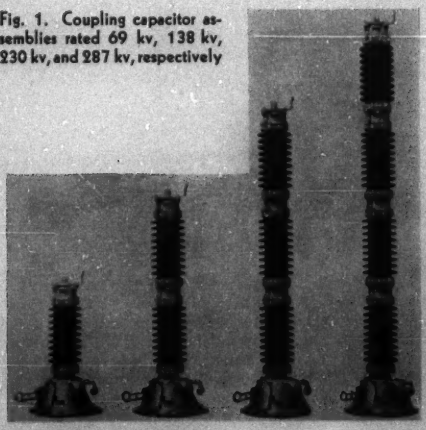


Fig. 1. Coupling capacitor assemblies rated 69 kv, 138 kv, 230 kv, and 287 kv, respectively

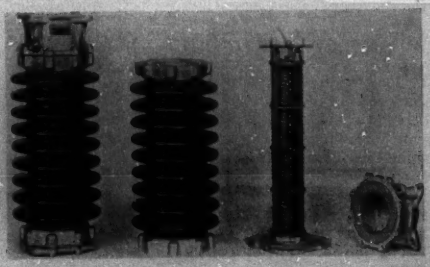


Fig. 2. 69 kv capacitor unit and component parts

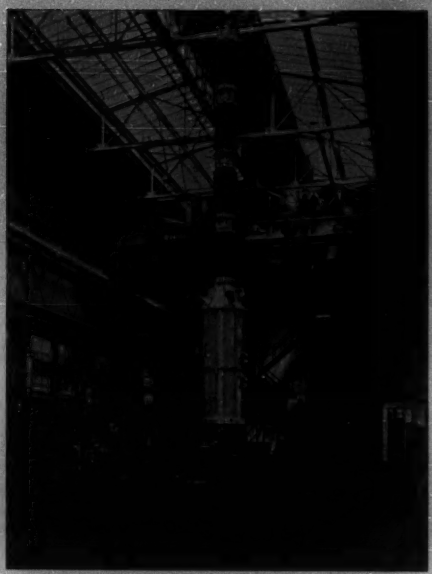


Fig. 3. Coupling capacitor assembly for the Boulder Dam transmission line, rated 287.5 kv, with potential device attached at the bottom

Bell crank operation of the potential device grounding switch is shown

up to the level of the opening in the cap, completely submerging the capacitor element. All gaskets are made of oil resistant weatherproof rubber compound. The gaskets at the ends of the porcelain are set in recesses in the castings and are under definite confinement when compressed. Positive pressure upon these gaskets is maintained by extra-heavy galvanized spring steel washers under the clamping bolt heads, so that no possible flow of the gaskets can open the joints to leakage of oil.

For suspension mounting, a plate with lifting clevis is bolted to the cap of the uppermost unit. The line lead is attached to a terminal lug carried by the suspension plate.

Bottom Unit and Base

The foregoing description applies to the unit designed for use as the middle or top section of a capacitor; of these, 3 are included in the 287,500 volt capacitor, in combination with one unit designed with a different type of base. The latter unit is the lowest of the 4 units in the stack and is built upon a cone-shaped base casting by means of which the capacitor is mounted upon the potential device housing, as shown in figure 3.

The base casting of the bottom unit is made of the same oil-tight aluminum alloy which forms the base and cap of the middle or top unit. The stack of paper-foil rolls is the same, but rests upon the end of a porcelain bushing, rated 15 kv, which is mounted in the upper end of the conical base, as shown in figure 4. The lead from the lower end of the stack is connected to the conductor rod of the bushing, and is insulated from the grounded base casting.

The bottom end of the bushing in the base carries a terminal block upon which are mounted: (*a*) the connection terminal for the lead to the potential device in the housing below the base; (*b*) one electrode of the protective gap, the other electrode of which is supported from the inside of the base; and (*c*) the receiving clip for the grounding switch which is hinged on a bracket mounted at the bushing clamp. This grounding switch is actuated by a push-rod mounted in the hinged door of the base. This push-rod may be operated through the bell crank mounted on the outside of the door by means of a standard switch hook, without disturbing the door; or the push-rod may be locked in place in the door in such a position that the switch will be closed automatically if the door is opened. The door is bolted to the base, with a cork gasket in the joint to exclude moisture.

As shown in figures 1, 3, and 4, a corrugated porcelain outlet is mounted in one side of the base, for passing the insulated lead to the carrier-current cabinet. This porcelain outlet provides generous creepage surface from this lead to ground and minimizes loss of carrier-current energy through leakage. At another point on the base casting is mounted the ventilating breather. For the Boulder Dam installation these breathers are packed with glass wool to exclude dust from the interior without interfering with the free passage of air.

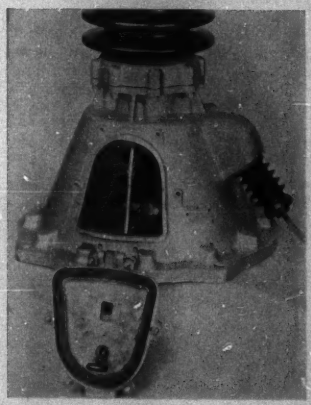


Fig. 4. View showing interior of the base of a bottom unit of a coupling capacitor

The grounding switch and protective gap may be seen. Appearance of the base with the door closed is shown in figures 1 and 3

The base is bolted to the flanged upper end of the pontential device housing, with an overhung cork gasket joint. For excluding dust and preventing

injury during handling and shipment, a temporary sealing plate closes the lower end of the base. Four lugs cast on the lower edge of the base provide for mounting upon a foundation when desired.

Assembly, Treatment, and Testing

Assembly is carried on with great care and precision in every detail. All interior parts and surfaces are made scrupulously clean as the assembly operation progresses. When the last bolt has been tightened, the entire unit is subjected to an air pressure test while submerged under water. Not the slightest leak is permitted to pass this inspection. Further assurance of complete tightness is furnished during treatment, when the units must hold a very fine vacuum for many hours.

The vacuum treatment and filling, which are applied to a large number of units at once, involve individual connections to each unit from common manifolds, one for vacuum and one for oil. During the vacuum treatment the units are maintained at oven temperature to insure complete drying of the capacitor paper.

After the specified length of treatment, degasified oil is admitted while vacuum is maintained. The oil enters by gravity until the units are full, after which they are allowed to cool with oil pressure maintained. When the units have reached room temperature they are removed from the oven, the oil level adjusted to its normal position, and the gas expansion chamber filled with nitrogen. The single opening is then sealed, after which the unit is ready for commercial tests.

Every unit receives routine commercial tests, such as measurement of capacitance, measurement of 60 cycle power factor, high potential 60 second

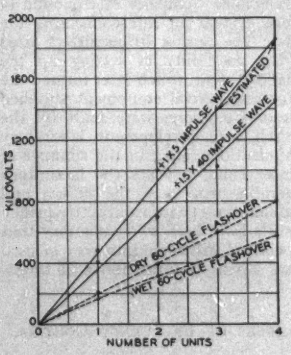


Fig. 5. Flashover voltages of coupling capacitor assemblies

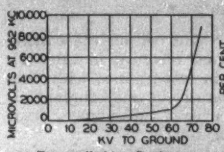
Solid lines—60 cycle flashover values

Dashed lines—impulse flashover values

holding test, and dry 60 cycle flashover. Capacitance measurements are allowed to vary between the limits of 0.0030 and 0.0033 microfarads at room temperature. Power factor measurements average 0.4 per cent. The high potential test is applied at 175,000 volts. The average dry 60-cycle flashover is 210,000 volts, with a permissible tolerance of −5 per cent. In the case of units for the bottom section of the capacitor, an additional test is made on the 15 kv bushing in the base, and the protective gap is adjusted to its prescribed setting (0.26 inches).

Characteristics

Dry and wet 60 cycle flashover voltages, and impulse flashover voltages measured with 1 × 5 and 1.5 × 40 microsecond waves, are shown in figure



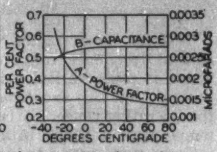


Fig. 6 (left). Radio noise characteristic of coupling capacitor unit at 40 degrees centigrade

Fig. 7 (right). Power factor-temperature and capacitance-temperature characteristics of the coupling capacitor

A—60 cycle power factor versus temperature, at operating voltage

B—Capacitance versus temperature

5 for series combinations of from 1 to 4 units. The comparative 60 cycle and positive characteristics of these coupling capacitors and the corresponding coordination gaps are shown in table I.

Voltage distribution along the stack of a specially constructed unit with taps, which was measured at 120 volts, 60 cycles, and at 110 volts, 150 kilocycles, was found to be practically linear. Measurements of radio frequency voltage at 952 kilocycles were made for assurance that these capacitors would have no undue effect upon radio reception. The data are plotted in figure 6.

Variation of 60 cycle power factor with temperature changes over the operating range was measured,

Table I—Flashover Voltages (Kv) of Capacitors and Gaps

Operating Voltage—Kv	Apparatus	60 Cycle Wet FO	60 Cycle Dry FO	60 Cycle 1 Min.	Positive Impulse Flashover 1.5×40	Positive Impulse Flashover 1×5
69	Capacitor	170	210	175	410	485
	Gap		205		335	420
138	Capacitor	320	390	325	700	1,005
	Gap		410		630	800
230	Capacitor	450	600	530	1,030	1,400
	Gap		680		1,000	1,310
287	Capacitor	585	800	660	1,460	1,860
	Gap		850		1,240	1,630

Note 1. Dry flashover voltages corrected to 25 degrees centigrade, 760 millimeters mercury, and 6.5 grains per cubic foot humidity.

Note 2. Wet flashover voltages corrected to 25 degrees centigrade, 760 millimeters mercury, 12,000 ohms per cubic centimeter water resistivity, and 0.01 inch per minute precipitation at 45 degrees inclination.

Note 3. All flashover voltages are of average values, with a permissible tolerance of −5 per cent.

and is shown in figure 7*A*. It is interesting that this capacitor has a negative temperature coefficient, so that within the operating range the power factor diminishes as the temperature increases.

Table II—Power Factor Tests

Internal Temperature	Per Cent Power Factor	
	50 Kilocycles	150 Kilocycles
50 degrees centigrade	0.85	1.24
80 degrees centigrade	0.47	

Test for power factor values within the carrier-current frequency range are recorded in table II. There is some variation in capacitance with temperature but this is comparatively small throughout the operating range. A curve of capacitance versus temperature is shown in figure 7*B*.

Tests were made to determine the temperature rise at working voltage, 60 cycles, and with carrier current of 50 kilocycles and 150 kilocycles frequency. From these tests the carrier current ratings in table III were derived. All ratings are based upon a maximum of 15 degrees centigrade internal rise over a 40 degree centigrade ambient, which corresponds to about 25 watts loss per unit.

Table III—Carrier Current Ratings

Frequency in Kilocycles per Second	Amperes per Channel		
	1 Channel	2 Channels	3 Channels
50	1.37	0.97	0.79
100	1.57	1.11	0.90
150	1.93	1.36	1.11

Mechanical tests were made to determine the tensile and transverse strength of the units and the factors of safety under suspension mounting and under wind pressure when base mounted. Tension tests were carried to 10,000 pounds without failure. This represents a factor of safety of 8 for suspension mounting of 4 units with potential device attached. Tests on the fiber studs which clamp the capacitor rolls and serve as an emergency tension member in the event of accidental breakage of the porcelain, indicate a satisfactory strength.

Transverse tests, made by applying horizontal force at the top of the unit while the bottom was held rigidly in place, gave results averaging 2,000 pounds to produce failure. With wind pressure of hurricane force, a base mounted stack of 4 units has a safety factor of 4.5.

Trial methods of packing for shipment resulted in the adoption of a special type of packing case with a felt base, and with outriggers and special precautions to insure being maintained in an upright position. Variations of this method, involving 2 or more units in a package, are contemplated for special conditions such as water shipments.

Resonant Lines for Frequency Control

Vacuum tube oscillators for radio frequency signals above 25 megacycles may be controlled with a high degree of precision by resonant lines, and at lower frequencies may be used to obtain a larger power output than is obtainable from crystal oscillators. The general principles of the design of concentric conductor lines and means for compensating temperature changes are discussed in this paper. Line controlled oscillators may be used with frequency multipliers, or to control oscillators at lower frequencies.

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In a previous A.I.E.E. paper[1] F. E. Terman indicated that resonant lines may be used to control the frequency of oscillators with a high degree of precision, and mention was made of the use of lines for this purpose in the transmitters employed by the Mutual Telephone Company of Honolulu in the radio telephone system for interconnecting the Hawaiian Islands. The survey transmitters used to demonstrate the possibility of setting up the Hawaiian interisland system, which later formed the basis of design for commercial equipment supplied by the RCA Victor Company, were built by the transmitter research and development laboratory of R.C.A. Communications, Inc., in the summer of 1929.[2] In the intervening 6 years the laboratory has made considerable progess in the design and application of resonant lines to transmitter frequency control. The results have been so satisfactory that it is believed line control will come into very general use in transmitters having outputs above 25 megacycles.

General Principles of Frequency Control

In a vacuum tube oscillator the most common sources of frequency variation are:

1. Variable reaction and loading from the load circuit.

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1. For all numbered references see list at end of paper.

2. Fluctuation in tube impedances due to alternating components of power supply.

3. Variations in circuit dimensions due to variation in temperature.

4. Mechanical vibration.

To reduce or overcome the effects of these sources of frequency variation the first requirement is an oscillatory circuit having an extremely high frequency selectivity, or sharpness of tuning, and an ability to store up oscillatory energy which is very great in comparison with the changes in energy caused by the sources of frequency variation. Resonant lines of correct design are capable of meeting these requirements.

Design of Uniform Lines

A satisfactory form of line for frequency control is one made up of concentric tubular conductors of such form that the outer conductor completely encloses the inner conductor. The oscillatory energy is all stored in electromagnetic fields between the 2 conductors and there is no radiation or undesired coupling to external objects and circuits.

If the 2 conductors each have uniform diameters throughout their length the minimum length of inner conductor for resonance is substantially a quarter wave length for radio waves corresponding to the operating frequency. The wave length is the velocity of light, 300,000,000 meters per second, divided by the operating frequency in cycles per second. At 25 megacycles the required length of inner conductor will therefore be about 3 meters or 9.84 feet and at higher frequencies it will be proportionally less.

The ratio of diameters of the conductors in a uniform line, to obtain a minimum power factor and maximum frequency selectivity, should be 3.6.[1,3,4] The power factor will be inversely proportional to the diameters of the conductors, assuming a fixed ratio of diameters, and therefore the frequency selectivity will be directly proportional to the diameters. To obtain a line capable of almost completely determining the frequency of an oscillator the diameters should be made as large as possible.

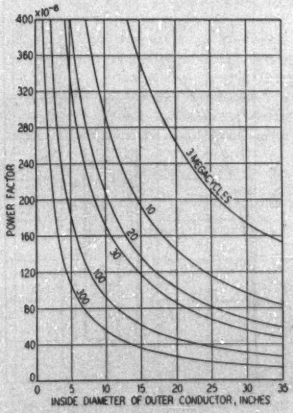

Fig. 1. Power factor curves for concentric conductor lines, ratio of diameters of conducting surfaces 3.6

When large diameters are used the length of line need be only a quarter or a half wave to store all the oscillatory energy required without flashing over or rising excessively in temperature due to losses. For most applications one or the other of these lengths will be used. For very high frequencies, above about 100 megacycles (3 meters wave length) the length of a quarter or half wave line may become inconveniently short in relation to the desired diameters. In such cases lines of greater length will sometimes be found desirable.

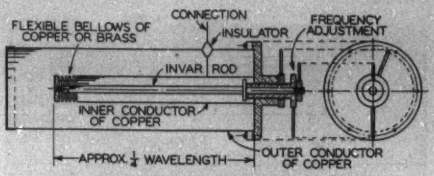

Fig. 2. Arrangement for preventing change of inner conductor length with temperature

Copper is the most satisfactory common material to use for constructing the lines. Silver plating the copper conducting surfaces, particularly that of the inner conductor, may be justified in some cases but usually it will be more economical to obtain an equal improvement by increasing the diameters of plain copper conductors.

Aluminum may be used in some instances to save weight but the ultimate gain in using it is small. It has higher resistivity, requiring larger diameters, which in turn requires thicker material for rigidity. Joints, which must be made very carefully to avoid insertion of resistance, are much harder to make with aluminum than with copper. Aluminum also has a higher temperature coefficient of expansion and has lower heat conductivity, tending to permit greater differences in temperature between inner and outer conductors.

The calculated power factors of concentric conductor copper lines having a ratio of diameters for the conducting surfaces of 3.6 are shown in figure 1. The power factors for frequencies other than those shown may be determined readily from the relation that power factor is inversely proportional to the square root of the frequency.

From this figure it will be noted that, at 100 megacycles, for example, using a line 18 inches in diameter, the power factor will be only about 52.5×10^{-6}. For each watt of power input, at the resonant frequency, the line could be made to maintain about 19,000 volt-amperes of oscillatory energy. The length of inner conductor required for quarter wave resonance would be about 29.5 inches and the overall dimensions for the whole line would be about 18 by 18 by 48 inches.

Slow changes in ambient temperature will change all dimensions of the line in proportion to tempera-

ture at a rate corresponding to the linear coefficient of expansion of the material. For copper the coefficient of expansion is about 16.8 parts per million per degree centigrade. Since the ratio of diameters of inner and outer conductors will not change with changes in temperature, the electrical properties per unit of length will not change and the variation in

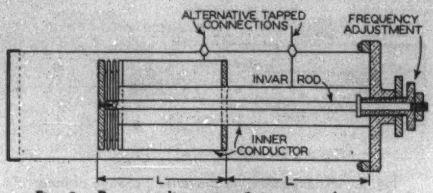

Fig. 3. Resonant line using 2 inner conductors to reduce length

natural frequency of the line will correspond fairly closely to the variation in length only. The frequency-temperature coefficient for a copper line will therefore be about 16.8 parts per million per degree centigrade.

Variations in frequency as the result of variations in ambient temperature may be reduced to any desired degree by temperature control but a simpler and more satisfactory arrangement is to hold the length of inner conductor constant in spite of variations in temperature. This may be done by making a small section of inner conductor out of a flexible metal bellows and then using a rod of invar, or other low temperature coefficient material, to hold the over-all length constant. Figure 2 is a cross-sectional view of such an arrangement. It provides an additional advantage in that the bellows and adjustable length of invar rod permit small variations in length of the inner conductor to adjust the frequency exactly to any desired value.

In addition to ambient temperature variations changing the frequency we must also consider the changes in dimensions from unequal temperatures set up by losses in the line when an oscillator is started. These changes may cause a transient frequency change when a line of the type shown in figure 2 is warming up. Their effect may be made small by using lines of large dimensions and of heavy material which will distribute the heat rapidly. Forced air circulation inside the inner conductor is beneficial but will be required only in special cases. Constructing the whole line of low temperature coefficient material with copper or silver plating on the conducting surfaces would solve the temperature coefficient problem completely and application of this method awaits only commercial production of these materials in the form of large tubes and plates.

Design of Nonuniform Lines

In many instances, particularly at frequencies below 50 megacycles, the length required for a quarter wave line of uniform diameters is objectionable. The length may be reduced without change in resonant frequency and without much change in power factor by using 2 diameters of inner conductor as shown in cross section in figure 3.

In this arrangement the smaller diameter inner conductor may be considered to be an effective inductance and the larger diameter inner conductor an effective capacitance. The inductance and capacitance each change in value by very nearly the same percentage with change in ambient temperature. If they are made substantially equal in length, and the sum of their lengths is held constant by means of the section of bellows and invar rod, then the frequency will not change appreciably with change in ambient temperature. A rise in temperature will increase the inductance but decrease the capacitance by an equal percentage and so balance out the effect on the frequency.

It would be difficult to lay down definite rules for designing this type of line because of the wide variations possible. In general the clearance between the end of the line and the outer casing must be great enough to withstand the required maximum voltage. This and the diameter of the outer conductor will determine the limit of shortening possible in each case. The power factor will be substantially the same as if a uniform line were used. The ratio of the diameter of outer conductor to that of the smaller of the inner conductors should still be substantially 3.6 for minimum power factor but considerable variation in ratio can be permitted before the power factor begins to increase rapidly. (See figure 4.)

Line Controlled Oscillator Circuits

Resonant lines may be used to control the frequency of oscillators in many circuit combinations. One circuit for use with a single 3-element tube is

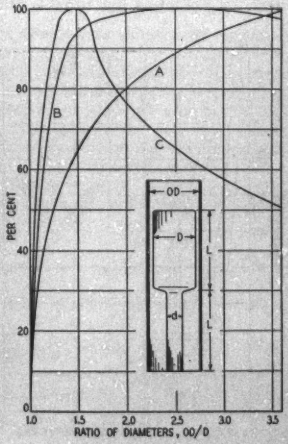

Fig. 4. Variation in over-all length of the 2 inner conductors, OD/d = 3.6 (A), variation of permissible voltage at end of line, conductor corners slightly rounded (B), and variation in energy storage rating in volt-amperes (C) for various ratios between inside diameter of outer conductor and outside diameter of the larger of the inner conductors in a nonuniform line

shown in abbreviated schematic form in figure 5. In this arrangement the line is used as a tuned circuit connected between grid and cathode. The anode is provided with a split balanced output circuit. Between the end of this circuit, opposite the anode, and the grid an adjustable capacitor is provided by means of which the regeneration may be controlled. In practice oscillations may be obtained with the capacitor adjusted either above or below a value equal to the anode to grid capacitance of the tube. Usually it is best to adjust the capacitor to a value higher than that of the tube.

If we assume that the output from the oscillator to the next stage is not very great, which is a desirable condition, then the power or resistive component of input to the line causes a phase shift in the radio frequency voltage applied to the grid which is lagging when the capacitor is adjusted for less than the balancing value and leading when the capacitor is adjusted for more than the balancing value. At very high frequencies electron travel time causes a very appreciable phase lag in radio frequency electron currents through the tube in response to grid potential variations. This lag tends to reduce the output and efficiency of the tube. By employing the circuit adjustment which gives the grid excitation an advance in phase we may compen-

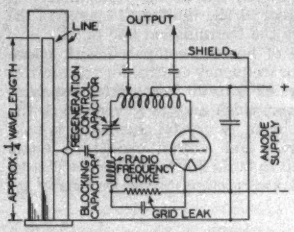

Fig. 5. Single tube oscillator circuit

sate for the electron current phase lag. The difference in performance of the oscillator with one adjustment or the other of the regeneration control capacitor is sometimes very pronounced, particularly when the oscillators are operated near the upper frequency limit of the tubes and when a relatively large proportion of the power is being used in the line.

The circuit of figure 5 is well adapted to supplying

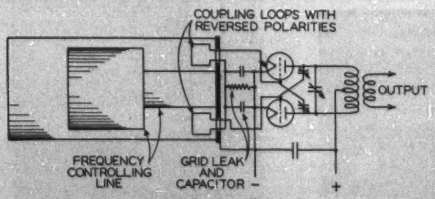

Fig. 6. Circuit of push-pull oscillator using a single nonuniform line

radio frequency excitation to the grids of 2 power amplifier tubes in a balanced or push-pull circuit. Usually the oscillator and amplifier tubes will be of a single type, operated from a common anode supply source. This makes a relatively simple, economical, and reliable system.

In figure 6 is shown a schematic circuit diagram

Fig. 7. Arrangement of apparatus at typical transmitter for 13.42 megacycles, showing U-shaped line for frequency control

of a balanced or push-pull oscillator having its frequency determined by a single nonuniform line. The operation of this circuit is very similar to that shown in figure 5 except that the grid circuits are inductively instead of conductively coupled to the line. This inductive coupling is accomplished by placing 2 single-turn coils radially in the space between the inner and outer cylinders and connecting so as to impress radio frequency voltages of opposite phase on the grids of the tubes.

In the circuits of both figures 5 and 6 negative continuous potential from rectified grid current is applied to the grids of the tubes through a grid leak or grid biasing resistor. The radio frequency bypass capacitor for this resistor should be small enough to prevent appreciable phase lag in grid bias voltage variations as the result of fluctuations in anode voltage or a-c cathode heating currents. The grid leak biasing makes the grids act as a substantially constant radio frequency resistance, in spite of power supply fluctuations, and reduces undesired frequency modulations which might appear if a fixed bias voltage were used.

Application of Line Controlled Oscillators to Transmitters

In applying line controlled oscillators to transmitters where frequency stability is very important it is desirable to protect the oscillator from the effects of antenna circuit variations by interposing one or more amplifier stages between them. When the oscillator is followed by a single stage amplifier, either neutralized or screen grid, the effect of antenna circuit variations upon the frequency is usually reduced to a small percentage of the effect which would be caused by coupling the oscillator directly

to the antenna and at the same time the power output from the amplifier may be much greater.[5,6]

For very high frequency transmitters it is often desirable to operate the oscillator at a half or a third of the final output frequency in order to improve its output and efficiency and to obtain more convenient dimensions of the line and circuits. The oscillator then supplies the input to a vacuum tube frequency multiplier which may, in turn, be followed by a power amplifier. The use of frequency multiplication is an aid to reducing feedback couplings to the oscillator which might tend to introduce frequency variations.[7]

In relatively low frequency transmitters where the lines tend to be excessively large it is sometimes desirable to operate the line controlled oscillator at 2, 3, or more times the final output frequency. The line controlled oscillator then supplies input to a lower frequency oscillator in such a way as to lock or synchronize the frequencies of both at an exact multiple relation. The lower frequency oscillator may then be followed by one or more power amplifiers.

Examples of Experimental and Commercial Applications

Up to the time of writing this paper there have been some 25 or 30 transmitters with resonant line frequency control built by R.C.A. Communications, Inc., and the RCA Manufacturing Company. More are being built. These transmitters range in frequency from 6.725 to 450 megacycles and in power output from about 10 watts to 30 kilowatts. About half of these have been built for commercial service or for use as models for commercial equipment. Some typical examples of these transmitters are shown in figures 7, 8, and 9.

The general arrangement of frequency controlling line, master oscillator, and power amplifier of WHR, operating at 13.42 megacycles with 30 kw, is shown in figure 7. This transmitter is installed at the Rocky Point station and has been in regular commercial service since the latter part of 1933. It has a record of frequency stability exceeding that of most other high frequency transmitters including crystal controlled transmitters. The length of line in this transmitter is a half wave length and, to save space, is bent into the shape of the letter U. The diameter of outer pipe is 20 inches and that of the inner pipe 5.5 inches. Compensation for temperature variation is obtained by means of a variable capacitor operated directly by expansion and contraction of oil in a pipe exposed to the same temperature variations as the line.

Figure 8 is a view of W2XBN, operating at 91.8 megacycles, installed on the top floor of the Continental Bank Building at 30 Broad Street, New York, N. Y. This transmitter was installed for multiplex transmission to New Brunswick, N. J. It provides circuits connecting the central traffic office at 64 Broad Street with the New Brunswick station for controlling transoceanic and transcontinental transmitters located there.

A transmitter located on the roof of the RCA Building, New York, N. Y., for the purpose of making propagation measurements on a range of frequencies above 25 megacycles is shown in figure 9. The pipe shown to the left of the transmitter extends above the roof of the building to support the antenna and carry the transmission line to it.

The advantage of lines as compared with piezoelectric crystals for frequency control for transmitter output frequencies of 6 to 20 megacycles lies principally in the power which may be generated in the oscillator. The output of crystal oscillators is usually less than 1 watt and seldom exceeds 5 watts while it is practical to build line controlled oscillators with outputs of 1 kw or more. This materially re-

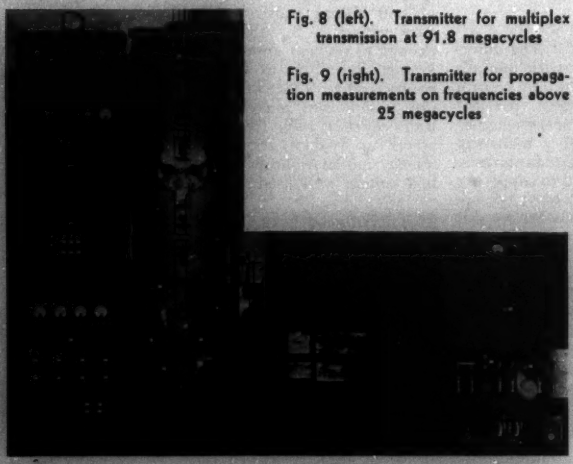

Fig. 8 (left). Transmitter for multiplex transmission at 91.8 megacycles

Fig. 9 (right). Transmitter for propagation measurements on frequencies above 25 megacycles

duces the number of stages required in a high powered transmitter and thus increases its reliability and often reduces its cost.

The selectivity of the crystals normally used in these transmitters may be judged by their power factor, which is of the order of 40×10^{-6}. The selectivity of the line used in the transmitter shown in figure 7 which operates at a comparable output frequency is less than the crystal, since its power factor is of the order of 125×10^{-6}. This indicates that the crystal is capable of a greater accuracy of control but in practice it has been found difficult to realize this advantage.

At output frequencies above 20 megacycles the line type of frequency control has marked advantages over a crystal since the line can be built to resonate at the desired output frequency, while with crystal control the number of frequency multiplier stages required would become excessive. Also, as shown in figure 1, the frequency selectivity of the line improves with frequency and can be made to exceed that of the crystal.

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A Radio Interference Measuring Instrument

Consideration of the factors involved in radio interference field strength measurements indicates that the effective values measured by conventional methods are inadequate for describing the interfering effect of the disturbing radiation. The instrument described in this paper provides a means for measuring with acceptable accuracy both crest and effective values of interference field strength, the ratio of which agrees with observed discrepancies between effective and apparent values.

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THE elimination and mitigation of radio interference is a problem of great importance because of the almost universal use of radio receivers.

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Radio reception with modern receivers is interfered with by many different kinds of phenomena that originate in nature and from man-made apparatus. The most insignificant electromagnetic radiation may cause serious disturbances if it occurs in the band of frequencies used for radio communication. Therefore, the measurement and evaluation of the interference characteristics of interfering radiations is important.

Measurements of radio interference taken at various times, with different instruments, by different individuals, and in widely separated geographical locations, show that the effective or root mean square field strength of radio interference from transmission lines and other similar sources gives values that are extremely low in comparison with the modulated continuous wave field strength required to produce the same apparent volume of sound from a radio receiving set.[1,2] These field strengths were measured with instruments designed to measure the effective value of the radiation from radio broadcast transmitters, and the measurements were made with an accuracy that was within 10 per cent of the absolute root mean square value or better. Notwithstanding this order of accuracy, which is considered satisfactory for such measurements, the apparent strength of the received interference signal was observed to be from 3 to 10 times that of a continuous wave signal having the same measured root mean square value. It is therefore apparent that in the control of radio interference it is not practical to establish maximum permissible interference field strength levels on the basis that the effective value of the field strength of a continuous wave radio signal and the effective value of the field strength of radio interference are comparable in the effect they produce in a radio receiver.

The lack of correlation between effective value measurements of discontinuous and continuous field

1. For all numbered references see list at end of paper.

strengths was repeatedly confirmed during the early stages of an investigation of the radio interference originating from high voltage transmission lines at Oregon State College. These experimental results show conclusively that it is necessary to know more about an interferering radiation than the effective value of the field strength before it is possible to predict the amount of radio interference it will produce.

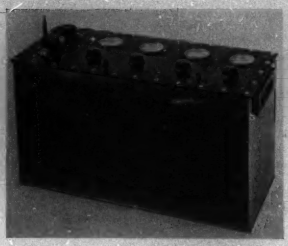


Fig. 1. Crest indicating instrument used with field strength set for measuring crest field strength

The measurement of both the effective and the crest field strength makes it possible to determine the ratio of the crest to the effective value, or the crest factor, which defines the nature of the measured radio interference. When the interfering radiation is discontinuous, with recurring intervals of very low or no field strength at all interposed between relatively short periods of high field strength, a high crest factor will be obtained. When the radiation approaches a continuous series of waves, the crest factor will decrease in value.

This paper describes an instrument that may be used in conjunction with a conventional field strength measuring set for measuring crest field strengths of either sine wave radiation or discontinuous radio interference. Effective and crest field strengths for some typical interfering radiations are reported to show the results obtained with the device and to emphasize the importance and value of such measurements. The instrument is still in the developmental stage, and further experience with it will no doubt suggest desirable improvements and refinements.

Measurement of Effective and Crest Field Strengths

The field strength measuring set used was a portable instrument that has been described in a paper by Axel G. Jensen.[3] Briefly, this set was a superheterodyne receiver having an indicating instrument in the second detector tube plate circuit for indicating the output. The amplification was ajustable over a wide range by a variable gain control and by selecting any part of 3 stages of intermediate frequency amplification. The antenna was of the loop type, and provision was made for introducing a known radio frequency voltage into the loop circuit from a local oscillator so that the absolute value of the field strength could be determined.

Measurements are made by tuning the set and adjusting the amplification so that a reasonable reading is obtained on the output indicating instrument. Then the local signal oscillator frequency is adjusted until it is equal to that of the unknown signal. With the loop turned so that the unknown signal gives a minimum output from the set, the local signal is introduced into the loop circuit and adjusted to give the same reading on the output instrument as was obtained with the unknown signal. From the value of the local signal output required to match the unknown signal and the effective height of the loop, the field strength for the unknown signal can be computed. This method measures the effective value of the local signal, because the output instrument will give the same indication in 2 instances only when the effective voltages impressed on the grid of the detector tube are the same, since this instrument is a permanent magnet type and averages the detector tube plate current which in turn is a square law function of the voltage applied to the grid of the tube.

If a device could be introduced in series with the output instrument which would indicate crest values instead of average values, the locally produced known signal could be adjusted so that its crest value would give the same indication as the unknown signal. Then if the crest factor or crest value of the local signal were known, the crest value of the unknown signal could be calculated. By introducing a resistance of the order of 10,000 ohms into the second detector tube plate circuit, a voltage of several volts can be made available for the operation of a crest indicating device. It was experimentally determined that there was no perceptible distortion of speech or music on a broadcast program by the addition of 0 to 25,000 ohms resistance in the second detector plate circuit. Therefore, the addition of 10,000 ohms resistance in series with the detector tube and the primary of the audio frequency transformer, for the purpose of operating a crest indicating device, was feasible.

The complete instrument for indicating crest field strengths is shown in figure 1. This crest indicating device is introduced into the field strength measuring set in series with the output microammeter by means of a plug cord, the end of which is shown in the figure at the extreme left end of the instrument. The instrument is essentially a vacuum tube crest voltmeter and may be described by explaining some of its fundamental characteristics.

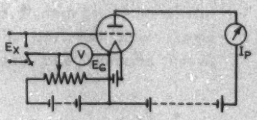


Fig. 2. Fundamental circuit for vacuum tube crest voltmeter

The general plate rectification method of measuring crest voltages taking advantage of the grid voltage-plate current characteristic is frequently called the null method or slide back method.[4] The operation of this circuit depends on adjusting the grid bias until the plate current is just zero. Figure 2

illustrates how the unknown voltage E_X is applied to the grid in addition to the d-c grid bias voltage E_G. The operation of this crest voltmeter circuit is illustrated graphically in figure 3 for the condition when the grid bias voltage E_G is adjusted so that a small plate current I_P flows at the crest of each positive half cycle of the unknown voltage E_X. When this small pulse of plate current for each cycle just comes to zero, it is evident that the crest value of E_X is equal to $E_G - E_0$. The voltage E_0 is determined with E_X equal to zero, or by operating the switch shown in figure 2 to eliminate E_X.

If a good method of indicating the critical crest point with a well evacuated vacuum tube having a sharp plate current cutoff characteristic is used, the reliability of the results of crest measurements with the null vacuum tube voltmeter circuit is very good. Using a 60-cycle variable voltage, tests with this type of circuit and with either headphones or a microammeter as an indicator gave results that checked the actual crest values very well.

The complete circuit for the crest voltmeter, as developed, is shown in figure 4. The instrument consists of the null vacuum tube crest voltmeter and a 3-electrode gas filled tube indicator circuit. The principle of operation of the indicator is apparent from this diagram. The voltage drop across a resistor in the plate circuit of the null vacuum tube voltmeter stage is impressed on the grid of the grid controlled tube in such a manner that if the grid bias is adjusted very near to the critical ionization potential, the tube will start conducting when a small pulse of current flows through the vacuum tube at the crest of an a-c wave impressed upon the grid of the vacuum tube. After ionization is initiated in the controlled tube, the plate current is independent of the grid voltage. Therefore, the plate circuit constants can be adjusted to permit a large current flow for operating a suitable device to indicate the crest adjustment.

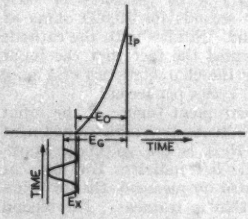


Fig. 3. General grid voltage-plate current characteristic for a vacuum tube

Operation of Instrument

The functioning of the complete instrument may be explained by following through one complete operation with the aid of figure 4. When a current flows through R_1 a voltage drop E_X is superimposed on E_G, the grid bias of the crest voltmeter tube. Now assume that E_G is adjusted so that at the crest of each positive half cycle of the alternating voltage E_X a small amount of current flows in the plate circuit of the crest voltmeter tube. Also consider that E_2 is adjusted so that if a small positive voltage is added to it the grid control led tube will ionize and begin to conduct. Then when the first positive half cycle of alternating voltage is impressed on the input to the crest voltmeter a small

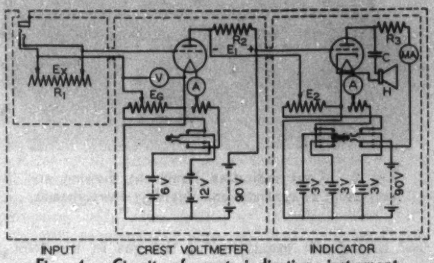


Fig. 4. Circuit of crest indicating instrument

current will flow through R_3 at the crest of E_X. The voltage drop across R_3 will have the polarity indicated in the diagram. This voltage E_1 is added to E_2 in such a manner that the potential of the grid of the indicator tube is decreased, permitting the gas in this tube to ionize and conduct. If the tube were not paralleled by the circuit *H-C*, the current through it would be limited by the resistance R_3 and the small voltage drop in the tube. This would permit a relatively large current to flow and would cause a conspicuous deflection on the milliammeter in series with R_3. The resistance R_2 is 250,000 ohms so that a voltmeter tube plate current of 1.0 microampere would give E_1 a value of 0.25 volt. This voltage is greater than the range of variations in the critical grid control potential for the indicator tube under a wide variety of conditions, and therefore insures reliable operation at all times.

The use of a grid controlled tube as the indicator for the vacuum tube crest voltmeter adds considerable flexibility to the instrument. By using the first stage of this arrangement essentially as an amplifier any part of the grid potential-plate current characteristic curve can be utilized for operation. By adjusting the grid bias on the grid controlled tube, the indicator can be set to operate at any desired value of current in the plate circuit of the vacuum tube.

The circuit *H-C* in parallel with the indicator tube is fundamentally an inverter circuit, in which *H* is a relatively low resistance headphone and *C* a condenser of 0.06 microfarad capacitance. As long as the tube is in a nonconducting state, the voltage across the condenser is equal to the battery voltage, but as soon as the tube begins conducting, the condenser is discharged rapidly through the tube. The rate of this discharge is limited only by the impedance of the headphones and the low voltage drop in the tube. Hence, the condenser continues to discharge until the voltage across the condenser and tube is too

Fig. 5. Crest indicating instrument showing arrangement of apparatus and shielding compartments

low to support ionization of the gas in the tube. Then conduction through the tube ceases, and the condenser is once again charged up to either the battery voltage or the critical static ionization potential of the tube, whichever is lower.

This inverter circuit provides automatic resetting of the indicator each time the tube is tripped by a voltage impulse from the crest voltmeter tube. If it were not for this arrangement, it would be necessary to take the voltage off manually each time the indicator tube became ionized, because the grid loses all control of conduction in the tube as soon as ionization occurs. The convenience of this circuit arrangement is at once obvious and crest voltage measurements are greatly facilitated by this refinement. The headphone H in series with C makes audible the operation of the indicator tube, in addition to the visible deflection of the milliammeter in the plate circuit.

Using a 3 element electron tube with unusually high vacuum to reduce the tube noise in the voltmeter stage, measurements were made of both 60 cycle and damped oscillation voltages. The crest values measured were compared with the crest values determined directly by the cathode ray oscillograph and were found to have a maximum error of less than 3 per cent of the maximum indication. This accuracy was well within the accuracy of the oscillograph indications and was considered to be quite satisfactory for such measurements.

The shielding plan for the circuit is shown by the broken lines in figure 4. This shielding is connected to the shielding of the field strength set through a copper braid on the interconnecting cord. The crest indicator instrument circuit is, therefore, connected to the shielding through the field strength measuring set circuit. The crest indicator circuit is arranged in stages, each stage occupying a separate compartment, as shown by figure 5. These compartments are copper boxes which serve as shielding. A large copper box encases all of the compartments and serves as an additional shield. As shown in the circuit diagram, the shielding compartments are connected together at only one point. These are in turn connected to the outer shielding case at only one point. Connection is made between this point and the field strength measuring set shielding.

The input resistor R_1 is a specially constructed decade unit, variable in steps of 1,000 ohms from 0 to 20,000 ohms, the elements of which comprise a woven fabric in which the conductor constitutes the woof and the insulation material the warp. This gives very low distributed capacitance and practically no inductance. The time constant for the

Fig. 6. Laboratory arrangement for making measurements of radio interference from conductor corona

resistor varies between 1×10^{-8} seconds for 1,000 ohms and 7×10^{-8} seconds for 20,000 ohms at 50,000 cycles per second. Studies with the cathode ray oscillograph confirmed the fact that the input resistor has essentially the characteristics of a pure resistance up to 50,000 cycles per second.

In the assembled instrument (figure 1) the input is at the left, the large knobs providing adjustment of input resistance. Next is the voltmeter stage. The instrument at the left indicates the filament current which is adjusted by means of the knob immediately in front of that instrument. The second instrument from the left indicates the value of the grid bias voltage E_G which can be adjusted by the corresponding knob. The indicator stage is at the right end of the instrument, with the indicating milliammeter at the extreme right. The perforations in the middle of the panel in this stage are above the headphone for giving an audible signal of the functioning of the indicator tube. The battery switches are at the extreme front edge of the panel.

A front view of the instrument with panel raised is shown in figure 5. The construction and arrangement of the 3 stages and various parts may be seen. The input resistance is at the left with the voltmeter stage next and the indicator on the right. The arrangement of the shielding boxes may

also be seen; these compartments are mounted and insulated from each other and from the exterior shield by bakelite strips. The compartments are connected together by short pieces of copper tubing through which connections are made from one stage to the next. These conduits fit in the notches shown near the front of the boxes.

In operation the local signal generator of the field strength set, in conjunction with which the crest indicating device is used, is adjusted twice. One adjustment is made to match the reading of the output microammeter on the receiver with the reading for the unknown signal. The other adjustment matches the indication of the crest indicating instrument to the indication for the unknown signal. From the first local signal value, the effective interference field strength may be determined, and from the second the crest value may be computed.

When making observations of interference of the type caused by corona, it is necessary to discriminate somewhat in choosing the crests for the crest measurements. Generally, 2 definite levels of the crest value of interference may be measured. The higher level appears to result from frequent abnormally high crest values of the interference caused by the corona. These intermittent crests occur rather irregularly and seem to have an average frequency of about 5 to 10 per second. These intermittent crest values of field strength are somewhat erratic and unreliable. The lower level of crest values is quite regular and distinct. At this level the audible tone from the crest indicator shows that these regular crest values occur on practically every cycle of the voltage producing the corona. The regular crest value of interference has been used for correlation with the effective value measurements and interference effects in radio receivers.

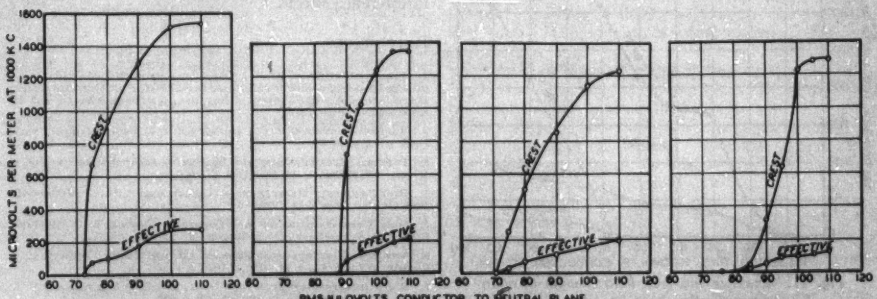
Typical Crest and Effective Field Strength Measurements

The arrangement of apparatus for making measurements of the crest and effective field strengths of interference caused by conductor corona is shown in figure 6.[5] The conductor under observation is suspended between treated maple insulators in front of the sheet iron plates which simulate the neutral plane. The ends of the conductor and insulators are shielded with large metal tori to prevent corona formation at the points of support. The test conductor is spaced 36 inches from the neutral plane, corresponding to a line to line spacing of 6 feet in a conventional transmission circuit. A voltage is applied between the conductor and plates by the testing transformer shown, voltage control being provided by the alternator field rheostats shown in the central foreground.

The arrangement of the measuring instruments is shown in the left foreground of the figure. The conventional effective field strength measuring set is shown on the back of the table, and the crest indicating instrument is immediately in front of the field strength set. The loop antenna is supported on the back of the table in order to obtain adequate coupling with the interfering circuit. The field strength measuring equipment is placed near the test conductor in order to detect the interference caused at the first occurrence of corona. All of the measurements of the interference field strength reported in this paper were made with the field strength set tuned to 1,000 kilocycles.

The effective and crest field strengths, of the radio interference from corona at various voltages on a 2/0 polished copper cable are shown in figure 7. Polished conductors were used for some measurements of conductor corona interference in order to obtain consistent and reproducible results. For such a conductor the crest field strength rises very abruptly as the voltage is increased beyond the critical corona voltage for the conductor. This characteristic corresponds closely with the noise caused in a radio receiver. The crest value of interference is from 5 to 10 times the effective value. In figure 8 are shown the effective and crest field strengths of the radio frequency radiation from corona on a polished 4/0 aluminum cable steel reinforced. The corona interference characteristics for this conductor are essentially the same as those for the copper cable.

Characteristic curves for weathered copper and



Polished 2/0 copper | Polished 4/0 aluminum | Weathered 2/0 copper | Weathered 4/0 aluminum

Figs. 7–10. Effective and crest field strengths of radio frequency radiation from corona

Cables 36 inches from neutral plane

aluminum cables are shown in figures 9 and 10. The increase of crest field strength immediately above the critical corona voltage is much less abrupt for the weathered conductors than for the polished cables and is less abrupt for the weathered aluminum cable than for the weathered copper cable. These characteristics agree with the audible nature of the disturbance in a radio receiver. The curves are typical of the characteristics obtained for several conductor sizes and spacings by measuring the crest and effective field strengths of the radio frequency radiations resulting from conductor corona.

The field strengths of interference from insulator corona[6,7,8,9] were measured by an arrangement similar to that shown in figure 6 except that a single conductor was suspended in the space occupied by the neutral plates. This conductor was free from corona over the range of the voltages used in the measurements. The insulator under observation was supported on a wooden arm and tied to the conductor with a number 6 tie wire. The insulator pin was connected to ground.

The solid curves in figure 11 show the effective and crest field strengths of interference from corona on a conventional 66 kv porcelain insulator. The interference from this insulator is contrasted with that from conductors by the gradual initial increase in field strength. This again agrees with the audible disturbance caused in a receiver. The interference field strengths for a 66 kv insulator designed to eliminate radio interference are shown by the dashed curves in figure 11. The interference starts at a much higher voltage than it does with the conventional type. Since the curves of radio interference are based on conductor to pin voltage, it should be pointed out that the operating voltage for these insulators is 38.1 kv conductor to pin. As in the case of the conductors, the crest field strengths measured for insulator corona interferences are several times as great as the effective values.

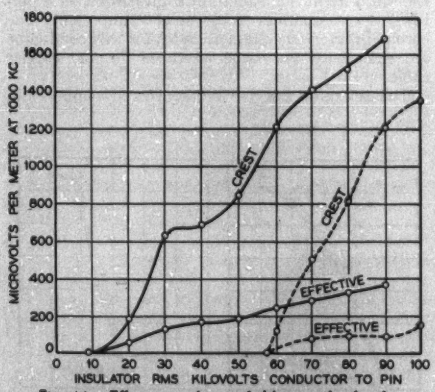


Fig. 11. Effective and crest field strength of radio frequency radiation from insulator corona

Solid curves—conventional 66 kv porcelain insulator
Dashed curves—66 kv porcelain insulator specially designed to eliminate radio interference

The high ratio of the crest value to the effective value found for the interference from both conductors and insulators is characteristic of many types of interfering radiation. These high ratios or crest factors are caused by the discontinuous bursts of electromagnetic radiation produced by the corona discharges. The general characteristic of the interference caused by a conductor in corona is shown in figure 12. This oscillogram shows the conductor to plate voltage and the audio frequency interference output of a radio receiver caused by the conductor corona. From the figure it may be observed that the interference is very high for a short time interval during the negative half cycle and does not recur

Fig. 12. Oscillogram of conductor to plane voltage and radio interference from conductor corona

until the next negative half cycle. As the number of electrodes of opposite polarity and the number of phases with electrodes of one or both polarities are increased, the time interval between successive interfering radiations is reduced and the continuity of the interference is increased. It is, therefore, very important to measure both the effective and crest values of interfering radiations in order to be able to describe adequately their characteristics.

The ratios of crest and effective field strengths obtained agree with discrepancies observed between effective field strength measurements and apparent values. This fact indicates that the method of measuring interference described offers a better means of correlating interference measurements with interference effects.

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Diesel Electric Motive Power for Railroads

Recent developments in internal combustion engines have provided a source of mobile motive power for railroads which has shown economies over steam operation in some classes of service. The continuing development of Diesel engines gives promise of their further substitution for steam power, but in the application of this unit, performance characteristics must be considered carefully. The recently developed "streamlined" Diesel electric trains are rather limited in application, but the Diesel engine has an immediate field of application in switching and transfer locomotives. Electrical transmission of power from the Diesel engine to the driving wheels of a train has advantages which make it preferable to any other type of transmission as yet developed.

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THE initial development of internal combustion engines for railroad motive power, which took place during the first quarter of the present century, was based upon the use of gasoline or gasoline substitutes because no Diesel engines had been built which were suitable for the purpose. In 1925, however, the Diesel engine, which already had been successfully used for other applications, was developed to the stage where it could be applied for railroad transportation. In that year, Diesel engines of 200 and 400 horsepower capacities were applied to rail cars of the Canadian National Railways, and a few Diesel locomotives were constructed with 300 horsepower installed engine capacity. There are now nearly 200 Diesel locomotives and more than 50 Diesel rail cars in service or on order, and the application of such units has only begun. When it is considered that the steam locomotive has had over 100 years of intensive development and that the Diesel engine as applied to rail motive power, has had scarcely 10 years of life in the face of serious obstacles, an optimistic view of the field for the Diesel engine in the years to come may be justified.

A paper recommended for publication by the A.I.E.E. committee on transportation, and scheduled for discussion at the A.I.E.E. Pacific Coast convention, August 27–30, 1935. Based upon a talk delivered before the transportation group of the Institute's New York (N. Y.) Section on January 1, 1935. Manuscript submitted February 8, 1935; released for publication June 13, 1935.

The Diesel Engine

Undoubtedly, most engineers are familiar with the Diesel engine, but for the benefit of those who are not, a brief description may be in order. In general construction the gasoline and the Diesel engines are nearly identical. The former, however, draws in its fuel in the form of a gas, the gasoline being vaporized and mixed with the proper quantity of air. This fuel mixture is then compressed and fired by an electric spark. The Diesel engine draws in nothing but pure air and, after this pure air is compressed, the fuel is sprayed into the cylinders in a very fine vapor and fired by the heat generated by compressing the air. This method of introducing the fuel is the fundamental difference between these engines, and is responsible for the much higher thermal efficiency of the Diesel engine. In the gasoline engine, the maximum compression of the gas fuel mixture must be low enough to guard against preignition of the charge due to heat of compression. In the Diesel engine, the compression pressures may be much higher because only air is involved. The higher temperatures and pressures in the latter case result in greater efficiencies. This also means that the engine parts must be slightly heavier to withstand the higher pressures.

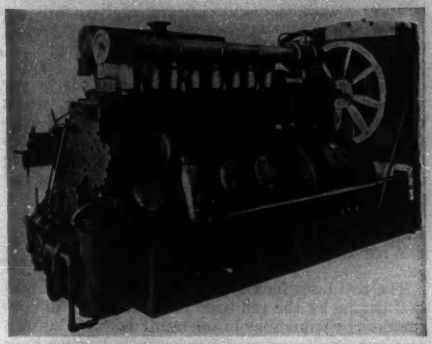

Fig. 1. A Diesel engine rated 265 horsepower, 900 rpm, 4 cycles, and having 4 9 by 12 inch cylinders

The Diesel engine "grew up" as a marine engine; it was of slow speed for direct connection to propellers, and weight was of minor importance. Few Diesel engine manufacturers could foresee sufficient field for the high speed light weight Diesel engine to warrant the high expense of development. The application of such engines to rail propulsion, however, necessitated small dimensions and light weight; with the growing demand, such engines have been

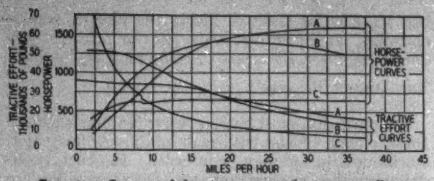

Fig. 2. Curves of horsepower and tractive effort versus speed for steam and Diesel electric locomotives

A—6 wheel steam switching locomotive
B—Consolidation steam locomotive
C—800 horsepower Diesel switching locomotive

developed. The first commercial rail car engine weighed around 30 pounds per horsepower, which compared very favorably with similar sized contemporary gasoline engines, and was a long step forward. This development has been a contributing factor toward the adoption of Diesel engines for rail propulsion purposes.

Reduction in Operating Costs With Diesel Operation

The real basis for the use of the internal combustion engine by the railroads has been and will continue to be reductions in operating costs. Gasoline cars were built and used in quantities because they could be operated by reduced crews, because maintenance expense was lower, and because attendant facilities necessary for steam operation could be eliminated. In rail car work, the Diesel engine has the further advantage of reduced fuel expense. A typical cost comparison of a steam locomotive and train as against a Diesel motor car with a trailer to handle the same service, is shown in table I.

This does not take into account any reduction in attendant facilities, as, in this particular instance, the freight service was still operated by steam, and the coal chutes, water towers, and ash handling equipment were retained.

If this service were handled by a gasoline-engined rail car, the engine maintenance would be slightly higher than the figure for the Diesel engine, and the fuel cost would be approximately the same as coal cost for steam, so that the net saving per year would be reduced from $20,650 per year to approximately $17,000.

The Diesel-engined locomotive had had its christening in switching service. In this class of work, the operating savings, as compared to steam operation, are very pronounced. A typical operating cost comparison is shown in table II. This comparison is of a steam locomotive having a maximum rating of 900 horsepower at the rims of the drivers replaced by a Diesel locomotive developing 425 horsepower at the rail, either locomotive performing the switching work effectively.

Performance, Relative to Steam

In applying Diesel locomotives, it must be recognized that there is a marked difference in the performance curves of steam and Diesel locomotives. This is best illustrated by figure 2, which shows the performance of an 800 horsepower (engine rating) Diesel switcher, a 6 wheel steam switcher, and a consolidation steam locomotive. The horsepower curves shown represent the power developed at the rail. It may be seen that the Diesel unit is of relatively constant horsepower, while the steam units are of variable power developing their maximum power at 20 miles per hour or above.

It has been shown repeatedly that Diesel locomotives of limited installed engine power can compete successfully in switching service with steam motive power of much higher potential horsepower capacity. The Diesel superiority lies in the high starting tractive force obtainable. Electric drive of the axles provides smooth and continuous application of torque, and reduces the tendency of wheels to slip, whereas the steam locomotive drive produces 4 distinct impulses at the wheels in each revolution. The minimum torque in a 90 degree rotation of the wheels is 29 per cent less than the maximum during this same period. Therefore, there is a pulsating torque varying from 71 per cent to 100 per cent (with an average of 89 per cent) of the maximum

Table I—A Typical Comparison for Passenger Service

Steam Train Investment	$42,707	
Diesel Train Investment		$31,646
	Dollars per Train Mile	
	Steam	Diesel
Crew wages	$0.2841	$0.2215
Motive power repairs	0.2791	0.0440
Car repairs	0.0376	0.0376
Fuel	0.1036	0.0310
Lubrication	0.0067	0.0100
Water	0.0253	0.0000
Enginehouse expense	0.1012	0.0120
Supplies	0.0079	0.0079
Total operating cost	$0.8455	$0.3640
Interest on investment	$0.0528	$0.0982
Motive power depreciation	0.0066	0.0380
Trailer depreciation	0.0154	0.0092
Fixed charges	$0.0748	$0.1454
Grand total	$0.9203	$0.5094
Savings per year (50,250 miles per year)	$20,650	

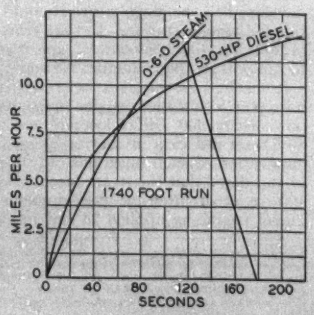

Fig. 3. Switching comparison of 0–6–0 steam locomotive and 530 horsepower Diesel locomotive, with 1,500 tons trailing load, on level track

The Diesel locomotive is the faster on runs less than 1,740 feet

Table II—A Typical Cost Comparison for Switching Service

	Dollars per Day	
	Steam	Diesel
Wages—engineer	$ 22.20	$22.20
Wages—fireman	17.43	0.00
Fuel	15.00	3.60
Lubricants	0.36	1.61
Water	1.15	0.00
Repairs	54.48	14.30
Enginehouse expense	7.00	2.00
Supplies	1.00	1.00
Total operating cost	$118.62	$44.71
Depreciation	$ 1.20	$ 7.20
Total expense	$119.82	$51.91
Savings by Diesels per day		$67.91
Savings by Diesels per year		$24,800.00
Return on investment	Approx. 40%	

available. Obviously, the useful tractive force of the electrically driven wheels may be considerably higher (without exceeding the adhesive limit) than that of wheels driven by reciprocating engines through side rods. It has been demonstrated in service that this may be 20 to 30 per cent greater than the useful steam tractive force for equivalent weight on drivers.

The effect of high starting tractive force in the acceleration of a train is shown by figure 3. It may be noted that the area under the curve represents distance (speed × time) and that the Diesel locomotive gains considerable distance over the steam locomotive during the first 67 seconds, and, in order to regain this distance, the steam locomotive must accelerate to a higher speed than the Diesel. If both locomotives then brake to a stop at the end of 178 seconds, they will have each covered exactly the same distance (1740 feet) and for any shorter distance, the Diesel will have consumed less time.

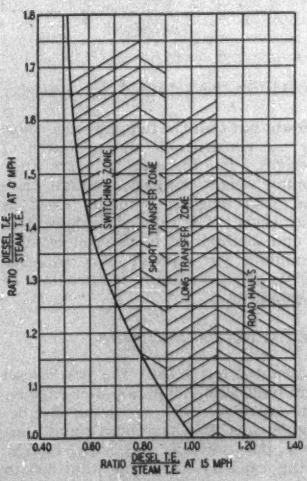

Fig. 4. Application guide for Diesel electric locomotives relative to a steam locomotive (approximate)

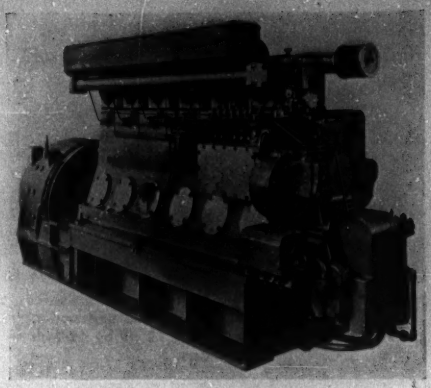

Fig. 5. A Diesel engine rated 400 horsepower, 900 rpm, 4 cycles, and having 6 9 by 12 inch cylinders

The effect of high starting tractive effort, as compared to that of the steam locomotive, may best be illustrated by figure 4, which is the result of a great many comparisons such as that shown in figure 3. For switching work, a Diesel locomotive with a relatively high starting tractive effort, as compared to steam, will compare favorably even when the horsepower is low, whereas when the initial tractive effort approaches more nearly that of the steam unit, more Diesel engine horsepower is necessary to perform the same work, horsepower being represented on the curve in proportion to tractive effort at 15 miles per hour. Thus, if the initial starting tractive effort of the Diesel locomotive (usually figured at 30 per cent of the weight on drivers, which value is permissible due to the uniform torque of electric motor drive) is 50 per cent higher than that of the steam locomotive, the tractive effort at 15 miles per hour need be but 60 per cent of that of the steam unit, to fall within the switching zone. This means that the horsepower developed at the driving wheels need be but 60 per cent of that of the steam locomotive at that speed in order for the 2 units to be comparable in switching work. If the service includes frequent short transfer hauls the Diesel horsepower should be 80 per cent to 85 per cent of the steam horsepower at the wheels. However, when these switchers are used in transfer or road service, the limited horsepower seriously affects the train performance, and the effect of rapid acceleration becomes of less importance. This means that progressively more Diesel power is required for short transfer work, long transfer work, and road hauls. This is also shown by figure 4. In calculating the steam locomotive performance curve any standard method may be used, but since it has been found that actual road performance is usually very considerably less than the calculated curve, the tractive effort

Fig. 6. A Diesel engine rated 800 horsepower, 900 rpm, 4 cycles, and having 12 9 by 12 inch cylinders

used at 15 miles per hour should be 75 per cent of the calculated value.

Development of High Speed Streamlined Trains

Within the last 4 years, the Diesel engine has been given serious consideration by the railroads. It has proved its effectiveness as a source of motive power and has demonstrated that it will actually reduce operating expenses both in rail car work and in switching work. The trend of the times has also been conducive to its adoption, especially in rail car work. A period of industrial stagnation always brings out radical ideas of all kinds, both politically and mechanically. New steels have been perfected; new methods of fabrication have been developed. New ideas of all kinds are rampant. The growth of air passenger traffic, even during the depression, has focused the attention of the public on aerodynamic construction to such an extent that even automobiles have suffered. Nevertheless, the airplane has had its effect on railroad train construction. The public preference for fast service, as evidenced by the air traffic growth and the stepping up of automobile speeds (40 miles per hour was fast road driving in 1925) has led some of the railroads to the conclusion that the provision of fast train service would be welcome, especially from Chicago to the western cities. Consideration of such fast trains led to the adoption of light weight construction, streamlining, articulation and the Diesel engine, since these features bring the power requirements down within the range of present engine construction.

The development of the modern streamlined passenger train may be definitely traced to rubber tires. The Michelin tire, as brought out in France for rail purposes and later tried in this country, necessitated light weight car construction. To construct such light weight cars, a new method of steel fabrication was developed in this country. With the increase in car weights and the consequent abandoning of rubber tires, the new fabrication methods were retained. This experience in light weight construction and reduced cross sections of cars pointed the way for further combination of such construction and aerodynamic lines, which puts the power requirements, even for high speeds, within the range of Diesel engine capacities. Thus, the so-called high speed streamlined trains which have been operated or are on order, are Diesel engine driven. As a matter of fact, increases in speeds of railroad trains are not as much a function of light weight construction and streamlining as of grades, curves, and traffic hazards. The only difference between a light weight, streamlined train and a conventional train is in the amount of power required for propulsion, and the present steam motive power is adequate to pull any normal train at as high a speed as these limitations will allow. Such spectacular runs as have been made with this new type of train have been under conditions which could not be tolerated for everyday railroading.

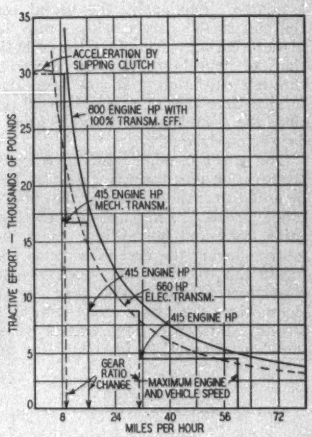

Fig. 7. Speed-tractive effort characteristics of mechanical transmission with 800 engine horsepower

There is no doubt but that the railroads as a whole will benefit by the construction and operation of such radical designs. For the past 10 years, they have been becoming weight-conscious, and are striving to decrease dead weights of rolling stock as compared to pay loads. The rapid development of new materials and methods of fabrication of such steels and aluminum for railroad cars will undoubtedly have its effect on future construction of conventional equipment.

Diesel Engine Capacities and Speeds

As has been pointed out before, the first Diesel locomotives were built with 300 horsepower engines. As has been the experience with all automotive developments, engine capacities have been rapidly increasing. Where the railroads originally bought locomotives of this capacity, they now want 600 to

900 horsepower for switching work, and even greater power for transfer service. Locomotives are on order up to 2,000 horsepower. It still takes 2 such locomotives to equal the performance of a modern 4-8-4 steam unit such as the railroads are now buying, and the first cost of 2 such locomotives cannot be justified by the operating savings, except in a few places. The Diesel designer, however, is striving vigorously to reduce manufacturing costs and, as these costs come down, the field of application will expand.

The manufacture of Diesel engines for railroad motive power is an accomplished fact. Much progress has been made since 1920—from the days when Diesel manufacturers thought that 250 rpm was a high engine speed, and some of the bolder of the conventional designers actually felt that it was possible to go to 350 or 375 rpm. Fundamentally, the success of the Diesel engine as a prime mover for railroad propulsion depends upon building within railroad clearance limitations, and to build large powers into these dimensions automatically dictates high engine speeds. The experience with the Diesel engine at 900 revolutions per minute has dispelled many of the supposed bugaboos of high engine speeds, with the result that most builders of railway Diesels are stepping up their speeds. Development of larger sizes beyond those considered possible at the present time may be expected in the future.

Three typical modern Diesel engines are shown in figures 1, 5, and 6.

Transmission Systems

The transmission of power from a prime mover to the wheels of a locomotive or rail car has been the subject of a great amount of thought. Mechanical transmission from reciprocating steam engines is simple, and has been proved to be practical and reliable. Transmission of power from internal combustion engines, however, is not as simple, since the prime mover cannot develop torque at zero speed. Among the systems proposed and tried are:

Mechanical drive (clutches, change gears, universal joints, etc.).
Hydraulic transmissions.
Pneumatic drives.
Electric transmissions.

The apparent simplicity of the mechanical system gave it an advantage during the early stages of self propelled rail car and locomotive development. With the gradual increase in engine sizes and train weights, every opportunity was afforded to develop such transmissions, and, as an actual fact, they were used with some success up to 175 horsepower engine sizes. In spite of the intensive development, such transmissions have not persisted in the larger engine capacities, and nothing spectacular has appeared to date to show a reasonable expectancy of results better than have already been found.

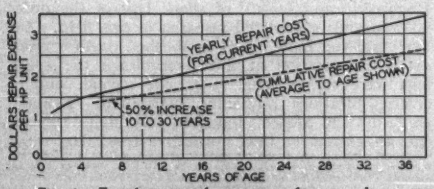

Fig. 8. Trend curves of repair cost for steam locomotive in switching service

Mechanical transmission involves a number of problems which have not, as yet, been successfully solved for large horsepowers (above 150 horsepower) and which are troublesome in even lower horsepower. These troubles include:

1. Transmission from a spring borne body to a swivel truck.
2. Transmission to an axle, one end of which may move up or down (with rail joint depression, etc.), and which has some lateral movement in the truck, as well as longitudinal movement in the journal box guides.
3. Engine mounting on the truck to reduce the problems of (1), results in high engine maintenance.
4. Gear shift transmission results in poor utilization of available engine power. Thus, each time the gear ratio is changed, power must be completely removed and engine speed dropped to approximately half speed (and half horsepower), following which the engine must accelerate the load to regain full horsepower. This is often impractical with varying railroad grades and results in long operation in an uneconomical gear ratio. This is shown by figure 7.

In spite of numerous attempts to use it, no hydraulic transmission has yet been found adequate for railroad service. The main difficulties are due to low efficiency, high maintenance, oil leakage, and emulsification of the oil.

There have been numerous attempts to employ compressed air for power transmission purposes. The fact that these attempts have resulted in no extended use of this system speaks for itself. Other freak drives (such as combinations of steam and Diesel drives) have not as yet attained a commercial status.

The only satisfactory system of power transmission for internal combustion engine rail motive power is the electric system. The reasons for this are:

1. Low maintenance costs as compared to other transmission.
2. Less physical labor for enginemen in control.
3. Greater over-all efficiency and engine power utilization.
4. Maximum tractive efforts and maximum speeds not a function of the engine.
5. Simple to apply power to multiplicity of driving axles.
6. Operation of auxiliary apparatus is simple.
7. Double end or multiple unit control is simple.
8. Power plant may be located in the most advantageous position.
9. Every engine has one or more critical speeds. These may be avoided by electrical transmission.
10. Experience has proved the economy and reliability of this system.

Trends in Repair Costs

It has been shown by tables I and II that Diesel car and switching locomotive operations result in savings over steam operation. One of the major savings which appear is that of repair expense. The railroads and some steam locomotive builders are

prone to discredit this saving in view of the lack of sufficient years of operation of the Diesels. The Diesel engineer, however, has considerable justification for the figures used and can point with certainty toward the future maintenance expense.

It has been demonstrated (and widely discussed) that there is a definitely rising repair expense trend for steam locomotives as their age increases. Figure 8 shows this steam locomotive trend. It may be expected that all machinery has a rising repair expense with age, the only undetermined factor being the rate of rise. An analysis of the 1932 report of the American Railway Association, committee on locomotive construction, and of the 1932 report of the heavy traction committee of the American Electric Railway Association has given a definite indication of this rate of rise for Diesel locomotives. In addition, a detailed analysis has been made by a competent railroad engineering officer, based upon Diesel operation on his own railroad, taking each piece of equipment in the complete locomotive and establishing its life, cost, and the labor required to replace the worn part. These trend curves are shown by figure 9. As a matter of fact, it is believed from electric locomotive experience and from gas car operation, that the curve will take quite a drop as operating experience piles up.

In closing, it should be emphasized that from the very beginning of railroads until early in the twentieth century, there was only one commercial source of mobile railroad motive power—steam. Now there are 2—steam, and the internal combustion engine. The rapid development which has taken place in the latter type since the introduction of the Diesel engine as a rail prime mover augurs well for this new method of power generation. The importance of the most modern Diesel developments in light weights and streamlining may be discounted as being the result of an industrial recession and as being limited in application, although the pioneering

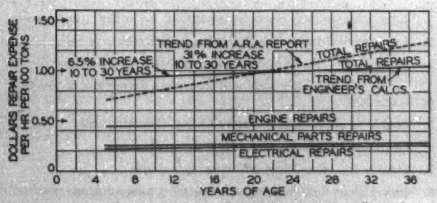

Fig. 9. Trend curves of repair cost for Diesel electric locomotive in switching service

work in weight reduction should have a far reaching effect on railroad cars of all kinds. The ultimate rail car will undoubtedly be of a conventional type, but of lighter construction as a result of the streamlined train experience. The immediate field for the Diesel engine is in switcher and transfer locomotives, with a gradual expansion into the road locomotive field as the economies become better established.

Spark Lag of the Sphere Gap

Measurements of time lag of spark-over of small sphere gaps at 3,820 volts were made with an instrument developed specifically for the purpose. Spark lags were found to fall into 3 distinct domains: 1 of relatively long initiatory lags of random distribution, and 2 of definite formative lags of different orders of magnitude corresponding to 2 different spark-over mechanisms. The controlling conditions which determine into which domain the spark lag will fall are given. The manner in which this lag may obscure the sparking voltage of the gap is pointed out and a remedial specification suggested. The results are applicable to larger sphere gaps and higher voltages.

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In the great majority of the investigations concerned with spark-over, the principal dependent variable under observation has been, naturally enough, the voltage at which the spark breakdown commenced. The time interval during which this voltage needs to act in order to initiate the spark-over has received, in comparison, only slight attention. This interval, the time lag of spark-over, or more briefly, the spark lag, is defined as the time interval during which a spark gap sustains a voltage greater than its minimum sparking voltage. Only recently, indeed, one may say with some precision, only within the last decade, has the time lag of spark-over been extensively investigated.

On the one hand, the theoretical predictions by Rogowski[12] and Loeb[8,9] of spark lags of the order 10^{-4} seconds stimulated research in this field. Zuber[17] and von Laue,[16] had established that for weak external ionization at low overvoltage the spark lags were rather long, *e. g.*, one second, and of erratic durations randomly distributed. Beams,[4] and Buss and Masch,[2] found at very high overvoltage an extremely brief formative spark lag, *e. g.*,

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12. For all numbered references, see list at end of paper.

2×10^{-8} seconds. Much work related to these theoretical problems was done in small gaps with initially uniform field and sparking voltages below 5,000 volts.

At the same time, spark lag was being studied in an entirely different connection and on an entirely different scale. The investigation of protection against brief lightning surges with their special wave form added the very greatest practical interest to the study of spark lags. Thus, just 10 years ago, McEachron and Wade[10] first co-ordinated the use at "full scale" voltages of 2 important instruments, the surge generator and the cathode ray oscillograph, which have been fruitfully utilized since. Torok,[14] by the ingenious method of "suppressed discharges," made visual observations of the incipient spark at approximately timed stages. Torok and Ramberg[15] more recently made a thoroughgoing comparison of the time lag of spark-over of insulator strings and of various arcing rings. Only last year[1] has the influence of time lag and wave shape been successfully included in writing test specifications for impulse spark-over, so that different laboratories can obtain comparable results at *this wave shape*, i. e., simulating lightning. Thus, engineering development had produced empirical information in many instances but had not yet led to any comprehensive classification of time lags of spark-over.

In particular, the relationship between the long, random, initiatory time lags observed at low external ionizations and the short formative lags observed at high external ionizations had never been clearly demonstrated by an experimental transition from one to the other. Further, the formative spark lags of static spark-over, i. e., of spark-over at low overvoltages, had never been ascertained. By means of a new timing instrument, these important measurements have been made. In conjunction with the previous literature of the subject, spark lags of the sphere gap are comprehensively classified and the spark-over mechanisms involved are made clear.

Conclusions

The conclusions drawn as a result of the study described in the present paper may be summarized as follows:

1. An instrument has been developed capable of measuring time lag of spark-over independently of lag variability and independently of voltage wave shape and magnitude.

2. Spark lags of the sphere gap were found to fall into 3 distinct domains.

3. In the first domain, i. e., with weak external ionization, the spark lags are long and of random distribution. The average lag increases greatly as the external ionizing source is weakened or the overvoltage decreased. The lags are primarily initiatory, i. e., spent in awaiting the arrival of electrons suitable to commence the spark-over process.

4. In the second domain, i. e., with adequate ionization and low overvoltage in a short gap, the lags are distributed about a definite value. The lags are primarily formative, i. e., represent the time required for the spark-over process to proceed to completion, i. e., to the point at which the gap voltage drops. The lags are of the general order of time required for a positive ion to cross the gap and assist in building up a space charge gradient.

5. In the third domain, i. e., with adequate ionization and a higher overvoltage or longer gap, the lags are also formative and of a definite value. Their magnitude is of the order of time required for a single electron avalanche to cross the gap.

6. The random initiatory lag contributes to the erratic performance of the sphere gap voltmeter.

7. This source of error should be eliminated by specifying an adequate ionizing source subsequent upon further practical experimentation.

8. The comparatively long formative lag of small gaps at low overvoltage may prove of practical importance in design of ignition gaps, safety gaps, etc.

9. At impulse spark-over the time lags and the exact voltage wave shape enter equally with the voltage magnitudes in determining whether spark-over will ensue.

10. Because of the variety of combinations possible, any attempt at a comprehensive classification of spark lags of point gaps must await much additional experimental work.

The Timing Instrument

Although instruments for measuring short intervals were available, they were not suitable for the tests at hand. As is well known, the phenomenal development within the last decade of the cathode ray oscillograph and the electro-optical shutter now make it possible to measure phenomena occurring with extreme rapidity, *e. g.*, within 10^{-8} seconds. These excellent instruments, however, have a quite limited range. That is, they can only measure a time interval reasonably close to the full scale value for which they are just then adjusted. They are not, therefore, suitable to measure successive individual time lags, one of which, for instance, is 10^{-8} seconds and the next 1 second. Furthermore, for statistical distributions requiring large numbers of readings the expense and delay of photographic readings rather than direct indications becomes seriously objectionable. It was necessary to have an instrument which:

1. Could measure quite brief time intervals (*e. g.*, in these particular tests 10^{-8} seconds).

2. Stood ready to measure *individual* lags from the minimum reading of the instrument up to any longer interval.

3. Could await the application of the sparking voltage for an indefinite length of time.

4. Could be adjusted with extreme precision as to the minimum sparking voltage above which it was to respond critically.

5. Would measure the duration of overvoltage independently of the magnitude, wave shape, or method of application, of the voltage.

6. Gave direct readings.

These stringent requirements were met by a vacuum tube circuit which might be called an incremental-voltage amplifier, since its action depends on the high amplification of the first increment of overvoltage. The circuit is shown in figure 1. Briefly, the first tube is an inverted vacuum tube voltmeter, drawing no power from the test gap and reducing the voltage to a value convenient to work with. Its output, in series with an adjustable bias, is brought to the second tube. The second and third tubes provide a high linear amplification, which swings the grid of the fourth tube from a substantial negative voltage to a substantial positive voltage as the gap voltage is rising a small increment past the value for which the bias is adjusted. The output of the fourth tube is thereby raised from zero to a

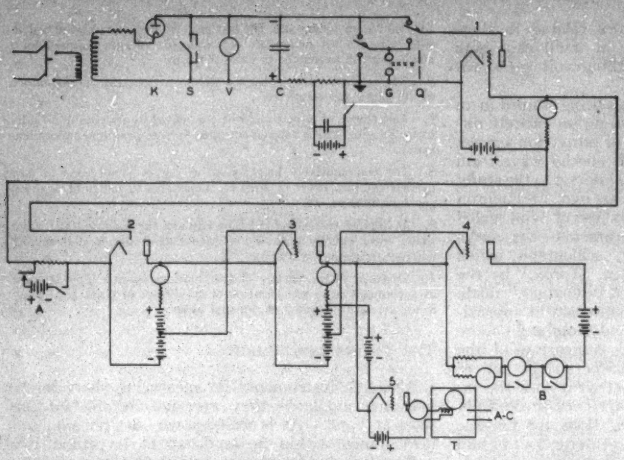


Fig. 1. An instrument for spark lag measurements

K—A 2-electrode vacuum rectifier tube
S—Safety gap and discharge switch
V—Electrostatic voltmeter
C—Storage condenser
G—Test gap
Q—Quartz mercury arc
A—Bias adjustment
T—Synchronous timer
B—Ballistic galvanometer

Tube	"B" Supply Voltage	Output Circuit Resistor
1—OM5	156	1.92 megohms
2—CX340	180	0.5 megohms
3—CX345	180	0.1 megohms
4—CX340	90	0.25 megohms
5—CX345	180	500 ohms

constant maximum value (i. e., to the plate supply voltage divided by the external plate resistance). This current is passed through ballistic galvanometers whose throws are directly calibrated in seconds. As the bias is adjusted so that the critical response is at the minimum sparking potential of the gap, the galvanometer reading gives directly the time interval that the gap voltage has remained above this minimum sparking voltage, i. e., the time lag of spark-over. The third tube also supplies another amplifier tube, which operates a synchronous timer that registers any longer interval. The plate currents of these tubes are calibrated and used to obtain a reading of the gap voltage.

Test Gap, Voltage, and Illumination

The spark gap used in these tests consisted of copper spheres of $^3/_4$ inch (1.904 centimeter) diameter and 0.0269 inch (0.0683 centimeter) spacing in dehydrated air at atmospheric pressure. The static sparking potential was 3,820 volts. A gap so small was used to afford a direct comparison with the "pure science" literature of the subject, and also, because of the greater economy and convenience of the lower voltage circuits. The results are entirely applicable to larger sphere gaps. Two voltage wave shapes were utilized, as shown in figure 2. The first approximated "static" spark-over; the main d-c voltage was set at 96 per cent of sparking voltage and a bank of "B" batteries was then thrown across a resistance in the circuit to raise the gap voltage suddenly to a constant value some per cent above the sparking voltage. The second wave shape, constant d-c voltage suddenly applied, approximated "impulse" spark-over but at small overvoltages. Both wave shapes were quite rectangular, the time of rise of the voltage and also the time of voltage drop each being very much less (*e. g.*, $^1/_{1,000}$) than the shortest time lags being measured. Photoelectric ionization was produced by illuminating the gap with ultra-violet light of measured intensity from a quartz mercury lamp.

The Random Distribution

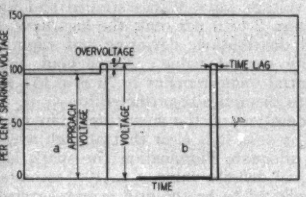
Many of the test series resulted in random distributions. Accordingly, it might be well at this point to say that a random distribution is a quite definite thing, and also to explain the method of plotting it. A series of time intervals, in this case spark lags, may be defined as having a random duration if each one is as likely to be terminated during any one time increment as during any other equal increment. The *constant* probability of its termination within a unit time increment may then be denoted by p. Hence, it can be easily shown[16] that a series of such random spark lags must fit the equation $n_t = 100\epsilon^{-pt}$ wherein n_t is the percentage of the total number of lags which is as great as or greater than t. The average time lag $T = 1/p$. Note that for $t = T$, $n_t = 100\epsilon^{-1}$ or $n_t = 36.8$ per cent. That is, most of the lags are shorter than average, only 36.8 per cent being longer; of these, however, a few are much longer, thus striking an average.

In plotting the data the series of spark lags are arranged and numbered in order of magnitude and this order number is then divided by the total number of spark lags in the series and multiplied by 100, thus giving each lag a per cent order of magnitude designation. This per cent order of magnitude is then plotted against its corresponding time lag interval, giving points on a curve of n_t against t. Each spark-over measured contributes one point to the curve. These are joined by light lines, the lower left hand corners of the light curves being the actual data points. The resultant curve is then placed so that the number of points above it equals the number below. Where the distribution is truly random, the curve obtained is a simple exponential

or, if plotted on semi-logarithmic paper, a straight line. The ordinate of any point on the curve gives the percentage of the total number of spark lags of the series which are as great as, or greater than, the time interval given by its abscissa.

Test Data

At each illumination a series of spark lag measurements was made for each of several voltages in the neighborhood of 105 per cent. This whole group of measurements was then repeated at other illuminations. The reader's inspection of the data here presented will perhaps be assisted by a brief qualitative statement of the results. At low illumination the spark lag distribution is random as shown by the straight line distribution curves obtained on semi-logarithmic paper; increasing the voltage decreases the lag duration generally, giving a similar but steeper distribution curve. Until a certain point, increasing the illumination, likewise, merely steepens the distribution curve. At higher illuminations, however, a transitional distribution appears wherein a fraction of the observed lags have a random distribution similar to those already mentioned and the remainder have an entirely different type of distribution. As the illumination is further increased a larger fraction of the lags fits the second distribution, and for all adequately intense illuminations all the lags fit the second type of distribution. This is a highly peaked distribution containing a few large and many small deviations from a single definite value. In fact, some 40 per cent of all the lags observed are of practically identical duration. These results are illustrated by the selected curves of figures 3 and 4.



a—"Static" spark-over
b—"Impulse" spark-over
The actual time for the voltage changes which are drawn vertically is about $^1/_{1000}$ of the smallest spark lags measured

Fig. 2. Voltage wave shapes

Figure 3*a* shows 3 curves of spark lag distribution at static spark-over at 3 different voltages and at 1 intensity of initial ionization. This intensity is measured by measuring the saturation current I, in micromicroamperes per square centimeter, ejected from a plate of clean nickel in vacuum by the ultraviolet illumination utilized. For this one illumination the average time lag, obtained from the curves of figure 3*a*, is plotted against per cent overvoltage in figure 3*b*. It will be noted that this curve also is a simple exponential. The average lag at a specified overvoltage is readily obtained by interpolation from this curve for use on the master curve of figure 7. Figure 4 illustrates, for static spark-over near 105 per cent voltage, the change in type of spark lag distribution as the illumination is successively increased.

As mentioned, for the random distributions at low illumination the effect of small increases in voltage is merely to decrease the lags generally, giving a similar but steeper random distribution. At the intermediate illuminations with transitional distributions, increasing the voltage causes a greater proportion of total number of lags to fall into the peaked distribution. At the high illuminations with peaked distributions small changes in voltage do not alter the lag distribution. The entire test series was repeated for impulse spark-over, with highly similar results. These relationships may be observed in figures 5 and 6, which contain a major portion of the test data.

At each illumination a curve, such as figure 3*b*, of the average lag of the random distributions was plotted against overvoltage. For static spark-over these curves were all exponential over the range from 1 to 6 per cent overvoltage and all had nearly the same exponent. Thus, the factor by which v, the per cent overvoltage, modifies the average lag may be inclusively stated as $f(v) = \epsilon^{-(0.39 \pm 0.08)v}$. For impulse spark-over these curves deviated somewhat from simple exponentials but still fitted this same equation near 5 per cent overvoltage.

The average time lags of static spark-over at 105 per cent voltage, as interpolated from the above mentioned curves, are plotted against illumination in the master curve 1 of figure 7. The peak value of the peak distributions is also plotted against illumination in the second segment of curve 1. At the illumination giving the transitional distributions the 2 curve segments are shown dotted. As indicated, the 70

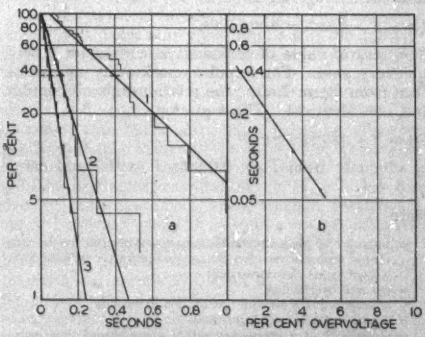


Fig. 3. Random spark lags at one illumination. I = 0.00183, approach voltage = 96 per cent

a—Spark lag distributions
Curve 1—Overvoltage = 0.7 per cent
Curve 2—Overvoltage = 3.5 per cent
Curve 3—Overvoltage = 4.9 per cent
The curve ordinate gives the percentage of lags which are greater than the time interval given by the abscissa
b—Average lag versus per cent overvoltage

per cent of the lags giving a random distribution have magnitudes fitting the curve for the all random distributions; likewise, the 30 per cent of the lags constituting the peaked distribution fit with the other peaked distributions. Master curve 2 of figure 7 is similarly plotted for static spark-over at 3 per cent overvoltage, and master curve 3 for impulse spark-over at 5 per cent overvoltage. These master curves show clearly how increasing the illumination decreases greatly the random lags, and how further increase in illumination gives rise to the lags of peaked distribution. The magnitude of the lags of the peaked distribution remains uninfluenced by a further 30-fold increase in the illumination. A better qualitative conception of the extent of these curves, for instance, curve 1, may perhaps be obtained by replotting a portion of it in figure 8 on ordinary graph paper. It is clear from curves 1 and 2, figure 7, that the small decrease in overvoltage from 5 per cent to 3 per cent more than doubles the random lags but leaves the peaked lags virtually unchanged.

Inspection of master curves 1 and 3 shows surprisingly little difference in the spark lags for static and impulse spark-over. Throughout the random lags those of static spark-over are less than half as big as those of impulse spark-over. Apparently the only effect of the 96 per cent approach voltage is, due to cumulative ionization by collision, to increase the general level of ionization at the gap.

Test Results

Quantitatively, the results of these tests may be summed up as follows. For this gap, for static spark-over, for illuminations from $I = 0.002$, the smallest studied, to $I = 0.5$ and for overvoltages from 1 per cent to 6 per cent the spark lags are random, fitting the distribution equation $n_t = 100\epsilon^{-pt}$, and the average lag is

$$1/p = T = 0.0037\epsilon^{-(0.39\pm0.05)v}I^{-0.76}.$$

The central value of exponent is correct for $v = 5$ in every case. For impulse spark-over, as can be seen from figure 7, etc., the relationships are similar but not identical. The equation

$$1/p = T = 0.0078\epsilon^{-0.33v}I^{-0.76}.$$

is adequate from $I = 0.02$ to $I = 0.5$ and for $v = 5 \pm 1$.

Here

I = intensity of photoelectric illumination measured by the current in micromicroampere per square centimeter expelled from a clean nickel plate in vacuum
v = per cent overvoltage
T = average lag of a random distribution in seconds
ϵ = the base of Naperian logarithms
p = probability of a spark-over within a one-second time increment
n_t = the percentage of lags enduring a time t or more
t = time in seconds

For $I = 0.5$ there is a transitional distribution, 70 per cent of the spark-overs occuring in a distribution whose average exactly fits the above equations and 30 per cent fitting the peaked distributions. For successively larger illuminations a successively larger

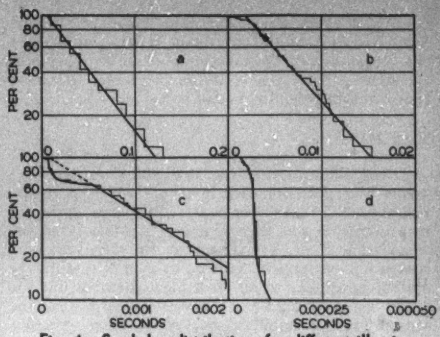


Fig. 4. Spark lag distributions for different illuminations

a—Random at I = 0.00183 c—Transitional at I = 0.365
b—Random at I = 0.0258 d—Peaked at I = 5.75
The curve ordinate gives the percentage of lags which are greater than the time interval given by the abscissa

proportion of the lags fit the latter distribution.

From $I = 0.5$ to $I = 10$, the largest studied, for either of the voltage wave shapes studied and for overvoltages from 2 to 6 per cent, the lags have a highly peaked distribution, deviating but slightly from a definite central value. Throughout this region this central value remains $(0.70 \pm 0.15) \times 10^{-4}$ seconds, as theoretically predicted.[8]

From consideration of the literature,[4,5] in part supplemented by test, it is clear that at high overvoltages with adequate illumination the spark lag must have a brief definite value, *e. g.*, 10^{-8} seconds.

These are believed to be the first comprehensive experimental observations of the transition from the initiatory lags to the formative lags, and also, the first observations of the formative time of static spark-over.

The Nature of the Spark Lag

It is now possible to point out the nature of the spark lag. The time lag of spark-over in every case consists of an initiatory lag followed by a formative lag. Under appropriate conditions either of these may become entirely negligible in magnitude compared with the other. The initiatory lag is the elapsed time from the instant the sparking voltage is applied to the gap to the instant of arrival of suitable initiatory electrons which allow the voltage to commence the spark-over process. The formative lag is the time required for one or another of the spark-over processes to proceed to completion, i. e., to the point at which the gap voltage drops.

Spark lags are found to fall into 3 distinct domains. First, are found long initiatory lags (*e. g.*, 10^{+1} to 10^{-3} seconds) of random distribution spent in awaiting a favorable fortuitous space and time arrangement of the somewhat insufficient supply of initiatory electrons. Second, are found intermediate formative lags (of the order 10^{-4} seconds) distributed about a

definite peak value of the general order of time required for a positive ion to cross the gap and assist in building up a space charge gradient. Third, are found short formative lags (of the order 10^{-7} seconds) distributed about a definite peak value of the order of time required for an electron to cross the gap.

The controlling condition for the first domain is that the external ionizing forces be inadequate. Here the initiatory lag spent in awaiting the fortuitous arrival or creation of electrons so located as to be capable of commencing the spark-over is very much greater than the formative lag. Since this appearance of electrons is as likely at any one instant as at any other, being entirely haphazard with respect to the instant at which sparking voltage is applied to the gap, the distribution of these initiatory lags is truly random. Note that if the voltage is increased the volume within which an electron must appear in order to be effective in initiating spark-over obviously increases. Hence the average lag decreases. The initiatory lags may be extremely large if the external ionizing forces are small, but as these are sufficiently increased the entire initiatory lag becomes negligibly small and the formative lag of either domain 2 or 3, as the case may be, prevails.

The formative lags are observed to fall into the second domain when the prevalent conditions are least favorable to the effective formation of electron avalanches, i. e., when both the per cent overvoltage of the gap and its absolute length are small. The formative lags fall into the third domain when the conditions are made more favorable to cumulative ionization by electron collision, i. e., when the per cent overvoltage is increased or when, while using the same per cent overvoltage, the gap length or air pressure are increased. The exact boundaries of this transition have yet to be observed, but, judging by the work of Dunnington,[6] at overvoltages of the order of 0.5 per cent the second domain prevails for gaps less than 0.28 centimeter long and the third domain for gaps greater than this.

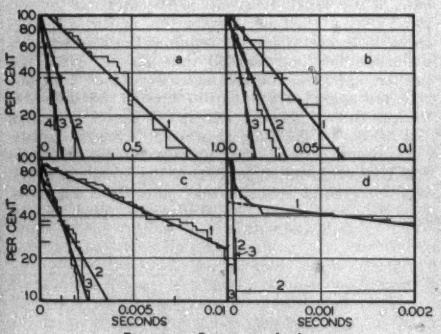


Fig. 5. Static spark lag

The curve ordinate gives the percentage of lags which are greater than the time interval given by the abscissa

Section	a	b	c	d
	0.00183	0.0258	0.365	5.75
Curve 1—% voltage	100.7	100.9	100.8	101.7
Curve 2—% voltage	103.5	103.5	103.8	104.2
Curve 3—% voltage	104.9	104.9	105.4	106.4
Curve 4—% voltage	105.9			

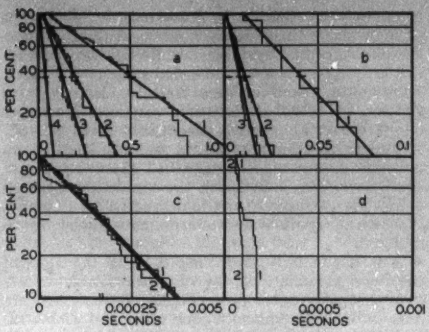


Fig. 6. Impulse spark lag

The curve ordinate gives the percentage of lags which are greater than the time interval given by the abscissa

Section	a	b	c	d
	0.00301	0.0536	0.600	9.80
Curve 1—% voltage	101.8	102.2	105.2	101.8
Curve 2—% voltage	105.2	104.6	107	104.9
Curve 3—% voltage	107.1	107		
Curve 4—% voltage	120.1			

The Spark-Over Mechanism

This difference in formative lag arises from a difference in spark-over mechanism which may be roughly described as follows. In domain 2 each initial electron avalanche leaves behind it a space charge formation whose density increases exponentially with distance from the cathode. This positive ion space charge travels across the gap into the cathode. As its most dense rear layer approaches the cathode it there produces the greatest voltage gradient which the entire phenomenon is capable of producing. This gradient being adequate, positive ion ionization ensues and spark-over is rapidly completed. The formative time in domain 2 must, therefore, allow for positive ion migration and the spark breakdown must commence at the cathode. For the conditions of domain 3 the exponential curve of positive ion density aforementioned, being steeper, produces a space potential gradient adequate for positive ion ionization at some point in mid gap *at once*, i. e., before the positive ions have migrated any appreciable distance. The flood of electrons released by this positive ion ionization arrives at the anode, starting the voltage drop, one step behind the initial avalanche, as it were. Thus, in domain 3 the formative time is that required for an electron to travel across the gap, and the spark-over commences in mid gap.

Direct visual observations of the incipient spark give striking verification that the spark may occur by 1 of these 2 distinct mechanisms. This was first observed, in a qualitative way, by Torok.[14] Torok found that for most of his tests the visual spark-over

began at the cathode. In a few tests on small gaps at high overvoltage Torok noted a distinctly different phenomenon; an intense white light at the middle of the gap was then the initial stage of the spark. Dunnington[6] used a Kerr cell, or electro-optical shutter, for visual observations of successive stages of spark-over at precisely timed intervals. His observations at various pressures and gap lengths and at small overvoltages, established these 2 types of spark-over, i. e., 1 in which the visible spark is seen to initiate exclusively at the cathode, and a second, in which the spark is seen to commence somewhere in mid gap.

It is particularly gratifying that, in the light of the above explanations, the various available reports in this rapidly developing subject of spark lags are seen to be consistent with each other and with a rational spark-over mechanism, whereas, hitherto, they had appeared isolated and even contradictory. This correlation, as well as a more detailed discussion of the spark mechanism, is available elsewhere.[18]

Engineering Applications

The points of engineering interest to which the foregoing information on the time lag of the sphere gap is applicable are too numerous to be more than mentioned. The magnitude of the initiatory spark lags of domain one undergoes the widest variation under varying conditions and may, therefore, often be great enough to be of serious consequence. By way of orientation it may be pointed out that "ordinary" open air contains per cubic centimeter on the order of 1,000 pairs of ions, and has formed in it each second about 10 new electrons by action of cosmic rays, atmospherics, radioactive minerals, etc. These 10 new electrons per second per cubic centimeter near the surface of the cathode sphere at the axis of the gap may be considered as a very rough "average" external ionization. (Small spheres, therefore, receive less ionization, having less cathode area.) Of course, this rate of ionization varies widely with locality and with atmospheric and stellar conditions. It will be increased by the proximity of high voltage equipment or of radioactive minerals and decreased by metal enclosures. Thus, within 7 centimeters of lead this ionization rate is reduced to the order of once every 20 minutes.[9] The external ionization at a small test gap can be increased by the use of radioactive salts, X rays, or ultra-violet illumination. The photoelectric emissivity of the cathode may vary greatly with slight changes in surface condition, such as adhesion of vaporous impurities, oxidation caused by successive power spark-overs, etc.

The Sphere Gap Voltmeter

Obviously, one of the important practical effects of spark lag is its modification of the apparent sparking voltage as measured by the sphere gap voltmeter. This will be different for different voltage wave shapes. For static spark-over, i. e., either d-c or 60 cycle a-c voltage gradients increased slowly and continuously until spark-over, the formative lags are too brief to be of any consequence. The random initiatory lags, however, may well be long enough so that the increase in voltage gradient has proceeded a perceptible amount past the minimum sparking gradient while awaiting the arrival of suitable initiatory electrons. In that case, when spark-over does occur, it occurs at a small overvoltage which is then mistakenly supposed to be the minimum sparking voltage of the gap. Of course, this source of error may be empirically eliminated by finding a rate of voltage increase, or of gap shortening, which is slow enough so that smooth calibration curves are obtained. Thus the present Standards[2] of the Institute specify a rate of voltage increase not to exceed 50 per cent of sparking voltage per 30 seconds.

There have been difficulties in applying this empirical precaution, however, as evidenced by the fact that erratic results have not always been avoided. One difficulty is, perhaps, merely that human patience was being pitted against an unsuspectedly erratic delay and, therefore, quite naturally arrived at a degree of deliberateness sufficient to outwait most of the delays encountered but not all of them. A more formidable difficulty is that the external sources of ionization may, as is evident from perusal of the preceding paragraph, on certain occasions be much weaker than at the time and place when the erstwhile satisfactory test procedure was being empirically established. As long as the source of initiatory electrons is left, as is the case at present, entirely unspecified and may be chiefly haphazard atmospherics, etc., the random lag may change 10,000 fold in the same laboratory from one day to the next.

The resultant erratic behavior of the gap can, perhaps, be best ameliorated by specifying a standard and fairly strong source of ultra-violet light and a cathode surface of sufficiently high emission characteristics. Concretely, consider the simply stated case of d-c spark-over. (The specification for a-c spark-over is just as definite but is less straightforward to state since it requires the coining of a definition for "a-c elapsed time lag.") With the present specified voltage increase rate of 1.66 per cent per second, errors can be limited, for instance, to less than 0.83 per cent *in 95 per cent of the spark-overs* by choosing a value of external ionization probability such that, at overvoltages as low as 0.415 per cent, only 5 per cent of the initiatory spark lags are greater than 0.25 second. That is, $n_t = 100\epsilon^{-\mu t}$ becomes $5 = 100\epsilon^{-\mu 0.25}$, from which is ob-

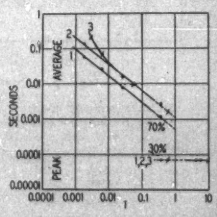


Fig. 7. Time lag of spark-over versus illumination

Master curve of average or peak values

Curve	Approach	Voltage
1	96%	105%
2	96%	103%
3	0%	105%

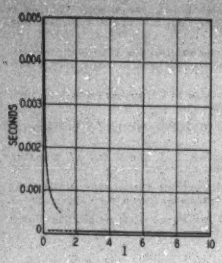


Fig. 8. Static spark lag versus illumination

tained $p = 12$ or $T = 1/p = {}^1/_{12}$ second. Hence, to insure this degree of accuracy it is necessary to specify an external ionizing source of sufficient strength to produce an average time lag of static spark-over at 0.415 per cent overvoltage of ${}^1/_{12}$ second. Otherwise stated, it is necessary to specify a source which produces 12 times a second, on the average, initiatory electrons *at those portions of the gap* where they can initiate spark-over at overvoltages as low as 0.415 per cent. Before such a standard can be practically specified, measurements of time lag of static spark-over must be taken on high voltage gaps whose electrode surfaces are modified by the high power sparks and arcs they sustain and by the subsequent cleansing operations. This is an important division of the subject that appears to be entirely untouched as yet.

For high frequency steady state static spark-over the initiatory lags enter much as for low frequency. In addition, the space charge migration times, which are essentially formative lags in the second domain, systematically modify the voltage magnitude required for spark-over. This has been thoroughly established by Reukema.[11]

The formative lags of the second domain are of practical importance, also, wherever very small gaps are used; for it is no small matter that very small sphere gaps break down by a different and slower process than larger ones. Small gaps are widely utilized for duties wherein a rapid breakdown is desirable, *e. g.*, ignition spark plugs, telephone plant protective gaps, etc. The fact that such gaps have an irreducible spark lag of the order 10^{-4} seconds at their minimum sparking potential and a lag less than ${}^1/_{1,000}$ as great at some definitely predictable overvoltage would appear to be of practical interest. A typical 9 cylinder aircraft engine going 2,000 rpm, travels 1.2 mechanical degrees or 5.4 electrical degrees in 10^{-4} seconds, and the voltage wave of a magneto rises for only a few degrees. A surge on an open wire line travels over 18 miles in 10^{-4} seconds. This time interval is not negligible. It is not intended to imply that empirical design in these various matters has been inadequate; merely, that more complete theoretical comprehension is likely to lead to improvement.

For impulse voltages or for any transient voltage wave shape of very brief duration, the brief formative lags of domain 3 are of importance. For such voltages it is now well appreciated that the time lags involved and the exact voltage wave shape enter equally with the voltage magnitudes in determining whether spark-over will ensue. To produce spark-over, either some overvoltage must exist for a time equal to the initiatory lag plus the formative lag of domain 2, or else an overvoltage sufficiently high to give the spark-over of domain 3 must exist for a time equal to the initiatory lag plus the shorter formative lag of domain 3. If the voltage rises with sufficient rapidity it can become sufficiently high before the charged particles originally in the gap are swept out. In this case these can act as the initiatory ions, thus reducing the initiatory lag practically to the vanishing point. As mentioned, recent test specifications for impulse testing now make it possible to obtain consistent results at this wave shape, i. e., simulating lightning. Considering the confusion prevailing on this point until now, as pointed out by the Institute's sub-committee on lightning,[1] engineers may be warned and realize the desirability of studying the time factors involved in various other spark-over problems of interest.

The Point Gap

Throughout this paper the spark lag of the sphere gap at spacings fairly small compared to the sphere diameter, i. e., of a gap with an initially uniform field, has been under consideration. In practice, many spark-overs, both desired and undesired, occur at what is essentially a point to point gap with initially nonuniform field. A few brief remarks concerning spark lags of such gaps may, therefore, not be amiss. It seems clear that the time lag of spark-over in a long gap must be built up of the items already mentioned. Just as in the short gap, there are initiatory lags. Where there is preliminary corona the initiatory lags will be greatly decreased, even to the vanishing point. Moisture in the gap captures free electrons and increases the initiatory lag. Moisture on the electrode, as recently shown by Hillebrand and Miller,[7] gives in effect a water electrode, and this tends to decrease the initiatory lag.

There are formative lags spent in awaiting the mass motion of positive ions toward the cathode or, depending upon the voltage gradient, formative lags spent in awaiting the passage of an electron avalanche. The possible time and space combinations of these 2 formative mechanisms allow an almost unlimited number of combinations in long gaps of various geometries. It is clear, therefore, that the time lags of point gaps will not lend themselves to any comprehensive classification without a great amount of additional experimental work.

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Registration of Engineers

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Following is the full text of an address presented at the A.I.E.E. summer convention, Ithaca, N. Y., June 24–28, 1935, and prepared at the request of the A.I.E.E. committee on education, in order that the membership might be more fully informed concerning engineers' registration and the related problems of the profession, and may determine to what extent the arguments for registration apply to electrical engineers, whether engaged in practice for themselves or employed by others, and whether engaged on private or public work.

ENGINEERS are pioneers, pathfinders, trail blazers in almost everything they do, with one exception. They have left it to the other professions to be the pioneers and trail blazers in the field of securing professional recognition, in the field of organizational and legislative activities for the advancement of the status of a profession. The medical profession started over 80 years ago, the legal profession over 50 years ago, but the engineering profession is just commencing to direct its planned activity to the problems of professional standing and recognition.

We are fortunate that others have blazed the trail and that other professions have solved for us many of the problems involved. If there is any wisdom in the collective mind of the engineers of the country, we will lose no time in profiting by the successful examples of the professions that have solved these problems before us; and the first essential step in such program is the enactment of laws establishing qualification standards for the practice of the profession.

Progress of Registration

Engineers' registration laws are now in force in 32 states. In these 32 states are located over 85 per cent of the engineers of this country. In addition to these states, the 3 possessions of the United States—Hawaii, Puerto Rico, and the Philippines—also have engineers' registration laws. The progress of enactment of engineers' registration laws dates from Wyoming in 1907 and New York in 1920 to Ohio in 1933 and New Mexico, Washington, Utah, Maine, and Oklahoma in 1935. More states are being added to the list progressively. Such legislation is now pending in 11 additional states, leaving only 5 states (of small engineering population) in which the profession has not yet decided to advance the registration movement. With the active impetus given to the movement by the National Society of Professional Engineers, more rapid progress now may be expected in extending registration to cover the remaining states.

Over 45,000 engineers have already been registered in 31 states: over 12,000 in New York State, over 6,000 in California, and over 4,000 in Pennsylvania. Engineers' registration is now an established fact, and it is here to stay.

The Philosophy of Registration

The underlying philosophy of registration laws has been aptly expressed by Arthur V. Sheridan, past president of the New York State Society of Professional Engineers:

"Regulation of human activities is a sine qua non of civilization. Without it chaos would be the concomitant of communal existence. There are, of

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course, limitations, for even regulation does not justify servitude. Throughout the ages philosophers have debated the ability of mankind to direct itself adequately. Regardless, however, of academic disputations the fact remains that society cannot avoid the responsibilities arising from the gregarious instincts of human beings.

"Modern civilization, the creation of the engineer, has found it necessary to regulate the practices of persons whose activities deal with the protection of human life, human health, human rights, and human property.

"Three professions, law, medicine, and engineering are primarily entrusted with the responsibility incidental to such activities. The elimination and exclusion, as matters of public welfare, of the dishonest and unqualified from the practice of these professions are undebatable tenets. It is to the accomplishment of such aims that truly professional associations are dedicated."

The Public Aspect of Registration

Engineers' registration is required for the protection of the public. The work of no other profession more truly concerns the safety of life, health, and property. There is a public demand for this legislation, and we owe it to the public and to our profession to take the initiative. We do not want the legislation to be thrust upon us. Being fully conversant with the problems involved, we want to have a hand in writing the law, in securing its enactment, and in directing its administration, as a recognition of our responsibility, as a profession, to the public.

The public needs to be protected against the quack, the incompetent, the unscrupulous, and the impostor, who do not belong in our profession but nevertheless practice in its name. The investor needs to be protected against "engineering" reports by the unqualified and the unscrupulous. The client needs to be protected against paying fees to quacks and incompetents who hold themselves out as "engineers." The courts need to be protected against the testimony of "experts" who pose as members of our profession. The public needs to be protected against improper planning, inefficient design, wasteful execution, and excessive cost, also against dishonorable dealings. Mere structural adequacy is not the only desideratum.

Protection of the public is the legislative justification and establishes constitutionality. This benefit has been established. Protection of the profession, its standing and its standards, is a concomitant benefit. The 2 benefits are inseparable. The elimination of the unqualified and the unworthy benefits both the public and the profession.

Professional Aspects of Registration

Engineers' registration laws derive their primary justification from considerations of public safety and the protection of public interest; but they are also necessary for the protection of the good name of the profession and its standing in public confidence.

A profession is judged by the qualifications of all who use its name, by the failures of the incompetents and by the conduct of the unworthy, unless a clear dividing line is established in public recognition between the lawful practitioners of the profession and those who are not admitted to practice.

A profession should be empowered to disown those who hold themselves out as belonging to it without proper qualifications or character and to bar the unfit and the unprincipled who seek to practice in its name. The public expects a trusted profession to maintain high standards of qualification and to clear its ranks of those who do not meet those standards and whose pretensions and activities would degrade its good name.

Without registration laws, there is no way: (1) to stop the practice of engineering by the nonengineer; (2) to stop the misappropriation and abuse of the designation "engineer"; (3) to oust from the profession those who prove incompetent and unworthy; and (4) to preserve to the qualified engineer his rights of practice against restriction, encroachment, and unqualified competition.

Registration places the force and sanction of the law behind the desire of the profession to maintain a clearly recognizable line of demarcation between the engineer and the nonengineer. It places the agencies of the law behind the efforts and aspirations of the profession to maintain high standards of qualifications and ethical practice.

Registration and Public Recognition

Registration places engineering on a par with law and medicine as legally restricted and recognized learned professions. With the aid of the registration laws that have come into being in our statute books, the engineering profession has made more real progress in the past 10 years in the solution of many of its problems and in securing public recognition than in all the decades preceding.

The other learned professions, such as law and medicine, have long had laws in all the states regulating professional admission and practice. Public respect and confidence toward those professions have grown in proportion to the virility with which they have used their registration laws to maintain high standards and to eliminate the untrained and the unethical. Engineers' registration will accomplish the same objectives for our profession. It is an essential step in our program of securing for the engineering profession its rightful place in public confidence and respect.

We cannot expect the public to distinguish between the engineer and the artisan or mechanic, between the professional man and the impostor, and between the professionally trained and the half-trained or immature, unless we adopt the accepted and established procedure for legally qualifying and identifying the members of our profession. The public will not have proper regard for our profession unless we, ourselves, hold it in sufficient regard to exclude those whose practice or pretensions would degrade it. We cannot do these things without registration.

Protection of the Designation

A problem closely related to registration is that of protecting our professional designation.

The individual engineer has invested many years of his life in professional education and arduous professional training in order to qualify as an "engineer." The profession is investing decades of united effort to win public recognition and esteem for those who bear the title "engineer." All of this investment is largely nullified if the use of the term "engineer" is left unprotected. The dignity and respect that rightly belong to the designation of a learned profession cannot be maintained when that designation is abused by misappropriation.

The public judges a profession by the examples it meets. When the public sees men who are unlettered and untrained holding themselves out as "engineers," respect for the engineering profession is weakened or destroyed. When the public sees the word "engineer" on the shop window of a plumber, an electrician, a radio dealer, or an automobile mechanic, a wrong picture of the engineering profession is implanted.

For years, the engineering profession talked about this problem—the abuse and misuse of the term "engineer"—but nothing was done about it. Finally with the aid of registration laws, means for successfully protecting our designation became available.

At first, public officials were slow to co-operate. They declared that we could not "copyright the dictionary." We pointed to the precedents of the other legally established professions which had successfully "copyrighted large chunks of the dictionary." Any unlicensed man hanging out his shingle as a "lawyer," a "physician," a "dentist," or an "architect" will be promptly arrested and subjected to the penalties of the law. These respective professions will see to it, and the agencies of the law will back them. (Recently, in New York, the legal profession had an insurance agent arrested because he allowed a customer to call him "counselor" without correcting her.)

Clauses protecting the designation "engineer" have now been written into most of the state registration laws, and have been made enforceable. In New York State it is now unlawful for any unlicensed person "to use the title engineer or any other title, sign, card, or device in such manner as to tend to convey the impression that such a person is a professional engineer." The Tennessee law forbids unregistered persons to "use the appellation architect or engineer, or any appellation which is a compounding, modifying, or qualifying by an adjective of the words architect or engineer, or both."

These and similar provisions of the registration laws in the various states have been tried and tested for scope of effectiveness. In the past few years, hundreds of violations have been successfully corrected, largely through voluntary co-operation.

Enforcement of Registration Laws

When the engineers' registration movement was young, many disregarded it or were ignorant of it because enforcement and publicity were lacking. Teeth have now been put into these registration laws, and enforcement procedure is being progressively strengthened. The machinery of enforcement has been put into effect, and men have been arrested, tried, and fined for practicing engineering without a license.

In one court, a man was convicted of manslaughter for the collapse of a structure which he had designed without a license to practice engineering. In another case, an unlicensed man was sentenced to the workhouse for using the designation "civil engineer" on his letterhead.

In 2 years in California, 23 violations of the engineers' registration law were prosecuted in the local courts, resulting in 21 convictions for unlicensed practice. The maximum penalty assessed was a fine of $100 or 50 days in the county jail.

In one year, 105 unlawful listings as "engineers" were eliminated from the New York City telephone directory, and 217 other violations were handled by the New York State enforcement authorities and corrected without resort to the courts.

The civil courts have established a significant precedent in repeatedly dismissing actions for the collection of engineering fees when such actions were brought by men who were not registered as engineers. The courts have ruled that a contract for engineering services is invalid if the party undertaking to furnish such services is not registered.

The courts have repeatedly disqualified men offering engineering testimony when such "experts" were found to be unregistered.

The supreme court of Tennessee ordered a concern to abandon its trade name "The Standard Engineering Company" because the members of the firm were not registered engineers.

The courts have ruled that even college graduates with professional degrees may not use such designations as "civil engineer" or "electrical engineer" until they are admitted to professional registration.

In New York State, 7 professional engineers nominated by the State Society of Professional Engineers have been sworn in as deputy investigators and added to the official enforcement staff to assist in investigating and correcting reported violations in the various parts of the state.

In Oregon, following approval by the attorney-general, funds from registration fees are used for a statewide campaign of newspaper advertisements informing and warning investors, employers, mine operators, engineers, industries, and utilities, concerning the requirements and purposes of the engineers' registration law.

Public officials are progressively taking a keener interest in the enforcement of engineers' registration laws. Construction plans signed by unlicensed men are rejected by federal and local officials. Men not registered as engineers are debarred from holding office as county engineers or city engineers. Civil service commissions are co-operating by requiring a license as a prerequisite for appointment to engineering positions. In every way registration laws are becoming more real and more effective in their operation.

Educational Qualifications

In recent years, another step of progress has been recorded in engineers' registration laws. We have brought the legislators and the public to recognize the fact that engineering is not an empirical calling, but a learned scientific profession. In recognition of that fact we have written into the laws educational requirements for the licensing of engineers. The laws now generally require qualifications of moral character, evidence of completion of academic and professional education, and in addition a number of years of practical experience in engineering work of a character satisfactory to the state board of examiners. Both college graduates and nongraduates have to pass written examinations. The gates are not yet barred to the man who has not had the advantages of a college education, and he is given an opportunity to show by examination that he has the equivalent technical training. Where a minimum of 4 years of practical experience is required of graduates of approved colleges of engineering, a minimum of 8 years (soon to be changed to 12 years) is required of the nongraduate before he is admitted to the licensing examinations, and in his case the examinations are necessarily more comprehensive.

Through high standards for registration, we can impress upon the public the fact that engineering is a learned profession.

Registration and Professional Unity

Another important principle that has been recorded through the agency of our registration laws is that of the solidarity of our profession. We have recorded the principle that engineering is *one* profession, although specialties may be many. We do not license the specialist; we license the engineer. We do not place any limitation upon the branch or specialty in which he may engage; instead we expect the board of examiners to make sure, before granting a license, that the man can be trusted not to engage in any specialized work in which he may not be qualified.

The same principle has long been established in the medical profession. That profession has firmly and consistently resisted every suggestion of legal division or superqualifications into specialties. Self-limitation of field of practice has been kept a matter of professional honor, and legal limitation has been rejected.

Others may wish to emphasize the diversification of engineering into specialties. It is for us to proclaim the fundamental unity of our profession. Whether a man writes "E.E.," "C.E.," "M.E.," "E.M." or "Chem.E." after his name, he has the same common basic educational training, the same governing professional qualifications, the same method of analytical approach to technical problems, the same ideals of professional practice, and the same interest in the profession's problems of public recognition, protective legislation, and relations with other professions.

Law and medicine have as many specialties as engineering, but lawyers and doctors would never approve of the legal subdivision of their professions.

Some of the states license men in specialties or branches of engineering. It is the prevailing opinion that such procedure is a mistake. Registration can and should be used to proclaim the essential oneness of our profession.

Protection Against Restriction of Practice

Another effective application of our licensing laws has been in the protection of engineers against discrimination and restriction of fields of practice. Our profession has taken the position that we do not seek to interfere with the rights of practice of any other profession, but at the same time we have firmly recorded the principle that we will not allow any other profession to restrict the rights of practice of the engineer. We have had our battles on that issue and the victory has been won.

In different states, legislation sponsored by architects would have eliminated or subordinated the engineer in the structural field; physicians endeavored to monopolize the sanitary field; accountants sought to exclude others from the making of financial reports; lawyers sponsored legislation which would have deprived engineers of the right to prepare contract documents and to engage in arbitration proceedings; and real estate brokers endeavored to monopolize the right to make appraisals. Such legislation has been consistently and successfully opposed by our profession. Suggestions to meet the situations by subdividing into specialties have also been consistently resisted.

Without our registration laws on the statute books, recording the rightful scope of practice of the professional engineer, our cause would have been lost. We would have been subordinated to other professions, our established field of practice diminished, and our profession dismembered.

The Model Registration Law

With the participation of several leading national and local engineering societies, a "model registration law" has been developed to serve as a guide for the drafting of new laws and the improvement of existing laws.

The definition of professional engineering, first written into the New York State law and then incorporated in the "model law," is as follows:

> "The practice of professional engineering within the meaning and intent of this Act includes any professional service, such as consultation, investigation, evaluation, planning, design, or responsible supervision of construction or operation, in connection with any public or private utilities, structures, buildings, machines, equipment, processes, works, or projects, wherein the public welfare, or the safeguarding of life, health or property is concerned or involved, when such professional service requires the application of engineering principles and data."

The minimum qualifications for registration as a professional engineer, also following the standard established in the New York State law, are:

> "a. Graduation from an approved course in engineering of 4 years or more in a school or college approved by the board as of satisfactory standing; and a specific record of an additional 4 years or more of active practice in engineering work of a character satis-

factory to the board, and indicating that the applicant is competent to be placed in responsible charge of such work; or

"*b.* Successfully passing a written, or written and oral, examination designed to show knowledge and skill approximating that attained through graduation from an approved 4 year engineering course; and a specific record of 8 years or more of active practice in engineering work of a character satisfactory to the board and indicating that the applicant is competent to be placed in responsible charge of such work."

Registration laws introduced for enactment since 1932 have generally followed the "model law" closely as a standard. It has been a most helpful contribution toward uniformity.

The "model law" has had, in its preparation, the benefit of all past experience and the best constructive thought of the profession. It is offered as the best draft of a registration law thus far developed by the profession, with all legal requirements carefully observed. The "grandfather clause" is retained, protecting any established individual rights of practice, in order to remove the only objection that has ever been brought against such legislation on constitutional grounds; and a "saving clause" is included to preserve the validity of the rest of the law in the remote eventuality that any section in it might be declared invalid. The constitutionality of such legislation is now well established.

Registration Fees

The registration fee is not an occupational tax. It is not intended as a source of revenue to the state. The "model law" provides that all fees collected should be used for the administration and enforcement of the law. Fees vary in the different states from $5 to $25 for the original registration certificate and from $1 to $5 for annual renewal. Engineers should not begrudge this comparatively slight contribution to protect their professional investment.

The slight expense imposed on engineers as a registration fee is trifling in comparison with the benefits derived. Anything that raises the standards of qualification and recognition of the profession benefits all engineers in it. The man who has invested thousands of dollars in education and many years of his life in training for the profession, should not hesitate to spend the small amount of the registration fee in order to protect and enhance the value of this investment. Many an aspirant to practice law or medicine would gladly pay many times as much to secure his admission to practice; so would many who have been rejected for engineering registration.

It is for the profession to estimate how small the registration fee can be made with assurance of adequacy to cover the expenses of administration of the law. In Colorado, where a surplus accumulated, the profession secured the passage of a bill to expend the fund for the establishment of a large engineering reference library. In New York, the state has retained a surplus of nearly $300,000 out of the fees collected, principally in the early years of large volume of applications; such profit was not intended. The aim is to adjust fees to the cost of administration, and to use any surplus for improving the enforcement organization. In time, legislators will be educated to appreciate that at least half of the total cost of registration and enforcement should be contributed by the state, since the law is primarily for the protection of the public.

Reciprocal Registration

Although many of the state laws contain provisions making it permissive to enter into agreements for reciprocal registration such procedure as between any 2 states is unworkable unless the 2 states have identical qualification requirements and standards. As a rule, no state is willing to delegate its qualifying authority to another state. Consequently, formal application for registration has to be made in each state in which the candidate desires to practice. Possession of previous registration in another state is given due weight in considering the application, and may be grounds for waiving examinations and examination fee.

Since engineering practice is frequently interstate in character and many engineers have a nationwide practice, it is important to facilitate interstate registration. For this purpose, the National Council of State Boards of Engineering Examiners (comprising 26 state registration boards) had established a National Bureau of Engineering Registration to serve as a central examining and certifying agency. The national bureau maintains the qualification requirements specified in the "model law," which are equal to or higher than the requirements of any state, and its certificate is accepted by the individual state boards as prima facie evidence of qualification without further examination. The national bureau application fee is $10, and many of the states (as suggested by the "model law") reduce their registration fee from $25 to $10 when the national bureau certificate is presented.

The procedure of utilizing a National Bureau of Registration follows successful precedents established by other professions, including medicine and architecture. It is a necessary expedient since it is impossible under our constitution to make registration a federal activity.

In addition, most of the state registration laws permit unlicensed practice for 60 days in any calendar year by a nonresident who is registered in his own state, and for a further period if application is filed for registration and until such application is granted or denied.

It is one of the objectives of the National Society of Professional Engineers to extend and improve registration legislation until every state in the Union has a model uniform registration law, with complete reciprocity for interstate practice.

Co-operation of Corporations

The engineer who is registered is more valuable to his employer, and many organizations require that their employees be registered. It is an asset to a firm to be able to announce that all of its employees are registered engineers

Large railroads, exempt under the registration laws, have directed all of their assistant engineers to secure registration, in anticipation of legal questions

of responsibility that might arise. Other corporations have voluntarily instructed their men to secure registration, withdrawing the title of engineer from those that failed to do so. Some corporations, anxious to have all of their engineer employees registered, are paying the registration fees for their men. Some firms require the engineers in their organizations to be registered in order to be qualified to give expert testimony. Employees making the design or inspection of structures should be registered, otherwise criminal liability is incurred in a failure.

With better understanding, the general attitude of corporations toward engineers' registration has been progressively changed from resistance to cooperation.

Registration and Politics

It is true that registration means the entrance of the profession into legislative activities, but it is certainly high time that the profession make its influence felt in legislative councils.

Once a proper registration law is enacted, no political influence need be feared to pervert the administration of the law. The members of the registration boards are engineers of high standing, nominated by the profession in each state; and, since their service is one of devotion to the profession, self-sacrificing and nonlucrative, there is no inducement to make the appointments a political consideration. Examinations, registration, and revocations are handled by the board of examiners, and cases of unlawful practice are decided in the courts.

The administration of the registration law is kept on as high a plane as the standards of the profession.

Registration and Ethics

Registration is the only means by which our profession can enforce its codes of ethics and fair practice. Without registration laws, codes of professional conduct and fair practice are merely documents that may or may not be respected by the individual. But with the backing and sanction of the law we have it in our power in the future to make these standards of ethics enforceable and to stop the practice of those who, by their malpractice, are injuring beyond repair the good name of our profession. The registration laws generally provide for revocation of license for evidence of incompetence or misconduct in professional practice.

In Ohio, the engineers' code of ethics is printed on the application form and is required to be signed by the candidate before his application for registration is considered. By legal ruling, such advance subscription to the code will facilitate disciplinary action for any subsequent violation. In addition, the county organizations of professional engineers have been asked to formulate and adopt local codes of practice and fees for adoption and disciplinary enforcement by the state boards of examiners.

The legal profession has recorded in the statutes strict penalties for various unprofessional acts, such as threatening lawsuits in collection letters or soliciting professional engagements. The penalty for dishonorable or unethical conduct is fine, imprisonment or disbarment.

Other professions, in their registration laws, have empowered their state boards to define unprofessional conduct and the courts have supported such authority.

In Canada, engineers' registration is strongly established and is administered by the Provincial Associations of Professional Engineers; registration and membership are synonymous. In Quebec and other Canadian provinces, the code of ethics and the code of fees are written into the law by reference, and any violation of these codes is cause for revocation of license to practice.

In the United States, the machinery of disciplinary action under the engineers' registration laws has already been put into effect, and licenses have been revoked on proof of incompetence, misrepresentation, and unprofessional conduct.

Extension of Registration

No state can afford to be without an engineers' registration law. No state can afford to become the dumping ground for the incompetent and the unscrupulous who are barred from the profession in other states. The individual engineer, if his own state has no registration law, is handicapped in securing reciprocal registration in other states; registered or unregistered engineers from all other states can come into his territory to compete with him, but he cannot practice in their states. Above all, the profession in any state cannot afford to be left out of the progressive advancement and accomplishments of the profession in other states. Registration legislation is the key to such accomplishment for the advancement of the profession.

The enactment of a registration law in any state is generally marked by a new awakening of professional consciousness and unity among the engineers of that state.

Some years ago, the American Society of Mechanical Engineers appointed a "committee on the economic status of the engineer." That committee, in its final report, concluded that the prime essential for advancing the status of our profession is the establishment of a clearly recognizable line of demarcation to distinguish the engineer from the nonengineer. In my opinion, registration is the only means of establishing this desired demarcation.

Registration has been used by other professions as a powerful instrumentality for raising educational qualifications, ethical standards, professional status, and public recognition. It will do the same for the engineering profession. It is the only enforceable means of protecting the practice and the designation of the profession against misappropriation and misuse by the unqualified and the unprofessional. Registration is the most effective instrumentality for impressing upon lawmakers, officials, and the public that:

1. Engineering *is* a profession.
2. Engineering is a *learned* profession.
3. Engineering is *one* profession.

Discussions

Of A.I.E.E. Papers—as Recommended for Publication by Technical Committees

ON this and the following 8 pages appear 2 additional authors' closures of papers presented at the 1935 A.I.E.E. winter convention, New York, N. Y., January 22–25, and the first discussions submitted of papers presented at the general technical and the insulation and protection sessions of the South West District meeting, Oklahoma City, Okla., April 24–26, 1935. Authors' closures, where they have been submitted, will be found at the end of the discussion on their respective papers.

Members anywhere are encouraged to submit written discussion of any paper published in ELECTRICAL ENGINEERING, which discussion will be reviewed by the proper technical committee and considered for possible publication in a subsequent issue. Discussions of papers scheduled for presentation at an A.I.E.E. meeting or convention will be closed 2 weeks after presentation. Discussions should be (1) concise; (2) restricted to the subject of the paper or papers under consideration; and (3) typewritten and submitted in triplicate to C. S. Rich, secretary, technical program committee, A.I.E.E. headquarters, 33 West 39th Street, New York, N. Y.

Resistance and Reactance of 3 Conductor Cables

Authors' closing discussion of a paper published in the December 1934 issue, pages 1581–9, and presented for oral discussion at the cables session of the winter convention New York, N. Y., January 24, 1935. Other discussion of this paper was published in the March 1935 issue, pages 324–6, and in the April 1935 issue, pages 436–7.

E. H. Salter, G. B. Shanklin, and R. J. Wiseman: In reference to the comments by R. W. Atkinson in regard to the difference found when the phase rotation of current was reversed, analysis of these data did not give a logical reason why a difference should be found. We could not explain it on the basis of accuracy of test methods because the difference is in the same order of magnitude as was found for other factors which we knew did influence a-c losses. It was decided to include the data in the paper with the hope that someone could offer a reason for that which we found.

Atkinson's comments on the disruptive effect of heavy currents are quite interesting. We are glad to see that his tests confirm that which is reported in the paper, namely, that for the expected values of short circuit currents, it is not necessary to provide for special binders to hold the conductors in place. As we must use a binder of some form in manufacture and a lead sheath, we do provide a reinforcing for those instances where extra heavy currents are likely to occur.

It may be that the effects of short-circuit currents on belted cables weaken them electrically and, therefore, eventually result in failure. However, to get a short circuit a failure must first take place, and in view of the speed with which circuits are opened, it seems a bit difficult to picture a permanent effect in the cable which eventually causes further failures. It would seem as though effects of oil migration are more readily responsible for the poor showing of belted cables as compared to shielded cables.

Louis Meyerhoff's comments are greatly appreciated. It would have been helpful to the committee handling the preparation of the paper if his ideas of proximity effect had been given them for consideration as possible explanations of the experimental data. As far as it was possible theoretical reasons for the total increase in conductor resistance were given and theoretical calculations checked remarkably well, except in those cases where the strands were all laid in the same direction. By eliminating the calculated proximity effect, the theoretical increase in resistance very closely equalled the actual; in other words, proximity effect was zero. Meyerhoff's reason is logical, but it must be remembered that the oxidized surface of the strands also aids normal stranding in reduction of proximity effect when the strands are highly crushed.

Referring to W. H. Cole's statement that the extra losses in his 3 conductor cable represented a deficiency of the order of from 5 to 8 per cent, or approximately $25,000, this is presumably based on the maximum carrying capacity of the cable line. Whether it is an actual deficiency or not, of course, depends upon whether the present or future peak loads required of this line become equal to the maximum allowable carrying capacity. This in turn depends upon how much reserve capacity this cable line was laid out for in the beginning.

The fact that magnetic binder cable has about 20 per cent higher reactance than nonmagnetic cable is of no particular importance so far as voltage regulation of the system is concerned and becomes only of importance when an attempt is made to parallel magnetic and nonmagnetic cables. Everything else being equal, a nonmagnetic cable should be preferred, but there would still be a demand for magnetic binder cable for purposes of paralleling in those systems where the practice of using magnetic binder cable is already being followed.

The last part of Cole's discussion seems to be based on the misconception that minimum proximity effect is realized with solid bar conductors. A comparison of the data in our paper will show that solid bar conductors cause maximum and not minimum proximity effect.

Compact rolling of the strands results in minimum proximity effect, although in physical appearance this type of stranding approaches nearest to solid bar. The reason for these 2 cases representing extremes of proximity effect is fully explained in the paper. Rolling of the strands gives much larger contact area between strands and a more uniform distribution of cross currents. These currents in turn are reduced in total value by the contact resistance as represented by the natural oxide film on the surface of each strand.

Constant-Current D-C Transmission

Authors' closing discussion of a paper published in the January 1935 issue, pages 102–8, and presented for oral discussion at the general overhead line problems session of the winter convention, New York, N. Y., January 23, 1935. Other discussion of this paper was published in the March 1935 issue, pages 327–9, and in the April 1935 issue, pages 447–9.

C. H. Willis, B. D. Bedford, and F. R. Elder: In answer to the questions regarding the operation of the monocyclic network, the following simple vector analysis of its operations is submitted.

The balanced monocyclic network, composed of pure inductive and capacitive elements, theoretically produces an absolute constant voltage-constant current transformation. In practice the losses are small, and results closely approaching the theoretical are obtained. When an inductance and capacitance of equal impedance are connected in series across a constant voltage source, a constant current must flow out the common connection of the 2 impedances.

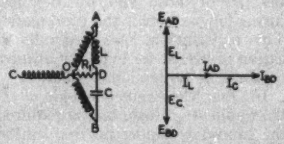


Fig. 1. Monocyclic vector diagram, special resistive load

For simplicity consider 2 special loads of

such a value that the capacitor and reactor currents add in phase to produce the load current. In figure 1 of this discussion the constant voltage AB is impressed on X_L and X_C in series. With the resistance load R_1 connected to the neutral of the a-c system, the voltages and currents are represented by the vector diagram.

The inductive current lags the voltage on X_L by 90 degrees, while the capacitive current leads the capacitor voltage by 90 degrees. The current in the resistance R_1 is the sum of these 2 currents.

In figure 2 the load consists of the series resistance and inductance R_1 and L_1.

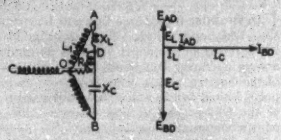


Fig. 2. Monocyclic vector diagram, special resistive and inductive load

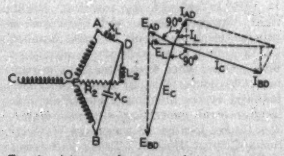


Fig. 3. Monocyclic vector diagram, resistive and inductive load

The voltage on X_L is decreased and its current is decreased in proportion, but a corresponding increase of voltage on X_C increases its current, producing a constant current output.

In figure 3 the series loads R_2 and L_2 produce voltages on X_L and X_C, shown by the vectors E_{AD} and E_{BD}. The current in X_L lags the voltage E_{AD} by 90 degrees, while the current in X_C leads the voltage E_{BD} by 90 degrees. Dividing the voltage and currents into components in phase and 90 degrees out of phase with the voltage E_{AB}, it is seen that the resulting load current is proportional only to the voltage E_{AB}, while the other components of current are equal and opposite and contribute nothing to the resulting current. With other loads of different magnitude and power factor, the point D in the potential diagram varies in or out, up or down, depending on the impedance of the load, but the current in the load remains constant both in magnitude and phase position.

With the apparatus shown in figure 5 of this discussion it has been demonstrated:

1. That either rectifiers or inverters can be put on the line in any order.
2. That load may be changed from ful load to no load and back.
3. That the rectifier and inverter currents remain practically constant with a short circuit on the d-c line and that the current through the fault is very small, normal operation being resumed upon removal of the fault.
4. That no harmful voltage occurs with an open circuit of the d-c line, and on closing the circuit operation resumes.
5. That any tube in either rectifier or inverter can be short circuited or open circuited, the direct current remaining substantially constant, some change in load (voltage) occurring, but that normal operation will be resumed with removal of the fault.

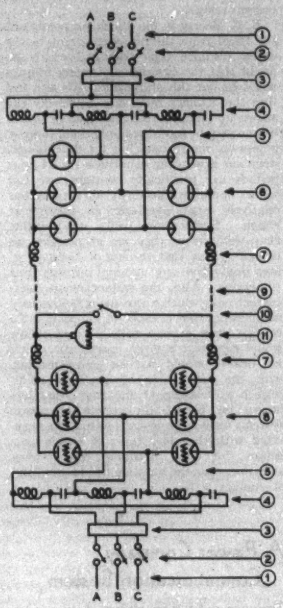


Fig. 4. Diagram of a constant-current d-c transmission system

1. 3-phase a-c constant voltage power system
2. Disconnect switch
3. Oil circuit breaker
4. Monocyclic network
5. 3-phase a-c constant current
6. 3-phase full wave rectifier
7. D-c reactor
8. 3-phase full wave inverter
9. Constant-current d-c line
10. Short circuiting switch
11. Disk insulator for flashover test

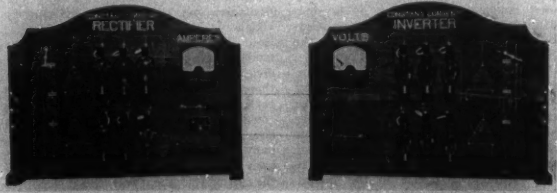


Fig. 5. Apparatus for demonstration of constant-current d-c transmission

Instantaneous Overcurrent Relays for Distance Relaying

Discussion and author's closure of a paper by C. H. Frier published in the April 1935 issue, pages 404–7, and presented for oral discussion at the general technical session of the South West District meeting, Oklahoma City, Okla., April 24, 1935.

L. C. Grigsby (Public Service Company of Oklahoma, Tulsa): The paper gives a good example of the application of instantaneous relays to a complicated transmission system. It emphasizes one very important point; that is, the importance of accurately determining the short-circuit currents on the system. This is absolutely essential for correct operation. The curves in figures 2 and 3 give a very good and systematic method for determining the relay setting and co-ordination. The application to lower voltage feeders in connection with fuses, as illustrated in figure 4, is interesting, in that it offers a satisfactory solution to a problem which has frequently been encountered.

There is one minor point on which I differ slightly with the author and that is the use of the internal relay, or "instantaneous trip attachment," versus the external relay. It is true that the cost of the external relay is somewhat greater than the internal attachment. However, for the more important lines or trunk feeders, we believe that the advantages, which include better provision for inspection, testing, calibrating, and ordinary maintenance, warrant the slight additional cost of the external relay over the internal relay.

On the system of the Public Service Company of Oklahoma the instantaneous overcurrent relays have been used for about 3 years. Our experience with them has been quite gratifying. In checking over the operating results, it was found that the percentage of relay operations checks very closely with those given in the paper. We have one case in which the instantaneous relays are used to relay the entire length of the line for any value of fault current. This section of line terminates in a stepdown transformer bank which introduces sufficient impedance to permit backing up of the relays on line sections fed from the low voltage side of the transformer bank. Out of a total of 11 relay operations since the installation of the instantaneous relays on this section of line, we have had but one instance when they failed to clear the fault. This resulted from the failure of the relays on the

low side of the transformer bank to operate.

The paper points out the necessity for considering the different combinations of generating capacity as influencing the setting of the relays and length of line section effectively protected. At one generating station of 30,000 kw capacity, consisting of 2 15,000 kw units, we have installed 2 sets of the instantaneous overcurrent relays having their operating coils in series. One set of these relays is given a high current setting corresponding to fault currents, with 2 machines operating on the system; the other set of relays is given a lower setting for fault currents, with one machine operating. A switch is provided to shunt out the operating coil of the lower setting relay when both generators are operating.

We have found that the instantaneous relays have materially improved our system stability by preventing the generating stations on loop circuits from pulling apart at the time of faults on the system. Through the rapid isolation of faults, the relays have prevented long duration of low voltage dips, and, consequently, have greatly improved service to the customer.

E. E. George (Tennessee Electric Power Co., Chattanooga): This paper brings out clearly the fundamentals of a scheme of relay protection that is being used rather extensively by certain companies. One company in the southeastern section has made extensive use of this type of protection with very good results. Its successful application seems to depend upon the amount of short-circuit kilovoltamperes being relatively constant under all generating conditions or in those cases where the variation is moderate, upon knowing accurately what the currents are under various conditions.

Judging by our own experience, we are convinced that all types of distance relays will operate successfully over long periods of time with very little maintenance; in fact, during the last 3 years our reactance type distance relays have probably had less attention than any other relay on the system. Improved types are now being brought out and, judging by their mechanical design, they should give still better service. Another advantage of the distance relay is that its starting unit makes an ideal fault detector or initiating unit for pilot wire circuits. We believe that this is a considerable advantage because much progress is being made in pilot wire reliability, pilot wire terminal equipment, and in the application of lower cost circuits to pilot wire protection.

C. H. Frier: L. C. Grigsby states that his company uses the external instantaneous overcurrent relay rather than an "instantaneous trip attachment" mounted inside the induction type overcurrent relays on the more important lines and trunk feeders because they believe the slight additional cost is warranted.

We considered both types of relays and decided in favor of the internally mounted instantaneous relay, first because the external relay cost 3 times more, and second because in the majority of cases we had no switchboard space available. The internally mounted relay setting, once adjusted, remains fixed and cannot lose its adjustment as we have developed a method to lock the adjustment in place. Relay field men find little difficulty in adjusting and maintaining these relays. They are reliable and the only maintenance required is the inspection and cleaning of the relay contacts. We therefore had no good reason for increasing our relay investment by buying the more expensive external instantaneous overcurrent relay.

E. E. George in his discussion points out the trend from the old overcurrent to the newer distance type relay. There is no doubt that the experience of many utilities will bear out this statement. We also feel that the distance relay is undoubtedly the answer to many vexing relay problems and we too may be forced to apply them to some points on our system, but for the present, since our generating conditions for 24 hour periods are practically constant, we can see no immediate necessity for retiring our relatively large investment in overcurrent relays. Furthermore, with the system characteristics as they are at present, we do not believe that the use of distance relays would give any material improvement to service. Also, the instantaneous overcurrent relay which we are using is obviously much easier and cheaper to maintain. To replace these devices with distance relays would represent a large investment which we believe would not be commensurate with the benefits to be obtained. The science of relaying in the past years has lagged far behind the growth of power systems until most systems were quite saturated with the older types of relays long before the more desirable relays were available, thus the question has become one of economy.

A Power Company Communication System

Discussion and authors' closure of a paper by E. E. George and O. J. Huie published in the March 1935 issue, pages 262–5, and presented for oral discussion at the general technical session of the South West District meeting, Oklahoma City, Okla., April 24, 1935.

O. S. Hockaday (Texas Electric Service Co., Fort Worth): In the development of a communication system for the use of power companies there is a growing tendency toward the co-ordination of service lease from the telephone companies and the service afforded by lines and apparatus owned exclusively by the power companies. Many power companies are finding it to their advantage in expanding their communication facilities to lease service from the telephone companies.

The extent to which such co-ordination can be carried out, however, depends very largely on the willingness and ability of the personnel of both the power and the telephone company involved toward co-operation. In most cases the power company already has some facilities which it must continue to utilize to the fullest. Any service supplied by the telephone company should fit into the existing system so that to be as flexible as possible. This generally involves interconnection between leased and privately owned lines.

If the power company is willing to install reasonable protective equipment, and the telephone people will assume a liberal attitude in the matter, there is no reason why such interconnection could not be established without any hazards to either.

The engineering aspects of the problems involved have been pretty well worked out, but a broad open-minded commercial policy must be observed if the power companies are to be encouraged in making wide use of leased service.

J. D. Browder (Oklahoma Gas and Electric Co., Oklahoma City): There is a point brought out in the paper which is unusual among operating companies in this section of the country, and in order to present that point I shall briefly trace the development of the Oklahoma Gas and Electric Company's communication facilities.

In many respects the growth and development of the system compare with those of the Tennessee Electric Power Company. When our first transmission lines were built in 1919 to connect the towns of Drumright, Sapulpa, Beggs, and Muskogee, a private telephone circuit was also installed on the same poles with the transmission lines. Other lines were later built to connect Oklahoma City, El Reno, and Enid, followed by the building of one of our first large central generating stations, Horseshoe Lake, located 22 miles east of Oklahoma City at Harrah. Two transmission lines were constructed between Harrah and Oklahoma City, on one of which was installed a private telephone circuit. With the exception of this circuit and the first one previously mentioned, our telephone communication was handled over commercial circuits at regular toll rates. But as our original properties were extended and interconnected to form a unified power system with a central dispatching office at Oklahoma City, additional communication facilities were required.

In 1924 carrier current equipment was installed at Oklahoma City, Enid, and Sapulpa, followed by similar installations at Etowah and Ponca City. The equipment at these 5 stations could be used only for dispatching purposes and was of practically no value for other company business owing to the lack of sufficient terminal facilities. Considerable capital investment would have been necessary to provide these facilities as well as to install additional station equipment to meet increasing requirements resulting from a rapidly expanding power system. With the expansion of the system to Shawnee, Ada, Ardmore, and other points in southern Oklahoma, the volume of business handled from the general office at Oklahoma City made it necessary to use toll service in increasingly large amounts. This situation, therefore, resulted in the need for more and better telephone service at less cost than could be obtained over usual commercial circuits. Consequently, in 1930 our company contracted with the telephone company for private leased wire service, and the carrier equipment was then dismantled.

This private service consists of approximately 550 miles of telephone circuits con-

necting the general office with the various generating stations and division headquarters at Enid, Sapulpa, Muskogee, Shawnee, and Ardmore, as well as numerous intermediate towns, switching stations, and substations. Private branch exchange switchboards are installed in the general office and at each division office, with operators on duty during regular business hours. The 4 principal circuits comprising the leased service radiate from the Oklahoma City board, where 2 operators are on duty during business hours handling traffic for all departments of the company. Dispatching calls are given priority over all other business on these circuits. Between 5:00 p.m. and 11:00 p.m. only one operator is required, and upon retiring from the board at 11:00 p.m. the leased wire circuits are switched directly into the dispatcher's office, where they terminate in a key-type switchboard designed especially for our purposes. Thus until 7:00 a.m. the dispatchers have direct control and supervision of the long distance circuits, at which time they are again switched back to the main private branch exchange board in the general office building.

Our dispatcher's switchboard is built in duplicate, yet it consists of one integral unit mounted flush in the middle of a large 2-position flat top desk so as to be accessible to each of 2 dispatchers who are constantly on duty. Each desk position is provided with 2 dispatcher's telephone circuits, a magneto and a common battery, which terminate in separate hand-type desk sets. The switchboard itself consists of a magneto section and a common battery section with all circuits being equipped with a battery operated lamp and buzzer alarm calling signals. Four 2-way dial trunks from the general office private branch exchange and one unlisted 2-way dial trunk from the central office terminate in the common battery section. In the magneto section we have the leased wire circuits as well as a 2-way rural trunk to the central office. The rural trunk provides quick communication with certain outlying substations regularly reached by rural telephone lines. It also enables the dispatcher to set up a connection between any leased wire circuit and any local dial telephone, as the switchboard itself has no direct means of interconnecting the 2 sections. This latter function, however, seldom becomes necessary on account of the unusual hours that the dispatcher has control of the leased wires.

In addition to the leased equipment just described, our dispatching communication facilities are supplemented by 6 company-owned magneto lines which are classified as exposed to power lines. These circuits terminate in a separate key-type switchboard built by our company and conveniently mounted on the desk within reach of each dispatcher. It, also, has 2 telephone circuits which terminate in separate desk stands so that either dispatcher may use the equipment separately or both simultaneously. Incoming signals are of the buzzer drop type; and a company-owned motor driven ringer is regularly used for calling, although hand driven ringers are provided for emergencies. By proper use of the keys, 2 or more lines may be connected by the dispatcher, in which case he serves as an operator for establishing communication between parties on different company-owned lines. Thus, we have 2 situations, which rarely occur and require very little attention when they do occur, where our dispatchers act as telephone operators.

Now, one of the outstanding features of the paper under discussion is the fact that the Tennessee Electric Power Company's dispatchers act as telephone operators in handling all calls no matter whether they are of an operating, commercial, or administrative nature. Not knowing anything about the conditions or volume of traffic handled, it appears that the dispatchers would be considerably handicapped in discharging their regular duties because of the time and attention required in serving as telephone operators. We would appreciate further enlightenment on this matter.

E. E. George and O. J. Huie: O. S. Hockaday mentioned one factor of extreme importance in stating that successful co-ordination of communication facilities depends very largely on the willingness and the ability of the personnel of both the power company and the telephone company. His statement that the commercial obstacles to complete co-ordination require more attention than the engineering problem is to be heartily endorsed.

J. D. Browder's description of the Oklahoma Gas and Electric Company communication system indicates that the facilities described are applicable in other locations and may be obtained when desired. Answering his question about all calls on the power company's long lines being handled by the load dispatcher, I would say that the best proof of the feasibility of this practice is its successful use for over 2 years. The only additional burden imposed on the dispatchers is during the time when there is no system trouble since administrative and commercial calls are not completed during the time when the lines are required for dispatching. This arrangement has also permitted a reduction in the number of private branch exchange operators but has not increased the number of dispatchers required.

The dispatcher's facilities for handling calls to and from the company lines are much better than those of the operator and calls can be handled much quicker than the operator could handle them. Another saving is that when commercial calls are handled by the operator, both the operator and dispatcher have to listen for code ringing if the turret and private branch exchange are connected in multiple, or if they are connected in series there is an extra switching operation which delays dispatching calls.

The arrangement we are using has had widespread approval over the entire system because of the increased speed of handling commercial and administrative calls. The extra work required of the dispatchers is offset to a large measure by the speed of handling trouble calls and by their ability to get control over the circuit instantly in case of trouble.

Furthermore, this arrangement permits the private branch exchange operators to give more time to exchange calls from the general public, thus giving customers better service, especially when these calls occur (as they usually do) during system trouble when the company's long lines are very busy on operating calls.

Having tried both schemes we much prefer the one we are now using, and if traffic should get heavy enough to require additional help, we would prefer to add an extra dispatcher, rather than to trunk the long line calls to the private branch exchange and add an extra operator.

Cable Sheath Corrosion —Causes and Mitigation

Discussion of a paper by J. B. Blomberg and Norvel Douglas published in the April 1935 issue, pages 382–83, and presented for oral discussion at the general technical session of the South West District meeting, Oklahoma City, Okla., April 25, 1935.

W. F. Rogers (nonmember; Gulf Pipe Line Company, Houston, Texas): The authors have prepared an interesting and valuable paper in regard to the determination and reduction of corrosion losses on lead cable sheath. Although the principal material of construction of the oil pipe line industry is steel and no lead is used, the corrosion problem is just as important, if not more so. It is interesting at this time to discuss some of the experiences encountered in studying soil corrosion of steel pipe and, especially, those experiences which parallel those of utilities using lead cable sheath.

The paper has listed the causes of lead cable sheath corrosion as any or all of the following factors:

a. Stray earth currents
b. Chemical corrosion
c. Electrochemical theory
   1. Galvanic potentials
   2. Differential areation
   3. Variation in electrolyte

The oil pipe line industry recognizes that corrosion may, and often does, result from stray electric currents. These cases are restricted to districts where oil pipe lines parallel or cross electric railway lines. Due to the nature of the business of oil pipe lines, it is not necessary or advisable that they pass through cities of the size requiring electric street cars. As a consequence, they seldom encounter this type of corrosion trouble to any great extent. There are, however, a few cases where pipe lines parallel electric interurban tracks for long distances. In one of the latter instances it has been only recently that a major pipe line company found it necessary to make an extensive investigation of the stray current which their 8 inch line was carrying and which was resulting in a rapid rate of corrosion attack, even though the pipe had been coated with an enamel and a wrapper when laid. The result of the survey lead to the recognition and acceptance of the fact that the line was acting as the negative feeder to the various substations along the right of way. Through proper bonding and the installation of low resistance metallic feeders, the pipe line was made negative to the rails throughout its length, and the current was led from the pipe line through a metallic connection to the negative bus

of the generator without loss of pipe metal. Such instances, in the midcontinent section at least, are relatively few and constitute but a minor portion of the corrosion troubles of oil pipe lines.

The oil pipe line industry does not recognize, at this time, instances of pure chemical corrosion, as differentiated from the electrochemical theory, such as is done in showing the formation of lead carbonate from lead, and such as is done in explaining the corrosion of copper in nitric acid. Thus, while the presence of acetic acid and carbon dioxide with lead causes a specific type of corrosion, these chemicals in steel pipe line corrosion are evaluated largely in regard to the increase in hydrogen ion concentration they cause in the soil solution and without regard as to the type of the acid.

Corrosion investigators in the pipe line industry consider that the electrochemical theory of corrosion can be used to account for any case of corrosion attack found which is recognized not to result from stray electric currents. These cases account for the major portion of the corrosion which occurs.

The authors have cited the St. Louis-Kansas City toll cable which was found to carry electric currents changing, over short intervals, from negative to positive potential to earth with resultant collection and loss of current. Electric currents of this same type are found on practically all pipe lines. They are differentiated from stray currents and for want of a better name, are called "long line currents." Their presence was first established by K. H. Logan, chief of the corrosion section, Bureau of Standards, and first presented to the pipe line industry in the paper "Pipe Line Currents," Logan, Rogers, and Putnam, at the tenth annual meeting of the American Petroleum Institute, Chicago, Ill., 1929. The conditions which give rise to these currents have not been isolated, but are laid to soil conditions developing large cathodic areas on the pipe. These currents have been found to flow for long distances, sometimes increasing in amount for several miles before beginning to leave the pipe. In other cases they reverse in direction every few feet. Apparently they are the same type as found on the St. Louis-Kansas City toll cable.

When studies were first made of these currents a possibility appeared that "hot spots" could be found by locating the points at which they left the pipe. It became advisable to test this theory and as a consequence, a survey was made of an 8 inch oil pipe line on the Texas gulf coast. ("Relation of Long Line Currents to Soil Corrosion," Gill and Rogers. *Physics*, v. 1, Sept. 1931, p. 194–204.) The line was approximately 8 miles in length and 8 years of age. The long line currents were measured over the entire length of the line by determining the potential drop over consecutive 100 foot sections of pipe. As the pipe weight was known, these potential drops were corrected to amounts of current flow. After this survey was completed, the line was taken up, cleaned, repaired, and put back into service. When the pipe was cleaned, the pit depths in it were measured. From these data curves were plotted to show the relation of the deepest pit in each 100 foot section to the gain or loss of current across that section. The results were that for any given pit depth there were practically as many cases where current was picked up across its section as where current was lost. As a result, it was concluded that this type of survey could not be used to determine corrosive soil areas with any greater precision than 50–50.

In contradiction to these findings, another major pipe line company, during the last year, has inspected some 2,000 miles of pipe by measuring the current flow over 100-foot sections taken from 1,500 feet to 1 mile apart. If current flow reversal is noted, the measurements are back tracked until the point of discharge is found. They report that 80 per cent of the cases of current losses were found to be in corrosive soil.

It would be most interesting if a second complete inspection of a pipe line or a complete inspection of a lead cable sheath could be made with respect to the changes in long line current throughout its length and the relation to the pitting found.

The use of cathodic protection by the authors to stop corrosion attack of the lead cable is of great interest. It is only during the past 3 years that this method of protection has been given any great consideration in the pipe line industry, and that has been largely for natural gas lines. Thayer installed cathodic protection on a small natural gas transmission line near Houston, Texas, and obtained results which led to further studies of the method and its adoption for many natural gas transmission lines. (Bureau of Standards, third conference on underground corrosion, 1932.) Although the St. Louis-Kansas City toll cable was protected in this manner although bare, all installations to date of cathodic protection which have come to our attention have been on coated pipe. It is the purpose of the electrical protection in these cases to prevent pitting and rust holes from appearing in the pipe at areas where the soil has stressed the coating from the pipe or where holidays were left during its application. Copper oxide rectifiers are usually used and the pipe made negative to the extent of 0.8 volt. This large potential difference has been somewhat decreased in later installations. Where only a small fraction of the pipe is bare, as is the case in a well coated line, the large potential difference of 0.8 volt does not result in the use of uneconomic quantities of current. It is also now being found that continuous application of the cathodic protection is not necessary, but that the current may be switched off at periodic intervals. Tests to determine the extent of this feature are now under way and will undoubtedly result in a lower current consumption than now thought necessary.

It would seem that corrosion problems for lead cable sheath and steel pipe have many features in common and the exchange of experiences of each cannot help but be of benefit to users of both materials.

L. C. Starbird (Southwestern Bell Telephone Co., Dallas, Texas): This paper deals with a subject with which I am very much concerned at this time. In practically every city in Texas we have had, during the last 2 years, conditions favorable for corrosion of cable sheaths.

In the cities in which street cars are operating, the general procedure and technique of mitigation are definite and have been successfully applied. The only requirements for this are co-operation between the various users of subsurface structures and a large amount of effort on the part of the employees actually applying the mitigation measures.

The problem of corrosion from local conditions is an entirely different matter. In my opinion there are 3 very definite questions in connection with this problem. First, given a small positive potential from the sheath to earth, is serious trouble likely to develop? Second, if trouble is likely to develop, what measures of mitigation will be effective? Third, what expense is justifiable in applying mitigation measures?

Beginning in 1932 there were a number of street railway systems abandoned. With each of these it was found that there was a small positive potential, ranging from 0.01 to 0.2 volt, together with a small current flow on the cable sheath. At first it was thought that this was the result of the deposit of metals or minerals on the sheath by the currents that had been picked up by the cables during the time that street railways were in operation, and that these deposits would be dissipated in a short time. Subsequent tests made 1 and 2 years after abandonment have shown, however, that there is no appreciable change in the cable potential.

Meanwhile we were called upon by one of the independent telephone companies to help them with a very serious electrolysis condition in their Greenville, Texas, exchange. The condition there was very similar to the others except that there had been no source of stray current for a number of years. On one particular cable run, about 3 blocks long, there had been an average of one cable failure per year for several years, and in one case, a cable failed in less than one year after it was placed in service. An examination of this cable showed that action was not confined to a small section, but was general through the cable. From this we can draw the conclusion that wherever this type of action is going to cause cable failures, all cables in the vicinity will be seriously damaged by the time any one cable fails.

A check was made of the conditions in several representative small cities in which street railways had never been operated. It was found that in a number of these the same small positive potentials existed, and presumably had existed for a number of years. However, no serious electrolysis failures have been experienced and in one case an examination by excavation of small sections of the sheath, revealed no appreciable action. We therefore have the condition that in some cases of this type, no serious trouble will develop if no measure of mitigation is applied, and in other cases very serious trouble will develop, and if we wait until a case of trouble does develop the entire plant will have been damaged in the meantime. I feel, therefore, that some supplementary methods, such as chemical analysis of the soil or placing short sections of cable in vacant ducts for observation, are required to determine if trouble is likely to develop. These methods are either expensive or take a considerable time to apply.

As an experimental measure in several

instances we have applied counter potentials, generally by the same method described in the paper. This, however, becomes an expensive mitigation measure when applied to a network of cable in the city where other subsurface structures are in use, and where frequent connections between the cable network and building frameworks, etc., are present. It is then necessary to remove the metallic connections between the cable and all other subsurface structures to conserve the amount of current required, and to apply the counter potential at very frequent intervals to prevent large differences of potential between the cable and other subsurface structures. The elimination of all metallic connections is a slow process and requires considerable time. The amount of power required for the application of counter potentials, while small for the individual point of application, becomes an appreciable item where there are a number. There should be some economical balance between the probable loss from corrosion in actual expense and in interruption of service and the expense of providing mitigation measures. I have not had enough experience to date to make an intelligent estimate of this economic balance.

The mitigation measures used at Greenville are rather interesting, particularly as to the effectiveness of a rather simple mitigation system. This network is small, consisting of about 20 manholes and approximately a mile of duct line extending about equally in the 4 directions from the central office.

This network was positive and remained so with potentials ranging from 0.01 to 0.15 volt to earth. The sheath current was also comparatively small, ranging from 0 to 0.2 ampere in the 4 branches. This soil is the rich heavy black land type and the water seeps into the manholes in sufficient quantities to keep the cables under water most of the year. The manholes and duct line are heavily dirted and this mixed with the soil water forms a sticky black muck. An analysis of this soil water and slush from the duct line showed calcium carbonate ($CaCO_3$), iron oxide (FeO), calcium sulphate ($CaSO_4$), aluminium oxide (Al_2O_3), lead carbonate ($PbCO_3$), magnesium carbonate ($MgCO_3$), and arsenic oxide (As_2O_3), relative concentration being in the order named. The pH value (hydrogen ion concentration) was not determined. During the investigation an attempt was made to overcome this condition by the use of counter potentials. The cable was so heavily grounded that a reasonable amount of current applied at one manhole would not effect the cable potential at the adjacent manhole. However, during the survey it was discovered that one particular guy wire was very negative to the cable and other subsurface structures. Investigation revealed that this guy wire was anchored to sections of iron buried about 6 feet deep. A temporary bond between this guy wire and the cable pulled the cable negative for about the distance of one manhole on either side of the point of bonding. As an experimental measure standard iron ground rods were driven in the sump in the bottom of a number of manholes and bonded to the cable. This was very successful and as a permanent measure, 10 feet sections of 70 pound rails were driven into the ground in the bottom of each manhole, and connected permanently to the cable. Current flow readings showed that current was flowing in all cases from the cable to these grounds and in some cases was as high as 0.1 ampere. This arrangement made the cable negative to earth at all manholes except 2 which were remote from the area where electrolysis trouble had been experienced.

The connections to this ground in any one manhole would appreciably reduce the cable to earth potential in the manholes on either side. However, there was some doubt as to whether the overlap of the influence of the grounds in adjacent manholes was sufficient to fully protect the cable midway between manholes. A test electrode was pushed through a vacant duct and readings taken at frequent intervals to ground and cables in the manhole. These readings indicated that the overlap was sufficient to fully protect the cable. Duct electrodes, when examined one year later, revealed very little corrosion. While this system of mitigation was successful at Greenville, it is not expected that it can be applied in many other cases.

Recommended Transformer Standards

Discussion of a paper by H. V. Putman and J. E. Clem published in the December 1934 issue, pages 1594–7, and presented for oral discussion at the insulation and protection session of the South West District meeting, Oklahoma City, Okla., April 24, 1935. This paper was also presented at the winter convention, New York, N. Y., January 22, 1935, and other discussion was published in the July 1935 issue, pages 770–1.

J. K. Hodnette (Westinghouse Elec. and Mfg. Co., Sharon, Pa.): There has been considerable discussion recently amongst engineers relative to a revision in the proposed standards for transformers to more closely co-ordinate the transformer insulation levels with protective devices. This applies particularly in the lower voltage or distribution classes of transformers where a reduction in the insulation levels would be made. It is believed that this has been an outcome of the transformer subcommittee's proposal to increase the 60 cycle dielectric tests on the lower voltage transformers and had as its objective a reduction in distribution transformer costs.

A better understanding of these transformers and the factors involved will show the soundness of the subcommittee's proposal.

For many years transformer manufacturers have been building insulation into distribution transformers far in excess of requirements for withstanding the present A.I.E.E. acceptance tests. This has been dictated by service conditions, lightning, switching surges, arcing grounds, etc. The proposed revision in the low frequency dielectric tests merely applies a voltage more nearly what the insulation is capable of withstanding, and no actual increase in insulation has been necessary.

In order to give a clearer picture of the factors with which we are concerned table I of this discussion was prepared giving the percentage of the iron opening occupied by different materials making up a 5-kva 2,400-volt and a 5-kva 6,900-volt distribution transformer. These transformers are of different constructions. The 2,400 volt unit is shell type with low-high-low coil arrangement and the 6,900 volt unit is core type with a low-high coil arrangement on each leg with a barrier between legs. It will be noted that the total high to low and iron insulation on the 2,400 volt transformer is 16 per cent of the total space. The low to iron insulation which is the minimum thickness that can be used due to mechanical requirements is 10 per cent. If the high voltage insulation is reduced to the minimum for mechanical requirements, the saving in space would be but 6 per cent.

Table I—Space Occupied by Copper and Insulation in the Iron Opening of 5 Kva Transformers

	Transformer	
	2,400 Volt Per Cent Space	6,900 Volt Per Cent Space
High voltage to low voltage barrier	10	8
High voltage to ground barrier	6	6
High voltage to high voltage barrier		12
Low voltage to ground barrier	10	6
High voltage part coil barrier	4	3
High voltage to low voltage ducts		16
High voltage layer insulation	22.5	24
Low voltage layer insulation	12.5	7
Copper	35	18

Similarly, the total high to low and iron barriers in the 6,900 volt transformer occupy 26 per cent of the space. By reducing the insulation to that of the 2,400 volt transformer a saving of about 11 per cent in space results. However, this insulation would not withstand the present A.I.E.E. acceptance tests and would be unsatisfactory from that standpoint alone.

While there is a great variety of types of transformers built, the information in table I is representative. It is apparent therefore that little can be gained by reducing the major insulation levels of distribution transformers. This major insulation is the vital insulation of the transformer. It separates the user of electricity from contact with the high voltage lines and as such is recognized by the safety codes. It has been established at its present levels by many years of experience and usage. To experiment with these well established principles would be hazardous indeed. The transformer subcommittee made a wise choice in maintaining the insulation levels of distribution transformers and in increasing the test voltages to correspond.

Robert Treat (General Electric Co., Schenectady, N. Y.): There is necessarily some divergence of opinion among different individuals as to what standards ought to be—each person's opinion depending on his viewpoint, past experience, and the premises he selects from which to reason. In general, one find 2 viewpoints in the group drawing up these standards—that of the users and that of the manufacturers. Sometimes there are more differences of opinion among

the manufacturers themselves, or among the users themselves, than between the 2 groups as groups. The standards finally recommended are necessarily a compromise between these divergent opinions. It has been said that there is seldom any logic in a compromise. I presume the standards recommended in this paper are as logical a compromise as it is possible to achieve at the present time.

One part of the standards deals with tests to determine the impulse strength of transformers. When standards for impulse tests on transformers were first recommended about 2 years ago, there was some agitation to get them congealed in the Institute standardization rules immediately. Those who at that time felt it would be wiser to await the result of some experience before taking this step will be interested to note that already important changes in the impulse test procedure are recommended.

The purpose of impulse tests is to demonstrate that a transformer has a minimum impulse strength (under the specified test conditions) which can be used as a basis for protecting it against voltages of lightning origin. The second test specifies "a wave sufficient to flash over the bushing, provided standard bushings are used, and having a crest voltage bearing a definite relation to the 60 cycle test voltage." The comment under table II in the paper implies that this "definite relation" is to have a constant value for tests at all voltages. This requirement would seem to be a little dangerous unless it is very certain that the 60 cycle test voltages are so wisely selected that when multiplied by this "definite relation" they always produce the correct value of impulse test voltage!

Furthermore, it is conceivable that the 2 requirements of the second test; namely, that the impulse wave have a definite relation to the 60 cycle test voltage, and at the same time be sufficient to flash over the bushing, may at times be incompatible.

It is suggested that at least this portion of the recommended standards might well be given further consideration.

Portable Schering Bridge for Field Tests

Discussion of a paper by C. F. Hill, T. R. Watts, and G. A. Burr published in the January 1934 issue, pages 176–82, and presented for oral discussion at the insulation and protection session of the South West District meeting, Oklahoma City, Okla., April 24, 1935. This paper was also presented at the winter convention, New York, N. Y., January 25, 1934, and other discussion was published in the March 1934 issue, pages 478–81, April 1934 issue, pages 618–22, and September 1934 issue, page 1311.

G. W. Gerell (Union Electric Light and Power Co., St. Louis, Mo.): The experience of my company with the power factor testing of bushings is rather limited. In 1933 the 66 and 132 kv transformer and oil switch bushings on Westinghouse equipment at the Cahokia and Venice stations only were tested by means of the Schering bridge. In the fall of 1934 all bushings on the 66 and 132 kv system were tested. In addition quite a few 33 kv bushings in certain of the a-c distributing substations were included.

Table I—Bushing Power Factor Test Results

Bushing Voltage Class	Good		Deteriorated		Bad		Totals
	No.	% of Total	No.	% of Total	No.	% of Total	
132 Kv	134	78	18	10	21	12	173
73 Kv	287	72	62	16	48	12	397
37 Kv	215	68	43	14	59	18	317
Totals	636	72	123	13.5	128	14.5	887

The 1934 tests extended over a period of 7 weeks during which a total of 887 bushings were tested, including 173 bushings in the 132 kv class, 397 in the 73 kv class, and 317 in the 37 kv class.

It is assumed that the determination of the power factor of a bushing places that bushing in a definite classification with respect to its condition. These classifications may differ for the various types of bushings in use, depending upon method of construction, type of insulation used, and normal voltage rating. Tables giving the rating of bushing quality by the power factor indication have been published frequently in the technical press and will not be repeated here. These limiting power factor values, it should be noted, are usually based upon an ambient temperature of 20 degrees centigrade, increasing rapidly for higher temperatures and decreasing for lower. Considering these factors, the bushings tested on our system were classified according to voltage rating and power factor, with the results as shown by table I of this discussion.

It is to be observed from this tabulation that 14.5 per cent of the total number of bushings tested were found defective. By employing a number of rather simple methods we were able to restore a little less than half of these to normal power factor. About 25 per cent of the defective bushings were repaired by removing the old oil and refilling with new oil free from moisture and other foreign matter. Approximately 15 per cent of the defective bushings were repaired by circulating hot oil or air through the bushings for a period of several days. In some the high power factor was the result of an external faulty condition, which when removed resulted in a normal power factor test on the bushing. In table II are indicated the case histories of a number of these bushings which are of unusual interest.

The remaining defective bushings were either the condenser or solid porcelain type (mostly in the 37 kv class). The matter of the disposition of these was referred to the manufacturers.

Two condenser bushings, one testing 0.094 power factor at 26 degrees centigrade and the other 0.085 power factor at 13 degrees centigrade, were returned to the factory for test. The factories report stated that the first bushing could be repaired, but at a cost practically equal to the cost of a new bushing with trade-in allowance. It was decided therefore to purchase the new bushing. In the case of the second bushing the factory retest of power factor showed it to be less than 0.06 at 20 degrees centigrade, and further it was stated that any bushing of this particular construction is to be considered satisfactory if its power factor tests 0.06 or less at 20 degrees centigrade.

Practically all the remaining condenser bushings could therefore be reclassified, placing them into the "investigate" group. No further action will be taken on these bushings, at the present time, but they will be given greater consideration during the next routine test.

In regard to a number of solid porcelain bushings in the 37 kv class, instructions have been received from the manufacturer and materials necessary to rebuild them are available. By such expedients practically all of the defective bushings found on our system have either been restored to a serviceable condition or final action has been deferred until the next routine test.

The detailed analysis of any bushing testing high in power factor is seriously hampered by a lack of knowledge concerning the design and construction of that bushing. If the manufacturer would supply complete information on each type of bushing, and in addition, give detailed instructions as to methods of repair the testing procedure would be materially speeded up and the effectiveness of the testing would be increased. It is understood that at the present time at least one manufacturer is preparing such information for distribution to those interested.

Inasmuch as temperature apparently has such a pronounced effect on the power factor of a bushing, it would appear desirable to give it greater consideration before placing a bushing definitely into one of the 3 classes used to indicate its condition. Before this can be effectively done, accurate temperature-power factor curves should be made for *all* types of bushings usually found in service. These curves should be based on the test results for a considerable number of bushings of each type rather than for one or 2 of each type. Further, the wide variations found in the power factor of several bushings tested at great temperature differences as illustrated by case 4, table II, would indicate that the published curves are subject to certain inaccuracies or that there are other unknown factors influencing the power factor determination. Assuming that accurate curves can be constructed, there is still the question of the determination of the correct ambient temperature. Usually in testing transformer bushings the air temperature is one thing and the oil temperature is quite another, the actual bushing temperature lying somewhere between these 2 temperatures.

Under the present methods, testing transformer bushings requires usually that a portion of the oil in the transformer be dropped, manhole covers be removed, and leads on the terminal block or on the

Table II—Case History of Typical Defective Bushings

Case No.	Bushing Type	Rating, Kv	Power Factor as Found	Repairs Made	Power Factor After Repairs
1	Oil filled	132	0.036 at 19 deg C	Removed old oil from bushings and refilled with new oil testing less than 0.002 power factor	0.0105 at 21 deg C
2	Oil filled	132	0.056 at 21 deg C	Hot oil at 85 deg C circulated through bushing for 3 days	0.024 at 16 deg C
3	Oil filled	73	0.07 at 26 deg C	Hot air at 85 deg C circulated through bushing for 8 days	0.038 at 19 deg C
4	Oil filled	132	0.053 at 21 deg C	No repairs—retested later during cold weather	0.019 at 5 deg C
5	Oil filled	132	0.15 at 29 deg C	Removed old oil, flushed and refilled with new oil	0.01 at 19 deg C
6	Oil filled	73	0.045 at 12 deg C	Removed old oil and refilled with new oil	0.038 at 20 deg C
7	Condenser	37	0.087 at 25 deg C	Returned to factory for disassembling and drying out. Cost of repairs excessive—replaced with new bushing	0.03 at 22 deg C
8	Condenser	37	0.085 at 13 deg C	Returned to factory; test indicated 0.05 power factor at 25 deg C—will be returned to service	0.05 at 25 deg C

lower terminal of the bushing be removed before tests can be made. Exclusive of the time required to make the actual test, from 15 to 20 man-hours and considerable material are required just to prepare the unit for test. The test is then made by 2 men in from 10 to 15 minutes.

It is felt that the manufacturer of test equipment should devote considerable effort to this problem, and in this connection it is to be noted that one manufacturer of test equipment has facilitated the testing of transformer bushings in the development of a new attachment for their power factor test set which does not require that the transformer oil be lowered, or that the windings be disconnected from the bushings, provided that the bushing is equipped with an insulated flexible lead-in wire.

Since our experience has been limited in the main to the use of the Doble set, we naturally classified bushings as being good, deteriorated, or bad, in accordance with the experience and recommendations of the manufacturer. I do not believe though that bushing manufacturers would be inclined to agree in all cases with these recommendations which undoubtedly are quite conservative. The case of the condenser bushings, cited previously, is a forceful example of this disagreement.

Although it is appreciated that a hard and fast rule cannot be formulated to determine whether a bushing should be discarded or not, it appears desirable that an agreement should be reached here before power factor testing of bushings can proceed on an efficient basis.

There is one other point that has been rather confusing to us. That is the proper interpretation of results of power factor tests on oil. We made such tests, in conjunction with the regular bushing tests, on oil samples taken from oil switches, transformers, and metering equipment. Some of these results were difficult of interpretation or at any rate the remedial measures were uncertain. For example, oil testing high in dielectric breakdown but high in power factor might be high in acid and not be materially improved by the ordinary filtering treatment, or oil testing low in dielectric breakdown and high in power factor might have its breakdown improved by filtering but not necessarily its power factor. The question which suggests itself is whether under these conditions other treatment or replacement of the oil should be considered, or if other tests should be made to determine the exact cause for the high power factor. This is probably more of an oil problem than a power factor problem but is related to power factor testing in the interpretation of the power factor test results.

In general, we are of the opinion that the power factor testing of bushings can become quite effective in forestalling failures. The published experiences of operating companies will be of great value, and should give a detailed analysis of the reduction of bushing failures as a result of testing, including the case history of those bushings that failed. The degree of its effectiveness will also, in a large measure, be dependent upon the co-operative efforts of the bushing manufacturer to supply detailed constructional and test data on their products and upon the testing set manufacturers in developing new and simple means of performing the tests.

I. W. Gross (American Gas and Electric Co., New York, N. Y.): Discussion of this paper in the light of work done over a period of some 5 years on the American Gas and Electric Company system with the Doble insulation tester has previously been given by Philip Sporn and the writer. (ELECTRICAL ENGINEERING, April 1934, pages 618–22.) Since that time we have continued testing bushings and apparatus with that test set and believe that at this time it may be of interest to summarize briefly some of the results which have been obtained in our work. To review the history of bushing testing in our own company, we started testing oil circuit breaker bushings with the Doble test set in 1929, which is several years previous to the appearance of the authors' field test set. The statement in the authors' paper, therefore, that a portable instrument for the measurement of dielectric loss was not available previous to the Schering bridge described in their paper, for purchase and use by the power companies, is rather misleading to say the least. The possibilities of detecting in the field insulation troubles in bushings, oil circuit breakers, and the like, became so apparent from the results of these tests that we extended the work in 1931 to testing a group of 44 kv bushings which had been giving us considerable trouble, with the result that we found a major part of them defective. The indicated defects have since proved to be real sources of trouble on the system, and although we were convinced at the time of test that the bushings were defective, it was not economically feasible to replace the entire group at the time of test. In 1932 we started a yearly routine testing schedule on oil circuit breaker bushings in the voltage class of 22 kv and above. The results of a large part of this work, as well as the previous field work, were reported in 2 articles in the January 1934 *Electrical World* by Gross and Turner.

The results of the testing work started in 1932 proved so beneficial and resulted in such a decrease in bushing failures that the testing program was extended in 1933 by the use of a second testing set to include testing of instrument and power transformers in the 15 kv class and above. The test set and method of application have been so successful that we can today look over the past 2 years and say that very few bushing failures have occurred on apparatus which has been tested by this method since 1932. The very few bushing failures which have occurred have been on types of bushings on which it is known that defects may occur without warning due to the entrance of excessive moisture into the bushing. Analysis of the few cases of trouble encountered has indicated that the bushings which have failed were either in good condition at the time of test or were distinctly bad as indicated by tests and had not been removed by the operating force before failure occurred.

The test set used is the Doble insulation tester which applies a test voltage of 10,000 volts (or less if desired) and indicates directly the current and watts loss fed into the bushing circuit. The power factor is calculated by simple operation of a slide rule. In our use of the test set, experience has shown that the power factor alone tells only part of the story. We frequently obtain in cases of defective bushings as much if not more information from the direct indication of the watts loss as from the power factor alone. The charging current is rarely used to indicate or segregate trouble. In the use of this set, we have not found it necessary to remove the leads from the oil circuit breaker or transformer to the nearest disconnecting switch as the authors of the paper seem to feel is necessary with their set. By leaving the leads connected, we have on occasions found defective insulators in the circuit from the transformer to the disconnecting switch which would not otherwise have been found.

The watts loss measurement we have found of great benefit in segregating trouble and in fact in some cases in picking out defects which are not entirely apparent from the power factor reading alone. For example, if all bushings in a breaker show approximately the same power factor, there have been cases where the higher watts loss in one particular bushing indicates a defect which on analysis has actually been found and the fault removed.

So many different types of faults have been located in the field varying from internal defects in the bushing, deposits over the immersed section of bushings, defective bus insulators, defective oil

circuit breaker lift rods, cross bracing, tank insulation, oil, transformer windings, etc., that it would be impossible here to give a complete story of such troubles. We have, however, summarized for ready reference the results obtained during the past 2 periodic tests. For easy identification, we are referring to the "first test" as the first periodic test made on apparatus from 1932 to January 1, 1935. The expression "second test" applies to the second routine test of apparatus which had already received the first test. The extent of the testing work will be made clear by the following table of the number of bushings and transformers tested:

Apparatus Tested	Approximate Number	
	First Test	Second Test
Oil circuit breaker bushings	8,700	5,700
Power transformer bushings	2,700	6
Instrument transformer bushings	2,100	180
Approximate totals	13,500	5,886

Thus over 19,000 bushings are included in these 2 tests, together with the windings of the instruments and power transformers.

For purposes of preliminary analysis, the results have been segregated on a power factor basis into 3 classes: *A*, *B*, and *C*. Class *A* covers tests showing below 0.04 power factor, class *B* power factors from 0.04 to 0.05, and class *C* for power factors above 0.05. With this classification, the following table shows the results obtained on the 2 tests:

Class	Per Cent of Bushings Tested	
	First Test	Second Test
A	81.8	90.6
B	6.5	4.6
C	11.7	4.8

From this table it will be noted that when the second routine test was made, the good or class *A* bushings increased approximately 9 per cent. The class *B* or defective bushings had decreased about one third, and the class *C* or bushings marked for removal had been reduced to approximately half the value indicated on the first test.

The first routine test indicated clearly that a considerable number of bushings in service were defective or warranted removal. The second test also indicates that by giving proper attention to the results obtained in the first test, the defective and hazardous bushings had been materially reduced. Thus it is clear that by intelligent application of this power factor test method, defective and hazardous bushings can be materially reduced.

At the time tests are made in the field the men in charge are advised of bad conditions found and the recommendations for servicing. All field data sheets are sent into a central point for detailed study and analysis, and any conditions not caught by the test men are reviewed and further recommendations made, if necessary. A month or more after the tests have been made, a follow up check is made to see whether the recommendations made at the time of test have been carried out.

The summary record of field tests is made by transferring pertinent data on the field test sheets to a permanent card index so that from year to year the condition of any bushing or piece of apparatus can be readily traced from this card index.

The mere detection of defects in apparatus, bushings, or in the apparatus itself by field test is only the beginning of the removal of the trouble. To say that a bushing is defective at the time of test without locating the trouble by further tests or as a result of past experience is of little value. We have often chased down the indicated trouble and found that in practically every instance the trouble was exactly as diagnosed by the field test man. Experience of this kind often makes it advisable to note the apparent source of trouble at the time of test and leave it to the maintenance men to clear the trouble at their convenience if the fault is not of sufficient severity to warrant immediate action. Considerable more speed in testing can be gained in this way.

In chasing down trouble in the field we have found a variety of conditions from that of bushings with water actually running out of them when given a high voltage test, to conditions of water absorption by insulating members such as bushings, gaskets, insulating barriers, wooden lift rods, wooden bracing rods, deteriorated oil, open transformer windings, carbon deposits over the lower end of the bushing, and deteriorated bushing stud wrappings. The fact that the instrument is capable of giving a direct reading of watts loss in the test circuit has been of great value in segregating many of the troubles mentioned above which were actually found in the field.

At the time we inaugurated our routine testing of bushings in 1932, we estimated the saving possible by adopting a test program, balancing the cost of the bushing testing work against the probable bushing failures as a result of past experience. Revising our figures to conform to results obtained, we believe we are at present carrying on our bushing test work at a cost approximately equal to one-quarter of what it would cost us if we permitted bushing failures to take place in the field as they had been doing previously. The fact that we have had only a very few bushing failures among the bushings tested since our tests were first started, and then in some cases on bushings which had been recommended for removal, speaks volumes for the ability of the test set to detect trouble, the care exercised by the test men in getting and analyzing the data, and the careful attention given by the operating men in remedying defective conditions brought to their attention as a result of the tests.

Headquarters for A.I.E.E. October Meeting

THE electrical engineering building of Purdue University, West Lafayette, Ind., shown here, is to be headquarters for the meeting of the Institute's Great Lakes District (No. 5) which is to be held October 24 and 25, 1935. The program has been practically completed with 3 technical sessions, one student session, and a dinner meeting on Thursday evening. In addition to the subjects of technical papers mentioned in preliminary announcements in the June and July 1935 issue of ELECTRICAL ENGINEERING, papers on electronics, measurement of very high voltages, and general applications have been included on the program. Full details of the program are scheduled for inclusion in the September 1935 issue. The student session, scheduled for Friday morning, will be of considerable value both for students and for the engineers in attendance. An important function of membership in the Institute is the encouragement and assistance of the oncoming generation of electrical engineers, and it is hoped that many engineers will wish to participate in these sessions. Those who wish to stay over Saturday, October 26, may witness the football between Purdue University and Carnegie Institute of Technology, although reservations for both the game and for hotels should be made early. Purdue University, which lays claim to having the largest school of electrical engineering and the largest building devoted exclusively to electrical engineering in the United States, extends its welcome to all who may attend.

News
Of Institute and Related Activities

51st Annual Summer Convention Successfully Held on Cornell Campus

WITH a confirmed registration exceeding the average recorded at summer conventions during the past 15 years, the Institute's 51st annual summer convention was held June 24–28, 1935, on the Cornell University campus at Ithaca, N. Y. A comprehensive digest covering all the principal activities, including the several program and other innovations, is given on this and the following several pages. This news report, together with the technical papers, all of which have already been published in ELECTRICAL ENGINEERING, serves to convey to the entire membership, the essence of the convention activities.

ANNUAL BUSINESS MEETING

With Vice President R. B. Bonney of Denver, Colo., presiding on behalf of President J. Allen Johnson (absent because of illness) the annual business meeting, comprising the opening session of the convention, was held in Moot Court Room of Myron Taylor Hall, Monday morning, June 24, 1935. Paying tribute to the administrative authorities of Cornell University for their generosity in assuming the position of host to the Institute's 51st summer convention, Chairman Bonney called upon Dr. A. R. Mann, Cornell provost, who spoke on behalf of the university:

PROVOST MANN CONSIDERS CONVENTION ATTENDANCE A LIBERAL EDUCATION

"In view of the identification of university teaching and research with the technical and scientific fields into which university graduates go, it seems altogether appropriate that occasionally such an organization as the American Institute of Electrical Engineers should hold its meeting on a university campus. . . .

"By their terms, those sessions . . . devoted to education and research may appear at first glance to lie closer to the cultural purpose of the universities than is true of . . . technical sessions, but . . . in the fields of higher education every advance in science and technique is of direct and positive interest. Indeed, I should think that attendance upon such a convention as this . . . would in itself constitute a brief but highly intensive course in higher education.

"If the technical and industrial branches of engineering are to be most ably served by the classrooms and laboratories of science and engineering in the universities, there is needed at all times the most informed and mature judgment as to what is really fundamental in education in engineering and the sciences, and a frequent truing up of the educational curricula and methods to the significant trends in the use of the products of these institutions. With the growing tendency for large industries to provide their own post-graduate schools for specialized training in consonance with their own particular needs, the educational institutions may profit very greatly by the discriminating judgment of those who employ their products as to what constitutes the best foundation in the undergraduate years—how liberal in content, how broad in the fundamental sciences, how inclusive of technical developments—all, of course, in harmony with what is practicable. . . .

"We can never wisely overlook the fact that the function of colleges and universities is education—higher education—by means of many departments of knowledge, including the sciences and engineering subjects. Equally important do we regard university research. Industries may at times assess such research in terms of its value to the progress of industry. We also attach much importance to such values, but university research serves at least 2 other purposes of possibly greater importance to industry. One of these has to do with the advancement of fundamental knowledge in the sciences and the principles of engineering and the arts. . . . . The other high justification of university research is its contribution to the training of young men in science and of professional and technical men in science and in the professional and technical fields. Education in an atmosphere of research does for the student the most perhaps that the university can do for him. . . .

"Where a high development of research is lacking the educational process is lacking. It would surely redound greatly and directly to the advantage of the engineering industries in America if they should arouse among the leaders of industry themselves greater concern as to whether the colleges of engineering, from which they draw most of their fresh increments of technical men, are enabled to develop adequate research facilities and personnel. Because the great industrial organizations have developed their own research laboratories to a high degree and may for this reason feel less dependent upon the university laboratories, perhaps industrialists have given less thought than their own best interests warrant to the technical educational implications of a strong research atmosphere in our schools and colleges of engineering. . . . The human factor is paramount in industry as in all categories of life."

REPORTS OF THE BOARD OF DIRECTORS AND COMMITTEE OF TELLERS

In presenting a digest of the board of directors' report for the fiscal year ending April 30, 1935, National Secretary H. H. Henline mentioned among other things that a total of more than 2,600 had attended the 3 national conventions and 2 District meetings held by the Institute during that year, and that during the same period 61 Institute Sections had held a total of 521 meetings, and 117 Branches had held 986 meetings, amounting to more than 1,500 meetings held this past year in many parts of the United States, Canada, and Mexico. The Sections held the largest total number of meetings ever reported for any fiscal year. Other details may be found in full in the report as published in ELECTRICAL ENGINEERING June 1935, pages 674–5.

In accordance with the by-laws and with the report of the committee of tellers as presented, Chairman Bonney declared the election of the following members, each to take office August 1, 1935:

President:

B. B. Meyer, chief engineer, Public Service Electric and Gas Company, Newark, N. J.

Vice Presidents:

W. H. Harrison, vice president, Bell Telephone Company of Pennsylvania, Philadelphia, Pa.
Mark Eldredge, chief engineer, Memphis Power and Light Company, Memphis, Tenn.
R. H. Fair, plant operations supervisor, Northwestern Bell Telephone Company, Omaha, Neb.
N. B. Hinson, chief engineer, Souther California Edison Company, Los Angeles, Calif.
C. V. Christie, professor of electrical engineering and chairman, department of electrical engineering, McGill University, Montreal, Que.

Directors:

C. R. Jones, northeastern transportation manager, Westinghouse Electric and Manufacturing Company, New York, N. Y.
W. B. Kouwenhoven, professor of electrical engineering and assistant dean, The Johns Hopkins University, Baltimore, Md.
G. C. Shaad, dean, School of Engineering and Architecture, University of Kansas, Lawrence Kans.

National Treasurer:

W. I. Slichter, professor of electrical engineering, Columbia University, New York, N. Y.

The board of directors for the administrative year beginning August 1, 1935, consists of these newly elected officers, together with the following hold-over officers: J. Allen Johnson (retiring president), Buffalo, N. Y.; J. B. Whitehead, Baltimore, Md.; F. O. McMillan, Corvallis, Ore.; F. J. Meyer, Oklahoma City, Okla.; G. G. Post, Milwaukee, Wis.; R. H. Tapscott, New York, N. Y.; W. H. Timbie, Cambridge, Mass.; F. Malcolm Farmer, New York, N. Y.; N. E. Funk, Philadelphia, Pa.; H. B. Gear, Chicago, Ill.; P. B. Juhnke, Chicago, Ill.; G. A. Kositzky, Cleveland, Ohio; Everett S. Lee, Schenec-

Future AIEE Meetings

Pacific Coast Convention,
Seattle, Wash., Aug. 27–30, 1935

Great Lakes District Meeting,
West Lafayette, Ind., Oct. 24–25, 1935

Winter Convention,
New York, N. Y., Jan. 28–31, 1936

North Eastern District Meeting,
New Haven, Conn., May 1936

Summer Convention,
Los Angeles, Calif., June 22–26, 1936

Middle Eastern District Meeting,
Akron, Ohio (date to be determined)

tady, N. Y.; A. H. Lovell, Ann Arbor, Mich.; L. W. W. Morrow, New York, N. Y.; and A. C. Stevens, Schenectady, N. Y.

Thereupon Chairman Bonney pinned the president's badge upon Mr. Meyer's coat lapel, introducing him to the membership as "one who has been a very faithful member and who has worked hard on a number of Institute committees for many years." The essence of President-Elect Meyer's response is published on page 807 of this issue.

The report of the tellers' committee on the vote for the proposed amendments to the constitution which had been previously submitted to the membership by mail, was made. These amendments called for modification of the election procedure to permit the holding of the meeting of the national nominating committee during the winter convention in January instead of early in December, with the resulting later publication of information concerning the nominations, and later election, but without changing the date of announcement or the date on which officers take office. The tellers' report showed that the 6 amendments to the constitution necessary for making these changes were approved by the membership, and Chairman Bonney declared them so approved.

The new sentences of the constitution, all in Article VI, and giving in parentheses the dates in effect before the recent changes, are:

Section 30, second sentence:
"The national nominating committee shall name on or before January 31 (previously December 15) of each year, one or more candidates for president, national treasurer, and the proper number of directors, and shall include in its ticket such candidates for vice presidents as have been named by the nominating committees of the respective Geographical Districts, if received by the national nominating committee when and as provided in the by-laws; otherwise the national nominating committee shall nominate one or more candidates for vice president(s) from the District(s) concerned."

Section 32, first sentence:
"During the first week in April (previously March) of each year the national secretary shall mail to all qualified voters an official ballot on which are to be listed all eligible candidates, nominated as provided in Sections 30 and 31."

Section 32, last sentence:
"The outer envelope of either class shall be identified by the name of the sender on its face, shall be sealed, and, in order to be counted, shall reach the national secretary not later than the first day of June (previously May)."

Section 33, first sentence:
"The president, during the month of May (previously March) shall appoint, subject to the approval of the board of directors, 7 Fellows, Members or Associates, not members of the board of directors or of the national nominating committee, to constitute the committee of tellers."

Section 33, second sentence:
"Any Fellow, Member, or Associate not a member of the board of directors or of the national nominating committee who shall deliver to the national secretary on or before the first day of May (previously March) a written petition signed by at least 20 Fellows, Members, or Associates, stating their desire that he be a member of the committee of tellers, shall also be a member of that committee, provided that the aforesaid signatures shall not have appeared on another similar petition."

Section 34, first sentence:
"The committee of tellers shall meet at the office of the Institute as soon after the first day of June (previously May) as possible, and shall receive, unopened, all ballots from the national secretary, who shall also make to it a written report of the number of ballots received on and before, and after, the first day of June (previously May)."

Institute Prizes Presented

The report of the national committee on award of Institute prizes, as published on page 677 of the June 1935 issue of Electrical Engineering, was read by R. N. Conwell, chairman of the committee, and the corresponding presentations were made by Chairman Bonney.

The annual District meeting of the North Eastern District having been dispensed with in favor of the summer convention at Ithaca, the report of the District prize award committee was presented by District Secretary A. C. Stevens, as published in Electrical Engineering, page 677 of the June 1935 issue, and page 785 of the July 1935 issue. District prizes were presented accordingly to the winners present.

Message From President Johnson

Just as the annual business meeting was drawing toward a close, a letter arrived via special delivery containing a statement from retiring president J. Allen Johnson of Buffalo, N. Y., whose illness prevented his attendance. Chairman Bonney read the letter, the full text of which was published on page 785 of the July 1935 issue of Electrical Engineering.

Lamme Medal for 1934 Presented to H. E. Warren

"For outstanding contributions to the development of electric clocks and means for controlling central station frequencies," the seventh in the series of the Institute's Lamme Gold Medals was presented during the annual business meeting to H. E. Warren (A'02) president of the Warren Telechron Company of Ashland, Mass. A brief biographical sketch of Medalist Warren may be found on page 351 of the March 1935 issue of Electrical Engineering.

Other Lamme Medal Awards

The 6 previous awards of the A.I.E.E. Lamme Medal have been made as follows:

1928—To A. B. Field (A'03, F'13) consulting engineer, Manchester, Eng., for "the mathematical and experimental investigation of eddy current losses in large slot-wound conductors in electrical machinery."

1929—To R. E. Hellmund (A'05, F'13) chief engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., for "his contributions to the design and development of rotating electrical machinery."

1930—To W. J. Foster (A'07, F'16) consulting engineer, retired, General Electric Company, Schenectady, N. Y., for "his contributions to the design of rotating a-c machinery."

1931—To Guiseppe Faccioli (A'04, F'12) deceased, January 13, 1934, formerly associate manager of the Pittsfield (Mass.) Works of the General Electric Company, for "his contributions to the development and standardization of high-voltage oil-filled bushings, capacitors, lightning arresters, and numerous other features in high-voltage transformers and power transmission."

1932—To Edward Weston (A'84, M'84, member for life and past-president) chairman of the board of the Weston Electrical Instrument Corporation, Newark, N. J., for "his achievements in the development of electrical apparatus, especially in connection with precision measuring instruments."

1933—To L. B. Stillwell (A'93, M'92, F'12, member for life, and past-president) consulting engineer, New York, N. Y., for "his distinguished career in connection with the design, installation, and operation of electrical machinery and equipment.

H. E. Warren (right) receiving the 1934 Lamme Medal of the A.I.E.E. during the summer convention at Ithaca, N. Y., from Vice President R. B. Bonney. Prof. C. L. Dawes (left) made the address outlining the career of Lamme Medalist Warren

The Institute's Lamme Medal was established by provision of the will of Benjamin Garver Lamme (deceased July 8, 1924) for the encouragement and recognition of "meritorious achievement in the development of electrical apparatus or machinery." By Mr. Lamme's will, 2 other similar bequests were made, one to Ohio State University, and one to the Society for the Promotion of Engineering Education. The Lamme Medal of Ohio State University, to be awarded a graduate of one of the technical departments for meritorious achievement in engineering or the technical arts was presented for 1935 to George A. Burrell of Burrell-Mase Engineering Company, Pittsburgh, Pa. The eighth Lamme Medal of the S.P.E.E. was awarded to William E. Wickenden (A'07, M'13) Case School of Applied Science, Cleveland, Ohio.

Dawes Outlines Warren's Work

In his address covering the life of Lamme Medalist Warren, Prof. C. L. Dawes of Harvard University traced the course of Mr. Warren's work from the time of his early and successful efforts in the manufacture of battery driven electric clocks through the various difficulties incident to the development and successful merchandising of the idea of universal synchronized electric time. Of Mr. Warren and his work, Professor Dawes said in part:

"His chief contribution (to the advancement of the art of electrical engineering) consists in the development of methods for securing accurate timing by means of the current taken from ordinary central station service wires. . . . Two distinct elements: first, providing a synchronous motor timing device by which accurate timing can be had wherever regulated a-c power service is available, and second, devising means by which the frequency of power systems can be so accurately controlled that accurate timing is possible and the operation and interconnection of power systems are greatly simplified. . . .

"Thus, thanks to Mr. Warren, the public is now provided with clocks and other timing devices which are much less expensive . . . and more accurate. . . . Mr. Warren's inventions also have contributed directly to the electric power industry itself. . . . Constant frequency enhances the value of central station service. Many industrial processes, such as papermaking and some textile operations, are sensitive to changes in speed and hence frequency; with the frequency exactly constant, a better and more uniform product is assured. . . . .

"In considering Mr. Warren's achievements and those of the donor of this medal, I cannot but help seeing a correlation between the 2. Mr. Lamme was a pioneer designer of the polyphase alternator which made the early a-c power networks possible, and after some 40 years the same general types of alternator and power system are still in use today. Mr. Warren is the pioneer who provided means by which the speeds of such alternators may be accurately regulated, thus permitting these a-c networks to operate at a constant frequency and thereby providing means for widespread power interconnection as well as increasing the usefulness of a-c service to the public at large. Hence to me it seems that Mr. Warren's contribution has in reality been the carrying to further perfection the earlier contributions that were made by Mr. Lamme himself."

H. E. Warren Cites Anecdotes

In his remarks, offered in response to Professor Dawes's address, Medalist Warren presented reminiscences covering various phases of his life work, citing as his first important work, the invention of an instrument for measuring temperature at a distance, for which he was granted a patent soon after his graduation from Massachusetts Institute of Technology in 1894; he also stated that his next work had to do with street and interurban railway construction and hydraulic governor design. Of his work he said in part:

"None of these positions had much of an element of timekeeping or of clocks in it, but I started working on electric clocks as a hobby . . . so in my spare time I worked on this idea, and tried out different designs of electric clocks.

" . . . Prior to 1916 the electric companies were selling 3 kinds of service—light, power, and heat. Now they are practically all selling light, power, heat, and time service, all . . . over the same wires. They are all distinct, all have qualities and values of their own, and that has been the result of this development.

"Now this work that I have done . . . seems to me to be nothing more than an extension of the trail of engineering progress into new territory. No one person can mark but a small portion of the long trail that goes back into the dim past and continues on indefinitely into the future. Gladly would I acknowledge the aid I have received from the pioneer scientists and engineers and inventors who have marked this trail up to the point where my work began. . . . In addition to these, . . . I would also include those who helped me in my early experiments, and some of those officials and engineers of the power companies to whom I was able to show the picture that was in my mind and who had sufficient enthusiasm to persuade their companies to give the aid and the co-operation without which I could not possibly have succeeded."

The Lee golf trophy, presented by the late Past-President W. S. Lee for 36-hole lowest net score. The winner's name is engraved on the 14-inch cup, which must be won twice for permanent possession. A. H. Sweetnam of Boston, Mass., won at Ithaca, this being his first winning

The Lamme Medal of the A.I.E.E., established by the bequest of Benjamin Garver Lamme (deceased July 8, 1924), chief engineer of the Westinghouse Electric and Manufacturing Company. According to the provisions of the bequest, a gold medal accompanied by a replica in bronze is awarded each year to a member of the Institute "who has shown meritorious achievement in the development of electrical apparatus or machinery." The Lamme Medal for 1934 was presented to H. E. Warren, president of the Warren Telechron Company, Ashland, Mass., during the summer convention at Ithaca "for outstanding contributions to the development of electric clocks and means for controlling central station frequency"

Other Program Features

Technical Sessions

The technical program at Ithaca was somewhat heavier than the average for summer conventions, embracing 10 technical sessions which accommodated the presentation and discussion of 39 papers and the presentation of 2 special addresses, all in accordance with the program as published on page 561 of the May 1935 issue of

ELECTRICAL ENGINEERING and amended on page 668 of the June issue.

All papers presented at the convention were published in advance in ELECTRICAL ENGINEERING in the February, March, April, May, and June issues, and thus made available to the entire membership of the Institute. Dr. D. B. Steinman's special address "Registration of Engineers" is published elsewhere in this issue, and Takeshi Takei's special address "The Electrochemical Industries in Japan" probably will be published in a future issue.

ATTENDANCE

Inasmuch as the holding of a summer convention of the Institute on a university campus was without precedent, advance prediction of convention registration and attendance was difficult, and the ultimate total was in doubt until after the final day's sessions had closed, because each day brought in a substantial new group of registrants. Analysis of the attendance figures included in the 2 accompanying tabulations and comparison of these with similar figures published in previous years reveals several interesting facts. For lack of space these are left to the reader to deduce. However, it suffices to say that the final officially recorded and checked registration of 904 persons is some 11 per cent above the average recorded attendance at summer conventions for the past 15 years, in spite of the fact that Ithaca is far removed from any large center of population.

ENTERTAINMENT

In addition to bridge parties and miscellaneous inspection trips through campus and other nearby points, including points of scenic beauty, several well arranged general entertainment features served to round out the convention program in a very satisfactory manner. The first general affair was the reception for the president-elect which was held in Willard Straight Hall Monday evening, followed by a dance. The attendance at this function was some 600. Next, there was the picnic outing held Tuesday afternoon and evening at picturesque Taughannock State Park on the shores of Cayuga Lake, which drew an attendance of 539. That same evening back on the campus at Willard Straight Hall there was presented an effective informal musicale at which some 400 were in attendance, with an overflow audience on the terrace outside.

A large part of Wednesday was given over to a well organized inspection trip through the Corning Glass Works at Corning, N. Y. Some 200 women made the 40-odd mile trip in the morning, and, after being conducted through the glass works, were the guests of the Corning Glass Works at bridge and golf, held at the Corning Country Club that afternoon. More than 350 men left Ithaca following the morning technical session, were conducted through the glass works during the afternoon, and were the guests of the Corning Glass Works at a buffet dinner held at the Baron Steuben Hotel early in the evening. All visitors were shown typical operation of the glass plant, from bulb blowing and thermometer tube drawing to the manufacture of baking ware. A focal point of particular interest was the 200-inch telescope reflecting mirror cast in December 1934 for the California Institute of Technology, Pasadena, and now being gradually reduced in temperature in a special electric annealing kiln. This affair was excellently handled by a special committee of local men and women.

A putting contest held at the Ithaca Country Club Thursday morning, and the general convention banquet and dance held at Willard Straight Hall Thursday evening, brought the convention's entertainment program to a close The banquet attendance was 388.

GOLF

Principal sports event was the annual golf tournament and other related and officially recognized events, which were played on the Ithaca Country Club course which conveniently adjoins the Cornell campus. Many prizes were offered by the local committee in addition to the official Lee and Mershon trophies. As was the case last year at Hot Springs, competition was intensified by the fact that several were playing with the hope of getting their names on one or the other of these trophies for the second time.

For the Mershon trophy competition, a total of 16 players qualified. This qualifying group was reduced subsequently by match play to a final round played Thursday, June 27, between Helwig and Keiffer, with the result:

Winner—L. R. Keiffer, Cleveland, Ohio; 1 up
Runner-up—F. C. Helwig, Toledo, Ohio

Mr. Keiffer won the Mershon trophy in 1932, and thus came into permanent possession of it by virtue of his success at Ithaca. The names that appear on this cup as it will be held by Mr. Keiffer are: L. R. Keiffer, Cleveland, Ohio, 1932; H. W. Eales, Chicago, Ill., 1933; G. A. Kositzky, Cleveland, Ohio, 1934; L. R. Keiffer, Cleveland, Ohio, 1935. The present trophy is the second cup donated by Past-President Mershon, the first having been won permanently in 1931 by L. F. Deming of Philadelphia, Pa., after having withstood competition since 1912. This trophy was offered for competition by match play on a handicap basis, subject to permanent possession by virtue of 2 winnings by an Institute member.

The Lee trophy, presented by the late Past-President W. S. Lee in 1932, is competed for annually on the basis of lowest net score for 36 holes, and must be won twice by the same player for permanent possession. The results for the 36-hole medal play at Ithaca were:

Winner—A. H. Sweetnam, Boston, Mass.; 166–16, 134.
Runner-up—L. W. McCullough, New York, N. Y.; 173–19, 135.

Names now appearing on the Lee trophy

The Mershon golf trophy, which passed into the permanent possession of L. R. Keiffer of Cleveland, Ohio, after his second winning at summer convention golf tournaments. Mr. Keiffer won at Cleveland, Ohio, in 1932, and at Ithaca, N. Y., in 1935. The previous cup donated by Past-President Mershon remained in competition from 1912 to 1931 before being permanently won. Competition for this trophy is by match play on a handicap basis

Table I—Analysis of Attendance at 1935 Summer Convention, Ithaca, N. Y.

Classification	Dist. 1	Dist. 2	Dist. 3	Dist. 4	Dist. 5	Dist. 6	Dist. 7	Dist. 8	Dist. 9	Dist. 10	Foreign	Totals
Members	223	108	109	14	45	4	11	7	6	7		534
Men guests	41	27	20	2	6	–	3	1	1	2	1	104
Women guests	87	71	60	5	13	2	10	10	2	6	–	266
Totals	351	206	189	21	64	6	24	18	9	15	1	904

Table II—Summer Convention Attendance During Recent Years

1935	Ithaca, N. Y. *	(1)	904
1934	Hot Springs, Va.	(4)	351
1933	Chicago, Ill.	(5)	988
1932	Cleveland, Ohio	(2)	1,022
1931	Asheville, N. C.	(4)	525
1930	Toronto, Ont., Canada	(10)	1,110
1929	Swampscott, Mass.	(1)	1,000
1928	Denver, Colo.	(6)	500
1927	Detroit, Mich.	(5)	1,200
1926	White Sulphur Spgs., W. Va.	(2)	350
1925	Saratoga Spgs., N. Y.	(1)	900
1924	Chicago, Ill.	(5)	750
1923	Swampscott, Mass.	(1)	1,616
1922	Niagara Falls, N. Y.	(1)	950
1921	Salt Lake City, Utah	(9)	426
1920	White Sulphur Spgs., W. Va.	(2)	314

* District numbers in parentheses.

The new Mershon tennis trophy, donated by Past-President Mershon, to replace the trophy which he had donated in 1927, and which passed in 1934 into the permanent possession of E. F. Lopez of Mexico City, after having been won by him at 2 summer conventions. The new trophy, some 35 inches in height, will remain at Institute headquarters. Allen O. White, winner at Ithaca, is the first to have his name engraved on the cup

are: C. H. Teskey, Cleveland, Ohio, 1932; G. R. Canning, Cleveland, Ohio, 1933; F.M. Craft, Atlanta, Ga., 1934; A. H. Sweetnam, 1935.

District team competition, on the basis of 36-hole medal play, was entered into by teams from Districts 1, 2, and 3. The team from District 2 won the event as follows:

F. C. Heiwig, Toledo, Ohio, 159; G. V. Smith, Mansfield, Ohio, 173; G. R. Canning, Cleveland, Ohio, 174; and G. A. Kositzky, Cleveland, Ohio, 177.

TENNIS

Tennis competition was not so widespread as was golf, but spectators were treated to lively sets. In addition to the men's tournament, there was sufficient interest in tennis among the women to justify a women's tournament which was won by Mrs. F. J. Groat of Brooklyn, N. Y., with Miss Helen Kroger of Covington, Ky., as runner-up. For the men's tennis tournament, Past-President Mershon in 1927 donated a trophy available to Institute members, the winner each year being recognized by having his name engraved on the cup and receiving a photograph of it. That trophy, subject to permanent possession after a second winning, passed in 1934, at Hot Springs, Va., into the permanent possession of Delegate E. F. Lopez of Mexico City, Mex. A second and larger trophy was donated this year by Past-President Mershon to be competed for under the same rules as those which governed competition for the first cup, with the exception that the cup should always remain at Institute headquarters, with the names of the winners engraved upon it. The winner of the Ithaca tournament, and the first to have his name engraved on the new trophy, was Allen O. White of Washington, D. C.

E.C.P.D. Initiates Plan to Accredit Eastern Schools

The Engineers' Council for Professional Development, sponsored by the leading national engineering societies, the engineering educators, and the engineering examiners announced during July the inauguration of its program for accrediting engineering schools in New England and the Middle Atlantic States. The program will be offered to the other parts of the country after a trial period in these 2 regions. Notice is being sent to the presidents of all degree-granting engineering schools in the 2 areas advising them that the E.C.P.D. stands ready to receive requests for consideration of particular engineering curricula which the schools may wish to submit. The plan to be followed in the accrediting procedure was outlined in ELECTRICAL ENGINEERING for February 1935, pages 249–50, and March 1935, page 343.

Through the E.C.P.D. committee on engineering schools, regional subcommittees have been organized to visit each institution requesting recognition for its curricula. The visits by these committees will begin early in the fall and it is expected that the accrediting in these regions will be well under way before the first of the year. The plans and procedures will be considered in the light of the experience in carrying out the accrediting process in these regions, and with such modifications as seem desirable, the plan will then be offered to the other parts of the country.

Accrediting is necessary at the present time for a number of reasons, the most urgent of which is the fact that a majority of the states have enacted laws for the licensing of engineers, and that licensing procedure requires a list of accredited colleges whose graduates may submit evidence of their graduation in partial fulfillment of the requirements of licensure. The Engineers' Council for Professional Development is undertaking this work because it is the only body which represents all of the interested groups: the engineering schools, the state licensing boards, and the national engineering societies.

While the primary purpose of E.C.P.D. through its committee on engineering schools is to identify those institutions which offer professional curricula in engineering worthy of recognition as such, in longer range the purpose is to aid in promoting the best interests of engineering education and to raise the general level of its effectiveness. Emphasis will be given to quality of work, rather than to statistical information, to a greater degree than in former accrediting procedures. No hard and fast prescriptions are laid down for curricula, physical facilities, investments or expenditures, or other specific points relating to a given institution, although all of these, and others, will be taken into account in appraising the institution as a whole.

Great progress has been made in certain of the professions in raising the standards of their professional schools. The most notable of these is the medical profession. It is believed that this program of E.C.P.D. is an important part of the broader plan for enhancing the status of the engineering profession.

The constituent organizations of the Engineers' Council for Professional Development are: American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, The American Society of Mechanical Engineers, American Institute of Electrical Engineers, Society for the Promotion of Engineering Education, American Institute of Chemical Engineers, and National Council of State Boards of Engineering Examiners.

Final Announcement—The Pacific Coast Convention

All plans for the Pacific Coast Convention of the A.I.E.E., which will be held in Seattle, Wash., August 27–30, 1935, have been completed. Headquarters will be in the Olympic Hotel, one of the finest and one of the most modernly equipped hotels in the northwest. The convention committee has arranged an excellent program which provides for the presentation and discussion of timely technical papers, yet there is ample opportunity for sports, trips, and recreation, as well as other specially arranged trips for the visiting women. The Puget Sound area is noted for its scenic beauty, and the convention, which will be held during part of the week preceding Labor Day, affords members and their guests advantages for several good vacation days.

The various features of the convention were announced in ELECTRICAL ENGINEERING for July 1935, pages 783–4. The tentative technical program listed therein is complete with the addition of a paper "Off-Peak Control of Water Heater Load" by F. M. Starr, of General Electric Company. This paper will not be published in ELECTRICAL ENGINEERING but copies will be supplied at the convention by the author. In regard to entertainment and trips, additional information now available is as follows:

ENTERTAINMENT

The previously announced salmon fishing contest which is scheduled on Wednesday, August 28, at 4:00 a.m., will be an unusual attraction. Contestants will leave the Olympic Hotel one hour before sunrise. The salmon will be running up the river then and the fishing will be in Seattle Harbor at the mouth of the Duwamish River. The visitors that get a large salmon on their line

will have a real thrill. A prize will be awarded for the largest salmon.

Also, the boat ride for the women in the afternoon will be another unusual feature. The "Sightseer" will leave Pier 3 at 2:00 p.m. and the trip will be made in the opposite direction from that previously announced, ending at Leschi Dock, where automobiles will meet the boat and return the party to the Olympic Hotel.

Inspection Trips

The following additional city trips have been arranged:

Ship-to-shore radio station—The Pacific Telephone and Telegraph Company

Distribution facilities—City of Seattle, Lighting Department

In connection with the suggested trip at the close of the convention to the Skagit River development of the City of Seattle lighting department, the northwestern section of the International Association of Electrical Inspectors will meet in Seattle the week following Labor Day. They are arranging a trip to the Skagit River development which takes 2 days, Sunday and Monday, following our convention, so it is possible that some of our people will find it desirable to take this trip with this larger party. The city of Seattle maintains a railroad from the Skagit River development toward Seattle as far as Rockport, which is about 100 miles from Seattle. While the convention transportation committee is not arranging to supply transportation to Rockport, it is possible that some of the Seattle members will also be making the trip and can accommodate some of the visitors. The cost of the 2 day trip on the city's railroad from Rockport, including lodging and meals, is $2.50. If anyone wants to go Saturday and return on Monday, making a 3 day trip, the additional cost is $1.50.

Reservations and Registration

Members and guests should fill in and mail promptly the return postcard sent with the announcement to members in the nearby territory. The registration and information desk will be opened on Monday, August 26, and will be maintained throughout the convention. All members and guests are requested to register promptly upon arrival and receive their badges.

1935 Lamme Medal Nominations Due Nov. 1

In fulfilment of by-law requirements, a second posting is hereby given to the necessity of all nominations for the Lamme Medal for 1935 being submitted not later than November 1, 1935. (See Electrical Engineering, June 1935, pages 669–70.) Presentation of the 1934 Lamme Medal was made to Henry B. Warren (A'02) president of the Warren Telechron Company, Ashland, Mass., at the opening session of the Institute's recent summer convention at Cornell University.

A.I.E.E. Directors Meet During Summer Convention

The regular meeting of the board of directors of the American Institute of Electrical Engineers was held at Cornell University, Ithaca, N. Y., on June 26, 1935, during the annual summer convention of the Institute.

Present: *Past-President*—J. B. Whitehead, Baltimore, Md. *Vice Presidents*—R. B. Bonney, Denver, Colo.; F. M. Craft, Atlanta, Ga.; F. O. McMillan, Corvallis, Ore.; F. J. Meyer, Oklahoma City, Okla.; G. G. Post, Milwaukee, Wis.; R. W. Sorensen, Pasadena, Calif.; and W. H. Timbie, Cambridge, Mass. *Directors*—L. W. Chubb, East Pittsburgh, Pa.; F. Malcolm Farmer, New York, N. Y.; H. B. Gear, Chicago, Ill.; B. D. Hull, Dallas, Tex.; P. B. Juhnke, Chicago, Ill.; G. A. Kositzky, Cleveland, Ohio; Everett S. Lee, Schenectady, N. Y.; L. W. W. Morrow, New York, N. Y.; A. C. Stevens, Schenectady, N. Y.; and H. R. Woodrow, Brooklyn, N. Y. *National Treasurer*—W. I. Slichter, New York, N. Y. *National Secretary*—H. H. Henline, New York, N. Y. By invitation: *Past-Presidents*—A. W. Berresford, P. M. Lincoln; *officers-elect*—E. B. Meyer, W. H. Harrison, C. R. Jones, W. B. Kouwenhoven.

In the absence of President Johnson, because of illness, Senior Vice President R. B. Bonney presided.

The minutes of the board of directors meeting of May 20, 1935, were approved.

Reports were presented and approved of meetings of the board of examiners held May 29 and June 19, 1935. Upon the recommendation of the board of examiners, the following actions were taken: 2 applicants were transferred to the grade of Fellow; 15 applicants were elected and 13 transferred to the grade of Member; 105 applicants were elected to the grade of Associate; 143 Students were enrolled.

The finance committee reported disbursements for the month of June amounting to $19,291.47. Report approved.

Report was made of the following appointments of representatives of the Institute made upon the recommendation of the standards committee: W. M. Dann to the sectional committee on transformers; A. M. Opsahl to the sectional committee on code for lightning protection; A. E. Kennelly, V. Karapetoff, C. H. Sharp, and W. I. Slichter to the sectional committee on electric and magnetic magnitudes and units.

H. P. Charlesworth was reappointed a representative of the Institute on the board of trustees of United Engineering Trustees, Inc., for the term of 4 years beginning in October 1935. L. A. Ferguson was reappointed to the Commission of Washington Award for the 2-year term beginning August 1, 1935. Dean Vannevar Bush was nominated for appointment to the division of engineering and industrial research of the National Research Council. President-elect E. B. Meyer was appointed a representative of the Institute upon the American Engineering Council for the term of one year, beginning August 1, 1935, to succeed J. Allen Johnson, retiring president.

The board accepted, with appreciation, from the American Telephone and Telegraph Company 2 copies of a sound motion picture of past-presidents of the Institute prominent in communication, entitled "Engineers of Speech," one copy for the Institute's archives, and the other for presentation to The Institution of Electrical Engineers (Great Britain). This film includes a reproduction of the joint meeting held during the A.I.E.E. winter convention of 1928 with The Institution of Electrical Engineers by means of the transatlantic radiotelephone channel.

Approval was given to the plan of the Engineers' Council for Professional Development for the establishment of a central certification agency as proposed by the E.C.P.D. committee on professional recognition.

An invitation from the Société Française des Electriciens to nominate a candidate for the Mascart Medal for 1936 was referred to the president and the chairmen of the Edison Medal and Lamme Medal Committees with power to act.

Appreciation was expressed, by resolution and otherwise, of the effective services of the general convention committee and its subcommittees, of the ladies entertainment committee, and of the hospitality extended by Cornell University, in connection with the 1935 summer convention of the Institute.

A resolution was adopted expressing to President Johnson the board's sympathy on account of his illness during the past several months, its sense of loss caused by his enforced absence from board meetings and other events, and its appreciation of his frequent inspiring messages to the membership and his attention to all the important duties of his office.

Other matters were discussed, reference to which may be found in this or future issues of Electrical Engineering.

Irving Langmuir Honored by A.S.M.E.

The Holley Medal for 1934 was awarded on June 20, 1935, at the semi-annual meeting of the American Society of Mechanical Engineers at Cincinnati, Ohio, to Dr. Irving Langmuir, associate director of the General Electric Research Laboratory, for his contributions to science and engineering, especially in the development of the gas-filled incandescent lamp, of the thoriated filament for thermionic emission, of atomic-hydrogen welding, of phase-control operation of the grid-controlled gas-filled tube, and in fundamental research in oil films.

The Holley Medal was instituted and endowed in 1924 by George I. Rockwood, past vice president of the A.S.M.E., to be bestowed for some great and unique act of genius of engineering nature that has accomplished a great and timely public benefit. It was awarded to Hjalmar Gotfried Carlson in 1924; to Elmer Ambrose Sperry in 1928; and to Baron Chuzaburo Shiba in 1929.

Dr. Langmuir also was recently elected to foreign membership in the Royal Society, England. Foreign membership, considered one of the highest honors that can be bestowed by British scientists on fellow workers in other countries, is limited to 50 persons throughout the world.

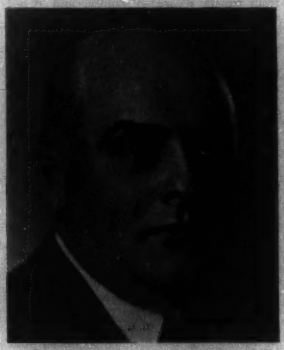
Newly Elected A.I.E.E. National Officers

N. B. HINSON
Vice President
Chief Engineer, Southern California Edison Company, Los Angeles, Calif.

W. H. HARRISON
Vice President
Vice President, Bell Telephone Company of Pennsylvania, Philadelphia, Pa.

MARK ELDREDGE
Vice President
Chief Engineer, Memphis Power and Light Company, Memphis, Tenn.

C. V. CHRISTIE
Vice President
Professor of Electrical Engineering and Chairman, Department of Electrical Engineering, McGill University, Montreal, Quebec



E. B. MEYER
President
Chief Engineer, Public Service Electric and Gas Company, Newark, N. J.

R. H. FAIR
Vice President
Plant Operations Supervisor, Northwestern Bell Telephone Company, Omaha, Neb.

G. C. SHAAD
Director
Dean, School of Engineering and Architecture, University of Kansas, Lawrence, Kans.

W. B. KOUWENHOVEN
Director
Professor of Electrical Engineering, and Assistant Dean, Johns Hopkins University, Baltimore, Md.

C. R. JONES
Director
Eastern Transportation Manager, Westinghouse Electric and Manufacturing Company, New York, N. Y.

Officers, Delegates, and Members Hold Annual Conference at Ithaca, N. Y.

SPONSORED jointly by the Sections committee and the committee on student Branches, the regular conference of officers, delegates, and members of the Institute was held in the Moot Court Room of Myron Taylor Hall, Cornell University, Ithaca, N. Y., Monday and Tuesday, June 25 and 26, 1935, as a part of the summer convention activities. In attendance at these sessions were delegates from 55 Institute Sections and counselor-delegates from 8 of the 9 Districts in which committees on student activities have been organized. In addition to these officially constituted delegates, there were other officers, officers-elect, and Institute members in attendance, bringing the total recorded attendance up to 95. The principal topics under discussion at the conference were essentially as outlined in a program previously mailed to the delegates and others:

Monday, June 24, 11:30 a.m.

1. Opening of conference; announcements by I. Melville Stein, chairman of the Sections committee.
2. Remarks by H. H. Henline, national secretary.
3. Institute finances—L. W. W. Morrow for chairman of finance committee.

Monday, June 24, 2:00 p.m.

Session A—Sections Committee Meeting—I. Melville Stein, Chairman, Presiding.

4. Communication from membership committee—Everett S. Lee, chairman, membership committee.
5. Relations with other professional bodies; L. W. W. Morrow, chairman, committee on coordination of Institute activities.
6. Publications policy of A.I.E.E.—C. O. Bickelhaupt, chairman of publication committee.
7. Section prizes—R. L. Frisby, chairman, Kansas City Section.

Session B—Student Branch Committee Meeting—Prof. L. A. Doggett, Chairman, presiding.

8. A general discussion of student activities of the Institute.

Tuesday, June 25, 2:00 p.m.

Session C—General.

9. Report on student Branch committee meeting of Monday afternoon, including recommendations for consideration at this time by the joint group.
10. The coming year—President-Elect R. B. Meyer.
11. Résumé of Sections committee meeting discussions of Monday afternoon.
12. Student relations; co-operation between Sections and Branches—Prof. Ben S. Willis, chairman, Iowa Section.
13. Section technical committees—John Bankus, chairman-elect, Portland (Ore.) Section.
14. Improving Section activities—
    (a). Increasing value of A.I.E.E. membership—Prof. Ben. S. Willis, chairman, Iowa Section.
    (b). Relations with the Public—J. M. Todd, chairman, New Orleans Section.
    (c). Section territory—I. Melville Stein, chairman of this committee.
15. New business.

The annual report of Section and Branch activities was published in full on pages 674–5 in the June 1935 issue of ELECTRICAL ENGINEERING, and therefore no pamphlet copies of the report were prepared for use at the conference and nothing further remains to be reported here.

Opening Session

In his opening remarks, Chairman I. M. Stein paid tribute to the effective work of the program committee which, widely representative, was composed of Chairman W. H. LaMond of the Cleveland Section (chairman), Chairman J. M. Todd of the New Orleans Section, and Chairman A. M. Bohnert of the San Francisco Section.

Vice President R. B. Bonney, in speaking by request in the absence of President J. Allen Johnson, called attention particularly to the progress that is being made throughout the United States in the continued development of Sections and student Branches, stating that "the report indicates that the number of these organizations has increased steadily during the past few years." He stressed the important opportunities for Institute service offered to these annual conferences which bring together delegates from widely separated points, and urged that "the importance of the local meetings of the Sections and the Branches . . . should never be lost sight of."

Upon the request of Chairman Stein, Vice President W. H. Timbie of Cambridge, Mass., spoke briefly with respect to the social and economic aspects of engineering. Professor Timbie characterized the engineer as "the most liberally educated man in the world at the present time," saying further that, to his mind, "engineering is more than technological work," and that "the biggest mass of information in this country is possessed by the scientists and engineers." He said further: "The thing that we think we can well do is to bring out and discuss some of the social and technological implications of engineering and not leave it to the other fellow who does a different kind of thinking." He called particular attention to the "Report of Institute Committee on Sponsoring Discussions of Social and Economic Subjects" that was published on pages 672–3 of ELECTRICAL ENGINEERING for June 1935.

Reports of National Secretary and Finance Committee

National Secretary Henline commented upon the opportunities for improvement of Institute activities that were offered through the widespread personal contacts made available through these annual conferences. Concerning Institute activities, Secretary Henline had the following comments to offer:

"During the past fiscal year which closed April 30, 1935, the Sections held more meetings than had been reported in any previous years . . . 521 meetings, with an average of about $8^1/_2$ meetings per Section . . . every Section has been active.

"The Branches also showed good records. During the past year 4 new Branches were organized, bringing the total to 117. About 50 per cent of the Enrolled Students who are coming to the end of their enrollment as students in the Institute are applying for admission as Associates, . . . nearly 50 per cent of the new members coming in.

"The Sections and Branches have continued the practice of holding a great many joint meetings, and as I have watched these meetings develop for several years it seems to me they are doing wonderful work in bringing the younger men into contact with the Sections. In many cases Branch chairmen become active in the Sections. Hence this joint work is bringing younger men into Section activities early after graduation.

"During the past year several new plans have been tried in the way of extending the Section activities and opportunities to greater numbers of their members. . . . Many Sections are doing excellent work in this respect. Some are holding special technical meetings between the regular meetings. The New York Section has operated 4 technical groups with great success. . . . San Francisco has been placing special technical meetings between the regular meetings, and Portland has also been successful in a similar development."

In speaking briefly concerning the question that has come up during the past year among some Sections concerning the question of co-operation with other groups, Secretary Henline mentioned the recent extension of American Engineering Council activities to provide for more simple and effective co-operation on the part of local groups throughout the country, and mentioned also the rapidly developing work of the Engineers' Council for Professional Development, pointing out that these and other similar opportunities for broader activities were readily available subject to the initiative and interest of the several local Section groups.

In reporting briefly for R. H. Tapscott, chairman of the finance committee, L. W. W. Morrow, member of that committee, referred to the board of directors report published in the July issue of ELECTRICAL ENGINEERING, pages 735–47, in which the complete financial statement for the fiscal year ending April 30, 1935, was published. In summing up briefly, Mr. Morrow pointed out that, with respect to the budget adopted in October 1934, the estimated receipts for the appropriation year ending September 30 were $218,000, whereas in the approximate 9 months' period ending June 21, some 86 per cent of the estimated 12 months' receipts had come in. Pointing out the further favorable balance, Mr. Morrow mentioned that the total expenditures for the 9 months' period were 73 per cent of the budgeted 12 months' amount. He reported with particular emphasis that the estimate on past dues paid in by those members that were delinquent already had been exceeded by a good margin.

To consider the question of the allocation of unexpended balances of Section appropriations, referred by the board of directors to the Sections committee for recommendations, Chairman Stein appointed a committee consisting of Chairman F. A. Hamilton of the Schenectady Section, Chairman-Elect John Bankus of the Portland Section, to serve with Chairman W. H. LaMond of the Cleveland Section. This committee was instructed also to consider resolutions that would more rigidly and equitably delimit the purposes for which the expenditure of Section appropriations would be permitted.

Sections Session

The first order of business in the Sections session Monday afternoon, June 24, was the report and discussion of the work of the membership committee.

Membership Committee Report

Everett S. Lee, Schenectady, chairman of the membership committee, spoke words of praise and high commendation to the many Section members and officers who have co-operated so effectively with the national membership committee during the past year: "I don't know how to express to you appreciation for the work that your Section membership committees have put into this job of membership this year. The reward of work well done is always more work; so your job is extended another year. Take that message back home to your Sections and see that your Section committees and chairmen are lined up in the coming year as they were in the past year."

For statistics, Chairman Lee referred to the tables included in the report of the membership committee as covered in the report of the board of directors (pages 740–1 Electrical Engineering July 1935) saying further:

"As to membership, as we see it, there are 3 groups—the Section membership committees, the membership of the Institute, and all those outside the Institute. We have tried to get the membership of the Institute to bring to the attention of the Section membership committees, and to those outside the Institute, the names of individuals that they thought should come in. . . . the figures speak for themselves.

". . . Institute headquarters has done an outstanding job in tabulating all the names, particularly those 4,200 names of members who for the past 3 years have had various vicissitudes and problems and troubles—each man having almost a different story—keeping all those stories intact so that resolutions could be brought to the board of directors for the best action possible. . . .

"We worked all year this past year; there was no summer let-down on the part of the membership committees. This was productive of very good results, and we obtained several hundred applications during the summer. Be sure you work out the invitations to your summer activities so that your members will invite their friends. That works out very well. Membership committees are going on along this summer also, so the membership committee job has become a 12 months' job."

Chairman Lee commented extensively upon the tabular information of the published report urging study and comparative analysis of the information given there; pointing out the obvious results of diligent membership work during the past year or so, he said further:

"I think it all represents a better situation in the Institute. . . . I know that the Section membership committees certainly have a right to feel proud of their record. From every Section applications have been received showing the universality of our work. . . . a little healthy competition often helps. For instance, following a letter received from Chicago saying that Urbana and New Mexico were in the same category, with the same number of members, both these Sections obtained new members."

Subsequent discussion emphasized the fact that, in general, quality was to be preferred in preference to quantity, but that there was also plenty of potential opportunity for membership promotion in that now only 14,000 or 15,000 of the 57,000 considered to be potentially qualified for membership actually are enrolled. An extensive discussion of the subject of "local members" brought out the generally expressed belief that on the basis of experience, promotion of the local membership idea in Section territory might be satisfactory provided it was handled in such a way as to serve definitely as a channel to national membership and not as an alternative.

Relations With Other Professional Bodies

Director L. W. W. Morrow, chairman, committee on co-ordination of Institute activities, spoke extensively on the subject of Institute relationships with other professional organizations. He first outlined briefly the activities of the 8 joint functional organizations of which the Institute is a co-sponsor, and concerning which rather complete information was published in the July 1935 issue of Electrical Engineering, pages 788–94. Mr. Morrow continued:

"Then we come to 2 distinctly new movements."

Engineering Registration

"One is the development of a movement, through law and other restrictive measures, to make engineering a guild or a very exclusive professional organization which, through licensing and through membership restrictions, is largely limited to a man who has had technical training and who is in actual technical activities as a specialized professional technical man. That movement has been developing rapidly. There are licensing laws now in most of the states, and the qualifications are largely technical.

"The guild movement, as I call it, if we followed it to its logical conclusion, would mean that no one could be a member of any of these engineering societies who could not be a licensed engineer in specialized professional technical work. It relates in a sense to law and medicine in its motivation, without reference to the fact that a lawyer or a doctor is rendering a personal service to an individual client, while engineering is a functional service entirely distinct from the other professions. But this movement is going on, and certain national professional engineering associations are being developed with the intention of making engineering a specialized profession, limited to technical men and excluding all that vast group of functional men that we call engineers who are not engaged in purely technical work.

"That movement, so far as the Institute is concerned, is represented by certain organized groups. One of them is the National Council of State Boards of Engineering Examiners. Another is the new society—the National Society of Professional Engineers. In a sense, the Engineers' Council for Professional Development also ties into that group. Through its 4 committees on student selection and guidance, professional training, engineering schools, and professional recognition, E.C.P.D. now is tending toward a sane development of that approach, not only in the selection of the students and the grading of the colleges, but in the post-graduate training and career work following graduation. The procedure is based largely upon the conception of engineering as being a guild or essentialy technical. The E.C.P.D. has been busy for 2 or 3 years laying the foundation for this work. It represents the several engineering societies and the National Council of State Boards of Engineering Examiners. Certain movements have been approved, such as the grading of engineering colleges. The committee on student selection and guidance is rapidly developing valuable material, and we are on the horizon of giving a new definition to engineers which we would rate as a requirement for membership in the Institute.

"That development requires study and I think should be discussed in front of all Sections this year. There are 2 points of view in these new developments. One is the exclusive point of view, and the other considers the function of engineering in modern life today that takes in the extremes from the business man to the narrow specialist. . . .

"We should be slow in taking action on these matters. The Institute is co-operating and is trying to take a sane viewpoint; it is not antagonistic. The problem is here and must be met. . . . "

Social and Economic Questions

"The second movement is distinct. . . . With the new developments in this country, engineers as well as everybody else are concerned with and interested in the social and economic aspects of national affairs. They think engineers should participate.

"Up to this time the only function of the Institute along that line was co-operation with American Engineering Council, which has functioned in Washington largely as the 'Embassy' of engineers. . . . But the pressure and the whole scene have changed so greatly that one of the late movements is for the American Engineering Council to decentralize and have in each state a committee of the same general type, that . . . could act with respect to legislation and social and economic matters in the state. That is being instituted as a broad-gauge movement, so that engineers are represented in the legislative councils, in state action, and in the social and economic scene where their opinions and advice will count. . . .

"The board (of the A.I.E.E.) itself has taken action recently (see page 672, Electrical Engineering, June 1935) to make possible in the Institute a broader policy regarding papers on social and economic affairs. Because this time is as it is, these things are more acute than they may be a few years from now, and now is the time for such discussions. But meetings on these subjects should be planned intelligently. . . . These subjects must be handled with more care than talking about a new design of a machine, for instance.

"Thus, this broad movement to participate more actively in national affairs—social and economic—is manifesting itself: (1) in relation to other societies, largely

through the development of the American Engineering Council; (2) indirectly . . . in the E.C.P.D. procedure; and (3) in the Institute in this new broad action of the board and in the programs contemplated for this year.

"How far to go in that direction or in the other extreme specialization direction should be discussed fully. It is a serious matter, and decisions should be based on information from the ground up."

A.I.E.E. Publication Policy

C. O. Bickelhaupt, New York, chairman of A.I.E.E. publication committee, presented a comprehensive digest covering recent developments in the policies and procedures governing the Institute's publications. In presenting his report, Mr. Bickelhaupt stated that the present procedure was subject to further development and urgently requested that the committee be given the benefit of any comments and suggestions that would reflect membership desires in connection with the publication services. (Mr. Bickelhaupt's report is scheduled for publication in full in the September issue of Electrical Engineering.)

In closing his comments, Mr. Bickelhaupt pointed out "that in carrying on the publication work in these very difficult and trying times it is very gratifying to know that we have been consistently reducing our expenditures and at the same time doing what we consider to be a creditable publication job. . . . Section delegates are entitled to know that the publication's expense for the current year is about 40 per cent less than it was for 1930. . . . "

Counselor-Delegates Session

According to the report presented by Prof. L. A. Doggett, of Pennsylvania State College, chairman of both the committee on Student Branches and committee on education, the afternoon's deliberation of the counselor-delegates and other persons interested in that phase of the work was given over to:

1. Consideration of the annual Sections and Branches report as published in the June 1935 issue of Electrical Engineering.
2. The question of national prizes for student papers.
3. The question of eligibility for student Branches of certain schools which have not been given that privilege.

Out of an afternoon's discussion, 2 resolutions were forthcoming:

1. Resolved that the committee on student Branches requests that the board of directors give consideration to re-establishing the office of assistant national secretary to give his time to student activities.
2. Resolved that articles written definitely to interest the students be regularly published in Electrical Engineering under the sponsorship of the Institute's committee on education.

Closing General Session

The first order of business of the reconvened general session was the presentation of the foregoing resolutions by Prof. L. A. Doggett, who, in discussing them, stated "We have felt that the student Branch activities have not had in the last several years sufficient support from the Institute at large. . . . As one matter of evidence, we have noted with considerable worry the fact that the attendance at the student Branch meetings has fallen off in the last 3 years from a peak of more than 60,000 to a low point last year of 36,000, whereas the attendance at Section meetings held practically constant at about 73,000. That change seems to be coincident with the new publication policy, which has totally removed the word "student" from Electrical Engineering. Therefore, we have 2 requests in the form of resolutions which we wish to pass along for the consideration of the board of directors."

Both resolutions were adopted after brief discussion and without dissenting vote.

President-Elect Meyer Speaks

Responding to Chairman Stein's request, President-Elect Meyer spoke briefly.

A message from Mr. Meyer is given on page 807 of this issue; another is scheduled for publication on the first text page of the September issue.

Section Activities

Prof. B. S. Willis, chairman, Iowa Section, speaking on assigned topic "Student Relations; Co-operation Between Sections and Branches," emphasized the importance of student Branch work by " . . . a student Branch is the field in which any missionary work is sure to bring lasting returns. We should strive to interest every student in electrical engineering in the Institute through the student Branch and to sustain his interest to such a point that he will when eligible transfer to the grade of Associate. We all give our moral support to the student Branches, and the Institute has wisely provided reduced dues and financial assistance to the student Branches, and prizes and other concrete tokens of encouragement. But I think the Sections in many if not in most cases do nothing active in the way of stimulating the interest of the students and encouraging the student Branches—that is, nothing definite."

Mr. Willis urged the individual member to "go out of his way to show a friendly interest in every student in electrical engineering with whom he comes in contact," and urged Sections to "prepare and circulate to the student Branches in nearby territory a list of young and enthusiastic speakers available for student Branch meetings." Discussion on this subject led to the adoption of the following resolution:

Resolved that it is the sense of this group that the Sections interest themselves more in student activities.

Further discussion on the same general topic led into the field of prizes and other means of tangible recognition and encouragement for student papers. Some urged more "assistance" of various tangible forms on the part of Sections and on the part of the national organization. However, the general consensus of opinion in accord with established facts was expressed by Vice President F. O. McMillan of Corvallis, Ore., who was a Branch counselor for a considerable number of years.

"I believe this discussion indicates clearly that the real fault in the situation lies with the counselor. The counselors are the persons responsible for the activities of these student Branches, and not the Sections. The Sections, of course, must co-operate with the Branches, and the Branches need their co-operation, but after all, the counselors must assume the responsibility for the activities of their own particular Branches. It seems to me that the whole difficulty lies in the fact that our student Branch counselors have not been sufficiently interested in or active enough to see that student papers are submitted" (so that they may receive consideration for District or national prizes).

Section Technical Committees

John Bankus, chairman of the Portland Section, spoke at some length on the assigned topic of Section technical committees as organized and successfuly operated by his Section. The full text of Mr. Bankus' report, together with supporting figures revealing the Section's experience, is scheduled for publication in the news section of the September issue of Electrical Engineering.

A brief résumé of some of the principal topics presented during the discussion on "Improving Institute Activities" is given in the following paragraphs:

Chairman Ben S. Willis of the Iowa Section suggested giving "every member of the Section a job in the work of the Section," and providing a "balanced program" including other than purely technical material and formal activities, as a practical means of increasing the interest and participation of individual Section members. With particular respect to Sections removed from the few really large centers of population of the country, he recommended also "that the national officers visit Sections more than they do . . . each Section should receive at least one visit per year from at least one national officer." He mentioned also the desirability of developing an increasing loyalty to and faith in the Institute.

J. W. Bennett, chairman of the Springfield (Mass.) Section, urged the desirability of developing speakers for Section meetings from among the Section membership, and emphasized the desirability of diversified meeting programs.

L. B. Robinson, Seattle, described the success of the Seattle Section in having student members present short talks in advance of the main address for Section meetings. He said "in general we will have 1 or 2 or 3 of the young men participate, in some cases giving a little historical sketch as a background for the main paper . . . in other cases giving some of the fundamentals on which the main paper may be based."

Concerning the relationship between the engineer and the public, Chairman L. H. Burnham of the Pittsfield, Mass., Section, described the Pittsfield Section as "an established institution in the life of the city of Pittsfield, recognized as such by the residents of the city." He pointed out that Pittsfield is far removed from large cities, and that the local Section of the Institute has, somewhat as a function of a civic organization, developed a large local supporting nontechnical membership for whom the Section holds a series of popular lectures on scientific and other topics during each season.

Section Territories

Chairman Stein reported briefly on the present status of the work of the special committee (E. B. Meyer, L. W. W. Morrow, E. S. Lee, I. M. Stein) appointed by the board of directors to study the proposition of revising Section boundary lines to include all parts of the United States in Section territories. He reported that the work was under way and would be reported upon at a later date.

Section Expenditures

Receiving the report of the special committee (W. H. LaMond of Cleveland, F. A. Hamilton of Schenectady, and John Bankus of Portland) appointed at the opening session of the conference for the purpose of drawing up a resolution that would convey to the board of directors the sense of opinion and recommendations of the conference concerning questions pertaining to Section appropriations, Chairman Stein presented the report to the body for consideration:

"Appreciating fully what the finance committee has done and is doing to keep expenditures within income, your committee recommends:

"1. That any Section holding at least 6 technical meetings per year shall not be obliged to return any expended balance of funds in its treasury.

"2. That traveling expenses in connection with District and national meetings shall be considered as outside of local Section activities and therefore should not be incurred by a Section.

"3. Inasmuch as '2' directly above will tend to limit attendance of delegates to District and national meetings, we urge restoration at the earliest possible date of traveling expenses to the former level of 10 cents per mile one way.

"4. That expenses for social meetings shall not exceed 15 per cent of total expenses for the year."

After rather extensive discussion as to whether or not it was advisable to recommend permissive action whereby local Sections could spend for convention delegates' traveling expenses any portion of the fund allotted to the local Sections for carrying on their local activities, the committee's report and recommendations were turned into a resolution and adopted as follows:

Resolved

1. That any Section holding at least 6 technical meetings per year shall not be obliged to return any unexpended balance of funds in its treasury.

2. That we urge restoration, at the earliest possible date, traveling expenses to the former level of 10 cents per mile one way.

Thus, this became the conference's recommendation to the board of directors in response to the questions referred to the Sections committee by the board for an expression of opinion.

Recognition of Section Competitions

Concerning the question of "national recognition of Section competitions to the extent of offering some sort of a prize," a special committee appointed the previous day by Chairman Stein (C. D. Brown, Milwaukee, R. L. Frisby, Kansas City, F. A. Hamilton, Schenectady) presented for discussion and consideration, the following resolution:

Resolved, that acceptable competitions conducted by the Sections, particularly for their younger members, result in many benefits to the Sections and to the Institute as a whole, these benefits comprising among others (1) increased membership, (2) increased participation in Section and Institute affairs, and (3) increased opportunity for self-development; and believing that Sections not now conducting competitions would be encouraged to do so by some form of national recognition, it is recommended to the board of directors:

1. That a certificate or other token, as may be decided from time to time, be made available each year to each Section holding during that year an acceptable competition, such awards to provide suitable recognition of the winner of the competition.

2. That any competitions, conducted according to rules adopted by Section executive committees, that are approved by the Sections committee and the committee on prize awards, shall be eligible for this recognition.

3. That national recognition of Section competitions, as outlined above, be given at the earliest possible date consistent with Institute policy.

Without discussion, this resolution was adopted unanimously and ordered referred to the board of directors for consideration.

With a unanimous "vote of appreciation. . . for the above conduct of this conference," the conference adjourned to reassemble in Los Angeles in 1936.

Reports on 14 Technical Conferences Held During the Summer Convention at Ithaca

An innovation introduced during the recent A.I.E.E. summer convention at Ithaca, N. Y., June 24–28, 1935, was the holding of a series of informal or round table conferences on technical and educational problems of the electrical engineering profession. These conferences were scheduled primarily for the benefit of specialists and the younger members, and were, in general, sponsored by subcommittees of technical committees. They afforded an opportunity for an interchange of ideas, regardless of whether or not the individuals interested were members of technical committees.

These informal technical conferences were held during the afternoons of the week of the convention, so as not to interfere with the regular technical sessions in which the formal papers were presented during the mornings. They proved even more successful than some sponsors had expected, and were attended by a large number of those present at the summer convention, in spite of the fact that as many as 5 were held in parallel.

In all, 14 of these conferences were held. Brief news accounts covering each of the conferences follow.

Transformers

By J. E. Clem, Chairman

The following report of the conference on transformers is intended as an informal news report, and not as a record of the technical opinions presented.

There were about 50 people present at the conference on transformers which mainly was in reference to the new standard bushings for distribution transformers, instrument transformers co-ordination, and the impulse test code.

A report on plans to formulate specifications for a standard line of bushings for distribution transformers was presented. During the discussion it was brought out that some time ago the transformer subcommittee agreed that the standard impulse flashover for bushings should be approximately 5 per cent in excess of the impulse flashover of the test gap used in testing transformers. Bushings for power transformers had been practically standardized as to flashover for sometime and the flashovers corresponded to the standard for the higher circuit voltages but exceeded the standard for the rated circuit voltages at the lower end of the voltage range. Inasmuch as this practice had resulted from experience, it was decided not to attempt to reduce the flashover of power transformer bushings down to the standard flashover values adopted.

The situation was different for distribution transformers and it was necessary to agree upon a line of flashovers in agreement with the standard together with the corresponding wet and dry 60 cycle flashover voltages. The discussion mainly was in reference to the fact that the flashover voltage for distribution transformer bushings was different and lower than that for power transformer bushings. There was some sentiment in favor of using but one standard flashover level for both power and distribution transformers. It was pointed out that the service record of distribution transformers has been, in general, quite good, and that transformers designed to withstand the tests according to the impulse test code with the proposed line of bushings would, in general, be stronger in insulation strength than the design of a few years ago. It was also pointed out that increasing the insulation strength of distribution transformers to the level required by the power transformer bushings would result in increased costs to the industry that are very difficult of justification.

The co-ordination of instrument transformers was extensively discussed. It was brought out that a situation exists, in regard to instrument transformers, which is similar to that for distribution transformer bushings. As a result of many years' experience, instrument transformers of 2 insulation levels are available. The higher level corresponds, in general, to that of distribution transformers of the same apparatus voltage classification and the lower level corresponds approximately to the next lower circuit voltage level. Many of those present could see no need for 2 insulation levels, but it was pointed out that about 80 per cent of the sales had been for equipment in the lower insulation level. Interchangeability of equipment was thought to be the major factor toward retention of the double standard. It was felt that ultimately there would probably be but the one insulation level and that the change-over would be more or less a gradual process.

The impulse test code has been in use for some time now and proposed modifications were discussed. There is a growing tendency toward requiring that impulse tests be made on the basis of kilovolts with a specified wave rather than on the basis of a given length of a rod gap. It was pointed out that the rod gap was chosen as the basis of impulse test at the time the test code was formulated because the various laboratories did not report the same kilovolts as the flashover of the gap. This difficulty has been fairly cleared up now and it seems desirable to change over to a kilovolt basis when the test code is revised.

Several proposals have arisen lately to modify the impulse test procedure. F. J. Vogel advocated a definite relation between the impulse test value and the low frequency high potential test in the factory. Some of the operators felt that the present impulse test does not take into account the fact that very steep voltage waves may be impressed on transformers in service. Present knowledge indicates that the lightning voltages to which transmission lines and connected apparatus are subjected bear a definite relation to the flashover value of the line insulation or to the voltage value permitted by protective apparatus, and that it seems reasonable to assume that the rate of voltage rise which lightning imposes on transmission lines expressed in kilovolts per microsecond bears no relation to the circuit voltage. It must be recognized that the lower voltage circuits will undoubtedly be subjected to considerably higher voltage in relation to circuit voltage than higher voltage circuits. These circuits are usually on wood pole lines and the flashover value of part of the wood is usually added to that of the insulator. Induced voltages on low voltage circuits may reach flashover value of the line or apparatus insulation. In general, this means that the lower voltage apparatus will receive a proportionately greater number of waves of dangerous magnitude and the rate of voltage rise in proportion to apparatus rating is increased.

F. F. Brand then suggested that lightning impulse tests, irrespective of the circuit voltage, be made at a definite rate of voltage rise and the value of voltage to be applied to the transformer be established in consideration of the limits to which protective apparatus hold this voltage. It was generally recognized that such a method of impulse testing was desirable and there was much discussion as to possible methods of making such tests. It was suggested that there might be difficulty of measuring very short times to flashover but it was pointed out that this difficulty might not be serious because when the time is short the voltage is low.

Research on Insulating Oils

By K. S. Wyatt, Chairman

The conference on research on insulating oils was highly successful, for not only was the attendance excellent, some 70 people being in attendance, but the discussion was active and of a stimulating and helpful nature. Most significant was the fact that several groups were represented who have worked on the oil problem in comparative isolation one from the other, namely, electrical engineers from the utilities, chemists both organic and physical from the oil refineries, and researchers from the universities.

Although the main object of the conference was to discuss ways and means of improving the stability of insulating oils, some attention was first directed at the economic importance of the oil problem to the electrical industry. Herman Halperin presented figures to show that the utilities in this country had an investment of $2^1/_3$ billion dollars in oil-insulated electrical equipment, which was being added to at the rate of 100 million dollars per year. Although the normal annual expenditure for insulating oils is small, about 3 million dollars, it was agreed that the problem of oil stability was of great enough economic importance to the industry to make imperative a strong research investigation.

The nature of deterioration of oils in service received some attention. C. F. Hill pointed out that the chief cause is oxidation, with contamination by gum, acids from varnish, and contact with metals as secondary factors. He emphasized that the degree of refinement had a marked influence on stability. Breakdown is thought to be largely a function of moisture content, an oxidized oil having higher dielectric strength if well dried. Viscosity and surface tension influence breakdown in service. Dr. J. B. Whitehead stated that the problem of deterioration of insulating oils is the outstanding problem in the advance of the art of high voltage underground power transmission. Two experimental methods might be followed, one large scale, simulating conditions in the factory, and the other the basic study of the inherent properties of oil. For the latter he suggested that measurements of conductivity, dielectric loss, dielectric strength, specific inductive capacity, and viscosity together with chemical tests should be made on different types of oils during subjection to high electrical stress and temperature under controlled oxidizing conditions. The influence of moisture must also be studied. Dr. Kenneth Hickman stressed the importance of the paper in accelerating oxidation of the oil, stating that peroxides are formed when paper is subjected to light or ozone and perhaps these or the rosin in the paper cause trouble. Professor Lars Onsager said the electron was the only active agent in the breakdown of oils. O. E. Fawcett described a detailed research program on transformer oils; he intends to investigate the possibility of adding some material to the oil to prevent oxidation.

The main discussion of the conference centered around ways and means of improving oils. D. W. Roper stated a new situation had developed in that some oil companies had introduced solvent refining methods which seemed destined to replace old-time acid refining processes. The new methods make it possible to select certain groups of hydrocarbons from the crude, some which it is highly probably have superior stability for electrical purposes if properly refined. He emphasized the effect of natural impurities and of contaminants on electrical stability. He listed the requirements for good cable oils and for good transformer oils. He was followed by E. H. Hillman, who thought that the best method of selecting samples for research was to obtain standard brands of motor oils now on the market. He championed the acid refining process. A. P. Anderson, on the other hand, thought the best method was to separate the constituents of each of 3 crudes covering the whole range of paraffinicity into 5 fractions, and to test each of the 15 samples for stability by all chemical and electrical measurements available during an aging program simulating service conditions. He thought that in improving these oils, the influence of chemical composition is of primary importance. The objection to working with motor oils now on the market is that there is no assurance that the hundred details of handling which may affect electrical properties will remain constant.

A short discussion then took place on the importance of developing more precise micro-methods for measuring the characteristics of oils. Dr. W. F. Davidson thought the development of such methods essential before progress could be made. He described several new methods; the determination of peroxides and copper soaps in oil; the potentiometric titration of acids in oils; the hydrophil method for the determination of oxidation products, and new micro-power-factor cells. Prof. J. C. Balsbaugh described a Shering bridge and vacuum cells for measuring power factor of small oil samples over a range of frequency. In the low range, power factor is affected by electrode material. Dr. Harvey Curtis preferred d-c measurements to loss measurements, thinking they would tell the whole story more cheaply and simply. He also said the more different were the types of attack on the oil problem the more rapidly would the solution come.

The results of the conference already have been of value for on the ideas suggested there the Edison Research Co-ordinating Council (sponsored by the Association of Edison Illuminating Companies) is basing its broad program of research on insulating oils to be started at the universities this fall. It is hoped that further conferences of a similar nature, but covering a narrower field, will be held under A.I.E.E. auspices.

Problems of the Student and Cadet Engineer

By M. G. Malti, Chairman

The conference of problems of the student and cadet engineer was opened with remarks by Prof. L. A. Doggett, chairman of the committee on education. He was followed by H. S. Osborne, who spoke on "The Future of Engineering and the Young Engineer." Dr. Osborne emphasized the fact that as long as science progresses there is bound to be a demand for engineers. He asserted that the present depression is only a temporary thing, and that the unemployment among engineers is bound to disappear with the depression and that the future will see an ever increasing demand for engineering service.

Dr. Osborne's talk aroused a great deal of interest and led to considerable discussion. The majority of those present agreed with him. The chairman of the conference stated, in support of Dr. Osborne's thesis, that scientific progress always leads to increased employment, and to a greater demand of engineering service. He pointed out as an illustration the radio industry, which sprang up like a mushroom, demanding not only technical services but also

ordinary labor. He further asserted that it is not scientific advance which causes unemployment, but rather ordinary inventions whose object it is to displace labor.

Among the speakers who discussed Dr. Osborne's paper was L. V. Reese, whose remarks were extremely timely and very beneficial, especially to the young men present at the conference. He gave those men some very practical and helpful suggestions, covering the most effective method of finding employment.

This period of discussion was followed by a talk by Alan Howard, who discussed "The Young Engineer in Industry." Mr. Howard emphasized the fact that the young engineer needs ability to sell his services as well as the capability of solving engineering problems. These 2 requisites, Mr. Howard pointed out, should go hand in hand, for if an engineer cannot do engineering work he has nothing to sell, and if he cannot sell his engineering services he will be unable to find employment.

He was followed by Prof. W. H. Timbie, who, speaking of the value of an engineering education in a non-technical and semi-technical career, emphasized the fact that and engineering education is beneficial not so much because of the facts that it gives to the engineering student, but rather because of the type of mental thinking it develops in him. He stated that the engineer is taught that his profession is one of service rather than of money-making, and that the engineer finds his highest satisfaction in serving humanity.

R. E. Hellmund, in discussing "The Qualifications of a Successful Engineer," stated that it is essential for engineers to maintain a balance between opposing qualifications in order to be successful. He took as an illustration 2 qualities, "ability, and industry," and stated that a person could be 100 per cent industrious, but zero per cent capable, and not accomplish anything. On the other hand, he could be 100 per cent capable but not industrious at all, and again not accomplish anything. Accomplishment, Mr. Hellmund stated, depended upon maintaining a balance between these 2 traits. These 3 talks provoked considerable discussion, after which Prof. C. L. Dawes spoke on "The New Graduate School of Engineering" and A. C. Stevens discussed the Engineers' Council for Professional Development.

Attendance at this meeting was well over the 100 mark, and it is gratifying to state that many of those present expressed their satisfaction at the discussion, as well as the papers presented. There is unquestionably a place for such technical conferences in the A.I.E.E. conventions, and it is hoped that this experiment will be continued in the future.

Mercury Arc Rectifiers

By O. K. Marti, Chairman

The attendance at the conference on mercury arc rectifiers was about 40 people. The first subject discussed was water cooling of rectifiers, corrosion, and remedies for the latter. It was pointed out that in order to carry off the heat losses from a rectifier, water is used for large iron-tank units. It was recently found that in some places, due to chemicals in the water, corrosive action is quite pronounced if tap-water cooling is used. Therefore, several other cooling schemes have been proposed, and most of the rectifier installations are now equipped with recirculating cooling systems on this account. R. O. Nixon submitted some data collected on the system of the Philadelphia Rapid Transit Company, which show that corrosion cannot be fully taken care of by the use of a film of paint applied to the water jacket and vacuum tank. Improvement in the amount of corrosion was, however, pronounced with certain paints, but the difficulty lies in that the paint, after a certain length of time, and especially if higher temperatures are used for the cooling water, scales off. Furthermore, his report showed that a considerable improvement was obtained by adding a corrosion-inhibiting chemical to the cooling water in the recirculating current. Mr. Nixon showed several slides illustrating the deposits of sludges resulting even from the use of drinking water and he brought out the fact that considerable pitting due to corrosion was found under the sludge, with their particular method of cooling.

O. K. Marti brought out the fact that by the use of the latest cooling system—i. e., recirculating cooling—introducing a heat exchanger, and insulating the latter from ground, practically no corrosion has so far been observed in many installations throughout the country, over a period of many years. He pointed out that it is, however, necessary that no air be added to the cooling water system, and that this provision can be met by using an expansion tank of the proper design. In this way not only is the corrosion due to aeration eliminated, but (through the insulation of the whole cooling system) the leakage current to ground is considerably reduced. J. J. Linebaugh stated that the use of the corrosion inhibitor in installations at voltages as high as 3,000 volts gave excellent results in such cooling systems as discussed above. Other preventive means were discussed, but it was felt that the use of a recooling system, insulated from ground should overcome these difficulties mentioned by Mr. Nixon. If this should not be sufficient, then the inhibitor could still be used in such a recooling system, and Mr. Nixon's data showed that it was effective in their system, which, however, permitted aeration.

R. L. Jenner showed a new development of a porcelain cooling coil, which can be used instead of rubber hose, especially in high voltage rectifier plants.

Another subject discussed was interference with communication circuits due to harmonics produced in the a-c supply circuits of mercury arc rectifiers. Dr. J. J. Smith outlined briefly the reason for possible interference caused on the a-c side of rectifier installations. P. W. Blye elaborated on this matter, and showed the relation between the power systems and the telephone systems, and developed the theory of some filter equipment which could be applied to the primary a-c network. H. E. Kent stated the various means for minimizing this interference on the telephone side as well as on the power side.

A third subject discussed was the proposed A.I.E.E. Standards, particularly regarding dielectric tests. On this subject, J. H. Cox and G. R. McDonald contributed a great many data, from which the conclusion was reached that it is immaterial whether dielectric tests are made under vacuum or at atmospheric pressure. Mr. McDonald discussed at length a tabulation of dielectric test specifications according to the rectifier standards of 3 different countries. It was also suggested that the A.I.E.E. Standards should be limited to voltages used in connection with present railway systems, say, 3,000 volts direct current, and that an addition to the present proposed Standards be prepared for rectifiers used in connection with higher voltages than 3,000 volts direct current.

D-C Test Code

By R. W. Owens, Chairman

At the conference on the d-c test code there were 14 people present, all of whom took an active part in the discussion.

T. T. Hambleton spoke of the determination of running light losses which are used in measuring the efficiency of d-c machines. L. R. Sellers discussed the various methods of setting the brushes on neutral with the advantages and disadvantages of each method.

The problem of maintaining a high insulation resistance in the field, together with the value of such measurements was the topic of C. H. Sanderson. Prof. W. I. Slichter who has given many years to the study and experimentation of determining a satisfactory means of measuring stray load losses gave a thorough talk on this subject. Mr. Hambleton also discussed the limitations in describing commutation.

T. M. Linville had just completed a study of the problems of flicker encountered with slow speed engine driven generators and gave his conclusions on this subject.

The meeting was open for subjects other than those scheduled and there were interesting discussions of many other problems which are involved in arriving at a standard of testing which would enable any manufacturer or user to make the same test report if testing an identical machine.

Circuit Breaker Standards

By R. T. Henry, Chairman

The technical conference on circuit breaker standards was attended by about 20 people. The principle feature of the discussion was a presentation by D. C. Prince of his experiences at the conference of experts on circuit breakers at Berlin, Germany, in April 1935. Mr. Prince described the discussions at that meeting regarding European and international standards for oil circuit breakers. R. E. Hellmund supplemented Mr. Prince's remarks and described his experiences at a similar meeting last year. J. E. Goodale presented some lantern slides illustrating the various methods of determining the current interrupted by circuit breakers.

A large part of the discussion covered the method of determining the current interrupted by circuit breakers and the question of whether this current should include only the a-c component or whether the a-c and d-c components should be included. Engineers in the United States and Great Britain favor including both the a-c and d-c components, while those in Germany and a num-

ber of the other European countries favor including only the a-c component. In this connection the oil circuit breaker committee of the Association of Edison Illuminating Companies has proposed a definition and specification of the current interrupted, and the discussion included this proposal.

There was also some discussion of the recovery voltage and the rate of rise of recovery voltage and the effect on the performance of oil circuit breakers.

A brief discussion of the situation regarding the test voltages for oil circuit breakers took place. There was also some discussion regarding the 1 second and 5 second current ratings for circuit breakers.

No definite action was taken on any of these subjects, but there was a rather free discussion and the conference served to present quite clearly the present status of some of these questions.

Reactance Coefficients of Synchronous Machines

By C. M. Laffoon, Chairman

The discussion on reactance and time constant coefficients of synchronous machines proved to be very interesting and profitable. Approximately 40 to 50 representatives were present from the manufacturing companies, technical schools, and operating companies.

There was a very lively and interesting discussion on the influence of saturation on reactance and time constant coefficients. Written discussions were sent in by Messrs. Early, Evans, Mortensen, Beckwith, Kilgore, and Laffoon. Oral discussions were concentrated on the application of reactance coefficients and the effect of saturation under different operating conditions. Oral discussions were given by Messrs. Peterson, Crary, Jones, Shirley, Mortensen, Kilbourne, and Kilgore, and by Professors Kingsley, Dennison, Bibber, Malti, and Lanier. There were also discussions by several other representatives whose names are not recalled.

From the discussions, the following general conclusions can be drawn:

1. The effects of saturation on reactance and time constant coefficients should be considered in applying these coefficients to most operating conditions.

2. The definitions and methods of test should be based upon values corresponding to rated current conditions, in order to minimize the expense and hazards involved in making the tests.

3. The values of reactance and time constant coefficients for other operating conditions should be obtained by multiplying the values at rated load condition by factors which can be taken from curves for the different types of machines.

4. Sufficient data are not available at the present time to reach a definite agreement in regard to the magnitude of the factors and the shape of the saturation factor curves for different classes of machines. This information is to be obtained from the different manufacturing companies by the subcommittee on synchronous machines.

Noise

By P. L. Alger, Chairman

At the conference on noise, and the meeting of the A.I.E.E. committee on sound which was held during the morning of the same day, it was considered desirable to proceed with the formation of a test code on noise measurements, recognizing that although in its early form it would be very sketchy, it will finally evolve into a very useful guide for practical work. The objective should be the adoption of generally understood and agreed upon methods of describing noise made by various types of electrical apparatus, these methods to be in accordance with the American Standards Association fundamental and meter standards already developed, and so far as possible consistent with methods to be developed by other groups such as the National Electrical Manufacturers Association.

The 4 major types of electrical apparatus to be considered in making such noise measurements are domestic appliances, office appliances, factory and substation equipment, and transportation equipment. The problem of describing noise of transportation equipment was deferred to a future time. The initial procedure to advance the work in the first 3 groups, however, falls into the following classes:

1. Draft of a general plan for describing apparatus noise under service conditions.

2. Draft of a general plan for describing apparatus noise under factory acceptance test conditions.

3. Preparation of an educational article on transmission of sound waves.

4. Collection of data on noise levels existing in home, office, etc.

Although it would be ideal if the apparatus noise could be determined under factory acceptance test conditions, and the acoustical properties of the environment could be determined by measurements in such a way that the noise under service conditions could be calculated from these 2 sets of data, it was agreed that in the present state of the art it is not practical to make such calculations, due to the complexity of environmental conditions. Therefore, the procedure in investigating noise conditions should be approximately as follows:

1. Measure the noise levels existing with the apparatus or noise source in operation.

2. Repeat the measurement with the apparatus shut down.

3. Determine the noise of the apparatus alone under factory acceptance test conditions.

4. By reverberation and other measurements, determine the degree to which the noise from the apparatus is affected by reflection, absorption, and other environmental conditions.

The ideas agreed upon as basic in preparing instructions for factory acceptance tests of noise were, broadly, as follows:

1. For convenience, a single point measurement of noise should be used wherever practical.

2. This noise measurement should be made in a direction corresponding to the maximum intensity noise produced.

3. The readings should be taken relatively close to the apparatus to minimize reflection effects of the environment, but far enough away to in some degree average the noise developed by the whole piece of equipment. Suggested standard distances are: 1 foot for very small apparatus; 3 feet for miscellaneous industrial equipment; and 50 feet for outdoor equipment or buildings.

4. When more than one marked frequency tone is produced, separate readings of the principal notes should be recorded.

5. Apparatus noise measurements should be made in an enclosure acoustically as dead as possible, or with minimum sound reflections.

It was also agreed that it is highly desirable to collect more authoritative information on the existing noise levels under all sorts of living conditions, determined with the American Standards Association standard on level meters. While much data has been published before on this subject, it has been in the old terms, with many discrepancies in the methods of measurements. Tables of data for noise surveys showing the levels estimated in accordance with the new A.S.A. standards, but measured with an unweighted meter, and also data on noise levels measured with a weighted meter and based upon the new A.S.A. standard reference level of 10^{-16} watts per square centimeter, were presented.

Dielectric Theories

By Hubert H. Race, Chairman

The conference on dielectric theories was attended by about 50 persons; it was entirely informal and is believed to have accomplished the purpose of providing opportunity for the exchange of ideas and information among those interested in this very specialized subject. The discussion was divided into 2 parts:

1. Dielectric properties of ice.

2. Dielectric properties of cellulose derivatives and fibrous insulation with special reference to the effects of water.

The underlying theories and considerable data on the first subject were presented by Dr. E. J. Murphy. General conclusion from the discussion of this subject was that the most probable theory for explaining the observed results is that of polar orientation.

The second subject was opened by Dr. J. B. Whitehead with a paper on the "Theories of Dielectric Capacitance and Loss in the System Cellulose-Water." The paper by Doctor Whitehead was followed by a presentation of electrical measurements on materials such as linen paper, kraft paper, "cellophane," and cellulose acetate by Dr. S. O. Morgan. The general conclusions from the discussion on the second subject were:

1. There are 2 dielectric polarizations in cellulose, one having a long relaxation time, probably due to electrolytic materials and very greatly depending on moisture content; and the second having a much shorter relaxation time, being dependent upon the cellulose itself and not very sensitive to moisture content.

2. In hygroscopic materials which have not been dried with extreme care, the dielectric losses at power frequencies probably result from conduction in adsorbed moisture films.

3. In very carefully dried materials, the observed dielectric capacitance and dielectric loss data appear to be best explained by the mechanism of polar orientation of hydroxyl (OH) groups.

Tensor Analysis

By A. Boyajian

The session on tensor analysis was sponsored by the electrophysics committee under Dr. W. F. Davidson, and the details of the program had been worked up by Prof. E. E. Dreese, chairman of the conference. On the program were 5 invited speakers, including engineers, physicists, and mathematicians, and the discussion of the significance and value of tensors in electrical engineering was participated in by a large number from the floor.

Anticipating the question which was bothering many minds, namely, "what is a tensor, anyway?" the chairman called on A. Boyajian to outline "The Nature of a Tensor." He presented the tensor to the audience as nothing but a "generalized vector," and proceeded to generalize the vector concept in easily understood terms

One of the informal technical conferences which aroused considerable interest and discussion was that on tensor analysis. Here is Gabriel Kron (center), exponent of the use of tensors, explaining a tensor analysis relationship to Dr. Ernst Weber (left) of Brooklyn Polytechnic Institute, and to Prof. Vladimir Karapetoff of Cornell University

analyzing the characteristics common to all of our familiar vectors. He drew the picture of a tensor as any set of quantities which form a system as a single entity, the system being the tensor and the set of elements the components of the tensor or generalized vector. These components are resolved or transformed in accordance with either 1 or 2 simple rules whenever the method of reckoning or system of resolution (the co-ordinate units of the mathematician) are altered. Generalized vectors were seen to be capable of any number of dimensions—for instance, 1 dimensional, as displacement; 2 dimensional, as area; etc. With the aid of this broadened conception and the criteria of transformation outlined, direct current in a network was seen to be a generalized "contravariant vector"; direct voltages a generalized "covariant vector"; the alternating currents and voltages of a polyphase system were seen to be generalized vectors with complex components; the currents (some direct current, some alternating current) in the various windings of a rotating machine and the velocity of its rotor were seen as the components of one (!) tensor; similarly, the voltages in the various windings and the torque on the rotor were seen to be the components of another single tensor; the impedance elements of any complicated system were seen to constitute a single "doubly covariant" 2-dimensional (that is, 2 circuit) tensor; simultaneous equations, which formerly were nothing but a collection of equations, were seen to be the equations of the components of a single generalized vector; and finally machine, circuit, and system connections, which yielded one set of currents (or voltages or impedances) from another set, were seen to be nothing but "transformation tensors." It then became obvious that a scheme of analysis which could view a complicated set of quantities comprehensively as a single system, a single generalized vector, and could write equations for it as for a single element and manipulate these equations as simple equations, could not help but be of very great value in the handling of complicated problems, and in writing generalized equations applicable to a great variety of types of equipment belonging to one general classification like "rotating machines," or, "static network," etc.

After the laying of this foundation, Professor Banesh Hoffman was called upon to build a mathematical superstructure. He explained tensor symbolism; developed the theory of "transformation" of tensors and gave examples of important tensors such as the "Christoffel symbol" and the "Riemann Christoffel curvature tensor," and their use in the "unified field theory" of Einstein.

Professor E. Weber was then called upon to present "The Tensor in Operational Methods," and he showed examples of the application of tensors in transmission network analysis, including transient phenomena, and pointed out useful fields of application of tensors in interference, cross-talk, stability, conductor vibration, etc.

Prof. J. L. Synge was then called upon to present "The Tensor in Physics." He explained the necessity of tensors in mathematical physics, and developed the equations of the "restricted theory of relativity" in tensor form. The equations of the electromagnetic field and related equations were exhibited in several comprehensive slides.

Turning back to engineers, the chairman called on Gabriel Kron and introduced him to the audience as a pioneer and a leading exponent in the application of tensor methods to electrical engineering problems. Mr. Kron spoke of the application of tensors to rotating machinery, and showed how the performance of rotating machines of any complicated structure and connections can be analyzed in a routine manner if the equations are set up in tensor form. He also pointed out how all the mathematical concepts of relativity dynamics appear in the study of rotating machinery. The utility of tensor concepts in field problems, where curvilinear co-ordinates appear, and in vacuum tube circuit analysis, was also mentioned.

An enthusiastic discussion followed.

Dr. C. L. Fortescue spoke of his interest in the subject and mentioned a number of books which he was studying at the present time, including one by Eddington and another by McConnel. He stressed the importance of approaching rotating machine problems from the point of view of the dynamical equations of Lagrange, which has actually been done by Kron in tensor form.

L. V. Bewley related his adventures in quest of an intelligible book on tensors, and mentioned "The Applications of the Absolute Differential Calculus" by McConnel as the more helpful reference. He expressed the opinion that time spent on the study of differential geometry (which is the subject matter covered by most of the tensor books) is time well spent, as it turns out that machine characteristics and equations are identical with various geometrical characteristics and equations.

Professor Guillemin and Doctor Barnes traced the beginnings of concepts of matrix algebra in the electrical literature with particular application to network synthesis studies.

W. H. Ingram expressed considerable skepticism about the value of relativity analogies to rotating machine studies and about the significance and utility of certain tensor concepts and equations as applied to rotating machine analysis.

P. L. Alger pointed out that the study of analogies can not fail but be highly instructive, and emphasized the fact that the basic equations of various scientific fields are generally identical.

H. H. Lauder recited his experience in the study of the bewildering array of the theories and equations of various rotating machines, and, how, when he became acquainted with tensors through Mr. Kron's work, the whole field of rotating machine theory and equations were at once unified and clarified for him, enabling him to make calculations for new types of machine at greatly reduced labor and thought. He found that with the same assumptions the tensor equation gave identical answers as other methods.

At 6:15 p.m., the chairman called on Prof. V. Karapetoff for concluding remarks. Professor Karapetoff declared this conference as one which will be remembered for many years to come as an historic session, ranking in character and importance with a few other historic sessions of the Institute, particularly the one in which the complex quantity theory and applications were first presented to the Institute as constituting a revolution in a-c calculations.

Research in Engineering Schools

By Vladimir Karapetoff, Chairman

The attendance at the conference on research in engineering schools was about 50 and would have been much larger if it were not for the conflicting conferences on schoo curricula and on tensor analysis. Professor Ernst Weber spoke on important research contributions by faculty members o colleges of electrical engineering in Germany, Austria, and Switzerland. The questior why original contributions to the science and art of electrical engineering by members of the faculties of American engineering schools lagged behind European schools was discussed from the floor by several teachers and practicing engineers. The consensus of opinion was that in both private and state-controlled colleges in this country emphasis is laid on elementary teaching rather than on research, and neither sufficient funds nor leisure is available for the latter. In Germany, where all technical universities are entirely controlled by the national government, head professors in each school are appointed from among mature practicing engineers who have already contributed to the progress of the art and who continue research in their chosen fields.

The committee on research of the A.I.E.E. has distributed lists of suggestions for research in colleges and some opinions were expressed at the conference as to the usefulness of such lists. The majority of those

present seemed to consider such lists of topics useful and desired their continuation. It was felt that student research should be promoted mainly for the development of interest and technique rather than for any important results to be expected.

Finally, the question of research and advanced study on the part of faculty members came for discussion, but apparently there were only a few in the audience who cared to contribute to this topic, so that the general impression was created that very little original research was going on among faculty members in this country. Dr. J. B. Whitehead of Johns Hopkins University spoke at length about his researches in cable insulation, the handicaps under which he is working, and the financial assistance received from the industry.

In closing the conference, Chairman Karapetoff expressed the opinion that apart from an individual interest in this or that research topic, the general function of the electrical engineering faculties should be to act as middlemen and interpreters between the profession and the industry on the one hand and the pure auxiliary sciences on the other hand. It is the duty of teachers of electrical engineering to follow closely at least one topic in the industry and also keep in touch with such branches of pure sciences as bear upon it. In this manner new developments in mathematics, physics, and chemistry are put in a form in which practicing engineers can use, and unsolved problems of the industry are put in such form that pure scientists can work on them. While a teacher in electrical engineering is concerned with the present status of the industry in his elementary teaching, he should have sufficient imagination and prophetic vision to anticipate the needs and the trends of the industry sufficiently far ahead to help create tools for the new developments and to prepare his best students for properly handling such new problems years hence.

Conductor Vibration

By A. E. Davison

Forty members attended the conference on conductor vibration held under the chairmanship of D. M. Simmons. Pre-arranged written discussions had reference largely to experience in the field which might be useful to members who were having similar experience, and who were seeking solutions for their problems. Among the prepared discussions were the following:

Pre-Stretching of A.C.S.R. Cables, A. E. Silver.
Oval-Shaped Cross-Section Conductors—Reports of Comparative Observations, M. E. Noyes and G. W. Stickley.
Analysis of Traveling Waves and Effects of Festoons Upon Them, W. B. Buchanan.
Conducting Clamps for Aluminum Cables; Life and Comparative Tests, E. Hansson.
Practical Long Time Experience With Loops and Festoons, A. H. Lawton.
Are Wire Failures Progressive Within Suppressive and Reinforcing Equipment? F. W. Deck.
Anti-Vibratory Clamps, C. L. Fortescue.
Experience With Vibration (Australia), E. Bate.

It is intended that these submissions along with some others will be mimeographed and circulated within the power transmission and distribution committee. It is also intended that members who are interested in any of the subjects mentioned may secure copies of the submission referred to, by writing to D. M. Simmons, chairman.

Discussions were introduced by E. M. Wright and W. S. Peterson, regarding experimental work and practice on the Pacific Coast. These discussions centered upon the methods used in connection with studies and experiments within wind tunnels upon vibration of cables, wherein an attempt is made to simulate field conditions.

Other features which came out in the general discussion were importance of details in the methods of clamping conductors, and such theoretical considerations as absorption within the span of cables and at discontinuities.

The introductory discussions which were submitted in writing are briefly as follows:

Considerable evidence has accumulated within at least one large operating system that redistribution of static stresses within A.C.S.R. conductors by pre-stretching adds materially to the life of the outer aluminum wires. They carry less static stresses, and therefore are in a position to resist successfully fortuitous bending stresses resulting from vibration.

A number of experiments have been made which indicate that there is a considerable alteration in the incidence of vibration under natural conditions, if oval-shaped conductors are used as compared with circular strand conductors. This statement is also true if 2 or more conductors are used for each phase regardless of whether they are fastened together at various points in the span so as to prevent wear. Although the incidence of vibration is altered, nevertheless, there are certain natural conditions by which vibration is set up within these specially designed conductors.

Some definite data was placed before the meeting regarding suppressive effects of festoons upon traveling waves and surges artificially introduced into conductors. These units compare favorably with field observations of suppressions under natural conditions where festoons have been used in a practical way. The better suppressions are of the order of 40 per cent.

Since a number of utilities are experiencing a reduction with age of conductivity at clamps, the recording of some experiments in Baltimore with A.C.S.R. splices over long periods would assist operators who have this problem before them. It was suggested that cold-flow pressing of joints with a liberal coating of red lead or some other compound which will reduce to a minimum oxidation within the splices is preferred practice. Twisted sleeves seem to lose their conductivity to a very considerable extent after a few years of use.

Representatives of 2 different utilities record experience as to the effectiveness of festoon or loop in reinforcing conductors where vibration troubles have developed, and in reducing to a negligible quantity over 10 year periods actual breaks of cables within a given system due to vibration.

Distribution Transformer Protection

By K. B. McEachron, Chairman

Approximately 35 engineers were in attendance and they discussed very freely certain aspects of protection of distribution transformers, with particular reference to the results of the interconnection of primary arrester ground and secondary neutral conductor. There was considerable discussion of the results of this interconnection and also a statement made that the secondary troubles were practically nil.

There was also discussion of the question of grounding the transformer tank and the part to be played by the isolating gap which is now being used on rural distribution transformers. Farm line transformer protection, and whether or not to use cutouts and lightning arresters, came in for their share of discussion. There was also a brief mention of the use of plain gap protection for distribution transformers and the relation which this might have to hazard from power currents to a customer connected in the secondary circuit.

Electrical Engineering Curricula and Educational Methods

By H. W. Bibber, Chairman

The conference on electrical engineering curricula and educational methods turned out to be quite in accord with the advance notice published in Electrical Engineering. Discussion was free, often spirited, and taken part in by nearly all present. At the conference, an agenda comprising some 26 questions was handed out. Those discussed were ones in which a large percentage of the group present were interested. The general trends of the discussion on the chosen topics follow.

Curricula

What policies can be adopted by schools to ensure a continuing process of inquiry, experiment, evaluation, and adjustment in the curriculum?

All agreed that changes were essential to meet the altered industrial and social conditions as well as technical advances. Changes in any one particular course or year of the program should not occur too often. Specific examples of policies were: preparation of a "5 year plan" of curriculum changes, the plan itself being subject to revision each year; review of the course content of all courses in the curriculum every 3 years with suggestions as to desirable revisions.

To what extent is an articulate philosophy of engineering education necessary in building curricula?

Many believed that more articulate discussion of the philosophy should take place in faculties. Agreement among men on the faculty may be assumed which does not exist, or one may be deceived as to how definite a philosophy certain instructors have. Great need exists for each teacher to see how what he does fits into the general plan.

It was suggested that an engineering course should aim at the cultivation of: desirable habits of mind or thought; moderate degrees of manual skill in drawing, the use of tools, and arranging apparatus in experimental set-ups; knowledge of the most fundamental principles of physics and a few facts about materials.

How much social orientation should be provided for engineering students, and how should it be done?

The general conclusion was that a considerable proportion of the curriculum (20

per cent was mentioned) should be devoted to social studies or the humanities. These should, however, be well taught and the professional departments should be much concerned as to the standards, methods, and objectives of instruction in such courses.

A strong plea was made for the consideration of an electrical engineering course as general education, in the light of the later careers of electrical engineering graduates, and the proportion of the total who actually follow technical electrical engineering work.

Since the electrical industry seeks men for positions in which the technical aspects of the job are not exacting, should departments of electrical engineering offer 2 curricula, 1 highly technical and the other providing more business subjects?

There is a growing tendency to recognize the fact that there are not only recognized divisions of the technical field, but there is a further superposed division of the entire field into a highly technical and a semi-technical part. A great many graduates land in jobs of the latter sort. Hence, many schools are providing technical options and administrative or business options in the junior and senior years. There was a feeling that administration of the combined business and electrical curriculum was better left in the hands of the electrical engineering department than to create a new "administrative engineering" course.

Educational Methods

How much time should be devoted to inspection trips and at what period of the 4 year curriculum should they come?

Many schools suffer from geographical location as far as good trips are concerned. However, the general feeling was that these trips are beneficial to students if not too concentrated. Usually going to local plants about once a week gives good results. The way in which trips are handled will largely determine their value. One procedure recommended was: (1) preparation by lecture or reading matter; (2) careful organization of trips, and sequence of steps in process, with sufficient guides so that there will be 1 guide to every 5 or 6 students; (3) tests to determine whether students have grasped important aspects of the plant; and (4) a report on some specified aspect, not a general report.

Does instruction by the project method, or the use of individualized assignment, prove successful in electrical courses?

If the number of students per teacher is not excessive this method may be very successful. It requires that courses be carefully laid out with adequate text reading material so that no lectures are necessary. Problems of graded difficulty are used. Laboratory work is successful if not too many men have to work in a group. Another aspect is to allow students to work out their own methods and schedule of laboratory work, requiring only that the results be turned in at a certain time.

Are comprehensive examinations of value only in honors courses or can they be employed with benefit in regular curricula?

Comprehensive examinations are being tried in some schools. There was one report to show that their value as an indicator of a student's grasp of a whole field was no better than the grades obtained in the individual courses in that field. As an instructional procedure, however, there seemed to be more agreement as to their value.

How successful are objective type examinations in electrical subjects in which so many principles are covered that problem type examinations are quite lengthy?

Objective type examinations were reported as successful when used to give a short quiz at the beginning of an hour, before new material was taken up. Doubt was expressed as to the value of long objective type tests, as the electrical field is one in which problems can be given that are objective in character, and which thoroughly explore a candidate's knowledge.

Is there merit or value in the use of a reading period of a week or 10 days free time before final examinations?

The reading period is a relatively new idea, and has not been widely tried out. There was one enthusiastic report of its value. In this case 3 weeks out of 15 were used as a reading period. Problem assignments were made for the period which involved the principles covered in text and lecture during the preceding 12 weeks. Many conferences with students were held during this period, and considerable benefits were evident.

Subcommittee May Issue Lightning Reference Book

Lightning and its effects on electric power systems and apparatus have been under investigation for more than 20 years and during that period many articles of interest and value have been published in technical literature thus providing a cumulative record of how the lightning problem has been attacked and partially solved. In the course of an extensive canvass of the literature being carried on by the lightning and insulator subcommittee of the A.I.E.E. power transmission and distribution committee, more than 250 papers and technical articles comprising some 1,300 printed pages have been indexed for the period 1918–35. In these papers are considered lightning characteristics, theory, laboratory and field tests, and protective devices used and their application and performance.

Recognizing the value of a conveniently bound volume in which would be reprinted all important papers that have been published on the subject of lightning, the subcommittee is considering the project of republishing these papers in one volume, provided there would be enough demand for this volume to enable the cost of production to be underwritten. If issued, the contemplated volume would be similar in size to the A.I.E.E. Transactions, comprising some 1,300 9 by 12 inch pages, making up a book about $2^1/_2$ inches thick. This book would include the full text and illustrations of all lightning papers published from 1918 to 1935 by the A.I.E.E., in addition to those published in the *General Electric Review*, the *Electric Journal*, *Electrical World*, and the *Journal* of the Franklin Institute, and perhaps the English translations of a half dozen or so of the more important foreign papers. A comprehensive cross-reference index of authors' names and paper titles of course would be an important part of the volume.

Advance Orders Required

The work of producing this lightning reference book has reached the point where it is necessary to know definitely how many copies of such a book could be sold, before any further steps could be taken. It is tentatively estimated that the price of the volume to members of the Institute will range from $5 up, depending upon the quantity to be produced and the number of papers to be included. It is expected that the book could be made available within one year.

For the benefit of interested persons and to assist the committee in its work, there is included on page 4 of the advertising section of this issue a convenient coupon that should be filled in and mailed at once.

Engineering Index to Solicit Funds

Organization of the Engineering Index National Committee is now sufficiently near completion to begin the actual solicitation of funds to be used in maintaining and expanding the Engineering Index, according to the announcement of its chairman, Dr. Frank B. Jewett (A'03, F'12, and past-president), president of Bell Telephone Laboratories, Inc., and vice president of the American Telephone and Telegraph Company. Plans for the expansion of this service were outlined in Electrical Engineering for March 1935, page 345.

With regional subcommittees, the group includes more than 125 representative engineers, educators, and industrialists in various sections of the country. These members will approach, in the next few months, several hundred leading industrial corporations for the purpose of raising funds.

The keynote of the program has been stated by Dean Collins P. Bliss of the college of engineering of New York University, who is president of the Index. "The program which the fund will make possible will be carried out over a 5-year period. Not only will the continued usefulness of the Index be insured for that period, but by the end of that time it will have become wholly self-supporting. And, what is equally important, the Index will have been extended to an ever-widening circle of users through a reduction of the subscription rates until the rates have become only about half of what they are now."

The Engineering Index, for which the fund is being raised, is unique in its field. It may be described as a virtually complete catalog, with annotations, of current technical literature in all branches of engineering. It is complete, descriptive, prompt, and accurate. It is published in 2 forms: the complete annual volume; and the cumulative daily and weekly card service, including 280 subdivisions. Altogether, about 2,000 publications from 40 countries and in 20 languages are reviewed by the editors.

A.S.T.M. Publishes Index to Standards. The index to "A.S.T.M. Standards and Tentative Standards," as of January 1, 1935, has been issued by the American Society for Testing Materials. All of the A.S.T.M. specifications and tests are listed in the index alphabetically under subject headings. A list in numeric sequence of the serial designations is also included. Copies of the index are available from the American Society for Testing Materials, 260 South Broad Street, Philadelphia, Pa., or from the office of the American Standards Association, 29 West 39th Street, New York, N. Y.

Review of Legal Education for 1934. The annual "Review of Legal Education in the United States and Canada for the Year 1934" has been issued by the Carnegie Foundation for the Advancement of Teaching. Copies of this review may be had without charge upon application by mail or in person to the office of the Foundation, 522 Fifth Avenue, New York, N. Y. This review, a $7^1/_4$ by 10 inch booklet, some 70 pages in length, contains material of interest not only to the legal profession but to all educators and to those interested in the advancement of any profession. Schools of engineering and architecture, medicine, and law are considered in relation to such problems as state licensing of the individuals in these professions. Information also is presented on the historical development of universities, and the present status of professional members engaged in teaching. The data given on progress in bar admission requirements should be of value to engineers interested in licensing within their own profession.

Inventor of Schafer Method Dies. Sir Edward Albert Sharpey-Schafer, inventor of the Schafer method of artificial respiration, died March 30, 1935, in his Northumberland home in England, at the age of eighty-five. He had an international reputation in the fields of histology and physiology. He was distinguished for his discoveries regarding muscular action. In 1903 he devised the plan of resuscitation, also known as the "prone pressure" method, that has resulted in the saving of untold thousands of lives of persons apparently drowned or suffocated.

Chemical Industry Medal Awarded. The American section of the Society of Chemical Industry has announced that the award of the Chemical Industry Medal for 1935 has been made to Dr. E. R. Weidlein, director of the Mellon Institute of Research, Pittsburgh, Pa. The award is made annually to a person who has made a valuable application of chemical research to industry. Presentation of the medal will be made at a meeting of the Society in the fall.

American Engineering Council

Government Work Relief Program

Following are excerpts from the current "news letter" of American Engineering Council:

The Public Works Administration's recent news release affecting their portion of the work relief program is of particular interest to the engineering profession. The following changes in P.W.A. policy are emphasized for the benefit of engineers who may be affected.

The P.W.A. will now make advance payments of not more than 15 per cent of approved projects to enable the applicant to pay for architectural, engineering, planning and legal fees, cost of surveys, and other preliminary steps toward the launching of actual construction. It is no longer necessary for engineers and others furnishing professional services to wait for actual construction to begin before they can be paid for such services.

The responsibility for fixing wage rates on P.W.A. projects has been placed on the borrower and recipient of the grant made in connection with loans. This policy makes it easier to adjust wage rates to fit actual conditions in each community.

The regulation requiring 90 per cent of workers on each project to come from relief rolls is retained; but it is now stated that exceptions may be made on individual projects with the approval of Harry L. Hopkins.

All of these are important concessions likely to be of much assistance to the entire engineering profession.

Comparatively few opportunities for engineering employment are expected to develop in Washington, but much activity is expected in the states under the direction of state administrators of the Works Progress Administration. State organizations are being formed now and engineers seeking employment should be advised to contact the state administrators of the W.P.A. Instructions to the state administrators tell them not to engage in or make use of politics in connection with the execution of the work relief program, but appointments and assignments indicate that political sponsorship in the state may be as necessary as similar approval in Washington.

Engineers serving in administrative, consulting, professional, and supervisory capacities will be paid salaries and fees slightly less than those prevailing in the area where they are employed. Engineers on relief rolls must work for a maximum of $94 per month until they reach the place where they can "strike out for themselves."

The National Youth Administration, newly created, will provide part time employment for young people between the ages of 16 and 25 inclusive from "relief families." Consequently, this is not a program for unemployed young people from "non-relief families." High school students will be paid $6 per month, college students $15 per month, and those doing graduate work proportionately.

The Federal Housing Administration, under the plan of insuring loans for industrial rehabilitation, is pushing the possibilities of plant modernization. Our understanding is that there are many applications involving engineering improvements in machinery and equipment. The F.H.A. does not supply the money for these, but insures loans from other sources. This development is of considerable engineering significance in so far as it improves the possibilities of credit for loans for capital goods.

Survey of the Engineering Profession

The co-operative survey of the engineering profession was an assured success when the final deadline for receipt of questionnaires fell on July 8. Although it is as yet impossible to arrive at the exact number of blanks received, the number is ample to provide a good cross section of the engineering fraternity and to chart its situation through the depression years. As soon as the pressure of urgent federal work permits, the Bureau of Labor Statistics will tabulate the results so that complete data will be available.

Plans for the final tabulation are reported in an article appearing in the July 1935 number of *Civil Engineering*, by Allen P. Richmond, Jr., quoted in part as follows:

"While the exact details are not finally settled, it can be said in general that all the information in the questionnaire will be transferred to punched tabulating cards. The Bureau of Labor Statistics has devised code systems by which this information can be recorded by punching on a card $3^1/_4$ by $7^1/_4$ inches. Once punched, the cards are fed through sorting machines, which can be set to count any particular item desired. Correlations can be established at will, such as "How many civil engineers, graduates of a college with a bachelor's degree, are employed by municipal governments?" or "How many mechanical engineers working for the government are under civil service?" The Bureau is planning a series of such correlations according to states, and is selecting for the first tabulations the correlations which could be of the most immediate value. There is considerable congestion at the bureau because of the great demand for statistics on other employment situations, but it is now anticipated that the results should be available early this fall.

"One very interesting fact regarding the individual questionnaires is that almost all engineers signed their names, thus enabling apparent discrepancies to be straightened out and other necessary editorial work to be done by correspondence. The questionnaires received to date have been completely filled out, and it is anticipated that the resulting statistics will be authoritative."

Other A. E. C. Items

Council's inquiries as to the participation of engineering societies in public affairs have produced many interesting letters and suggestions which are helping in the compilation of a record of experience in this important field. Various explanations are offered as to the reason why engineers, having made an inestimable contribution to the general welfare in their technical work as individuals or as a profession, do not appear more in the general field of public affairs. The system of public affairs committees which Council is developing, together with the more aggressive action of engineering societies through the country, may tend to establish natural channels whereby engineers will be drawn into public matters with the aid of their colleagues, rather than fighting their way as individuals without help, encouragement, or objectives other than their own.

"The Formation of Capital," a new study by the Brookings Institution, completes the triology begun in "America's Capacity to Produce" and "America's Capacity to Consume," the findings of which are correlated and given added significance when viewed in their relation to the capital structure. As with the earlier reports, this study has been summarized in a pamphlet by the Maurice and Laura Falk Foundation of Pittsburgh, Pa. Council has a limited supply for distribution to engineers interested in new concepts of economy.

A study of business cycles has been reported in the July 1 bulletin of the National Bureau of Economic Research, 1819 Broadway, New York, N. Y. (price 50 cents). This analysis seeks to make use of the improved and extended accumulation of statistical data in recent years, in revising past theories of cyclical behavior.

News For State and Local Engineering Societies

Continuing along the lines of last month's letter, Council is giving separate attention to the work of state and local engineering groups. Many individual engineers and secretaries of societies have written to Council to report their news and it is hoped they will make this a regular practice. New types of public projects, promoted by engineering societies are particularly well worth knowing of at this time. For example:

A study of the existing foundations of the City of New Orleans is being carried out as a white-collar project under F.E.R.A., according to the secretary of the Louisiana Engineering Society, which group is sponsoring the program. Work is under supervision of 4 prominent engineers. Co-operation of engineers, architects, contractors, and public agencies has been enlisted in the assembly of data from borings and other investigations. The work is employing 25 engineers, architects, and draftsmen with additional clerical help. Engineering societies wishing to have similar work done in their areas may consult local relief and works progress officials.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or to reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Emergency Practices in Resuscitation

To the Editor:

The following comments on artificial resuscitation were inspired by the paper in ELECTRICAL ENGINEERING for July 1933, pages 475-7, entitled "Resuscitation by Countershock" by W. B. Kouwenhoven and R. D. Hooker, which discusses in a very interesting manner the effect of electric current in the bodies of rats.

Obviously, experiments cannot be made on human beings to determine the effect of electric current through the body, or organs of the body, such as have been made on rats, so that we may be a long time learning more along this line or interpreting what we already know into practical use in emergencies.

However, in the field of emergency practices more should be written and discussed; not only in the hope of improving technique as we now understand it but of emphasizing the most important points of the best practice at present known, and teaching the whole public that technique and the principles back of it.

Very often we find trained first aiders, trained to go through certain motions, who do not know what those motions are intended to do in order to produce the final result; hence, in an emergency, confronted with complications or unexpected conditions, they are at a loss, confused, fail, or at least lose valuable time.

Everyone should fully understand that for artificial respiration the purpose is to so compress the abdomen as to force its contents gently up against the diaphragm, pushing it upward to form just enough compression in the chest (just a little more than atmospheric pressure) to cause the "air" to be "exhaled," not *forced* from the lungs. Operators can work intelligently only when they understand how the diaphragm raises and lowers normally, and what causes it to, and how the abdominal muscles assist by compression of the abdomen, for deep breathing.

They should understand more of how stimulants act on heart and respiratory nerve seats; yes, and how carbon dioxide, and oxygen, and oxygen-carbon dioxide mixture act; then they can be expected to administer these intelligently and avoid errors.

They should know more about blood circulation and its physiology and functions. They should know about the post-asphixia and post-strangulation pneumonia danger, too. They should know that an expulsion from the bowels is *not* a proof of death, but is to be expected as a probable result.

Let me relate briefly 3 cases to illustrate.

A lineman contacted a pair of 2,400 volt conductors and dropped unconscious in his safety strap. A fellow-worker, who had been *taught*, as well as trained, pushed the victim's head forward (face downward) where he hung; swung 3 parts of the hand line around the man and pole, and rhythmically squeezed his abdomen against the pole until others ascended and prepared to lower him, and continued on the way down. The time interval before help arrived, and other circumstances, were such that nothing else would have saved the man's life. Any other attempt would have failed.

Another lineman received a minor and momentary shock; a whole crew was at hand, and he was on the ground at the time; they started artificial respiration and called a doctor who came quickly. The doctor administered straight oxygen, instructing the men to continue while he went for something else. The colon expelled and the men considered, had heard, that that indicated death and quit, put him on his back. They remarked afterward that black areas continued to spread over the body, proving death.

Too much oxygen could inhibit voluntary breathing; with no stimulation of respiratory impulse or heart action, practically no circulation, and the body rapidly chilling. The spreading cyanosis should have been encouraging rather than discouraging, but should have suggested to a *taught* man that the body should be covered and the limbs rubbed to assist circulation, because what use is the oxygen drawn into the lungs if it is not distributed and the carbon dioxide returned and discharged?

A gumdrop lodged at the entrance to a man's windpipe; he was strangling. An executive at hand lost no time but, encircling the man's abdomen, gave a quick squeeze with the desired result. If time had been lost waiting for a doctor or while other methods were tried, the lodgement probably would have become tightened and the doctor might have been too late, as has often been the result. This executive used the right idea instantly, without discussion, and probably saved the man's life.

At least the first case described above is the result of what I am advocating, the second case the result of manual training

Table I

Item							
With Wind Loading							
1. z	=	0.082					
2. S-c	=	0.539					
3. T_1'	=	8,672					
4. T_s'	=	8,312					
5. D'	=	11.4					
Cable Unloaded							
6. z	=	0.07	0.08	0.09	0.10	0.12	0.14
7. S-c	=	0.286	0.373	0.473	0.584	0.841	1.144
8. T_1	=	7,610	6,700	6,000	5,440	4,590	3,990
9. T_s	=	7,260	6,350	5,640	5,080	4,230	3,630
10. D	=	8.3	9.5	10.7	11.9	14.3	16.7
11. $T_s' - T_s$	=	1,052	1,962	2,672	3,232	4,082	4,682
12. S = item 2 + c	=	644.6					
13. $S\left(\frac{T_s' - T_s}{AE}\right)$	=	0.1055	0.1967	0.2679	0.3240	0.4092	0.4694
14. Items 7 − 2 + 13	=	−0.147	+0.031	0.202	0.369	0.711	1.074
15. Item 14 + (αS)	=	−23.8	+5.0	32.7	59.8	115.0	174.0
16. $\theta = \theta_0$ + item 15	=	−13.8°	+15.0°	42.7°	69.8°	125.0°	184.0°

only. The last case was not a comedy, at least it was not for a while for all present.

First aid textbooks do not do the trick, even when used. Medical men do not seem to realize that it *can* be done, this teaching of lay persons, but some day these things will be taught through required courses in every school in the country; why not now? Cases like the first and third here occur occasionally; those like the second are in the majority; can't we help?

We are not discussing what may be the result of passing a current of electricity through the heart to convert fibrillation, nor the use of adrenaline or heparin; but the layman can absorb, can understand, at least enough to govern him better; of much he is not now taught and retaught.

Many papers have been written; most contain material beyond the purpose now suggested here; all omit some things; *none* reach more than relatively few people; can our industry supply the need? I think it can and should. We should teach our employees in the electrical industry more, not just train them in a manual method; and we should see that the entire public is taught as much as possible; and finally, we should keep the knowledge before our men all the time, so in an emergency they will be ready to act at once, and regardless of circumstances.

Very truly yours,

J. M. Buswell
Electrical Inspector,
San Joaquin Light and Power Corp., Fresno, Calif.

Transmission Line Catenary Calculations

To the Editor:

The paper by D. O. Ehrenburg, "Transmission Line Catenary Calculations" (Electrical Engineering, July 1935, pages 719–28) develops a very original method of making sag and tension calculations. As far as I know his method of approach is entirely new, and I have not previously seen the point brought out that the values corresponding to horizontal span length and difference in elevation of supports for pure vertical loading are different with wind loading.

In reading over the paper, the following method of calculating stringing curves occurred to me as a substitute for the graphical method given in figure 3 of the paper. Referring to the accompanying table I, the first 5 items, which are for wind load conditions, are obtained by interpolation from table II of the paper, for the initial value of $Z = 0.082$, as determined in example I. The next 5 items are copied directly from table II, light load conditions.

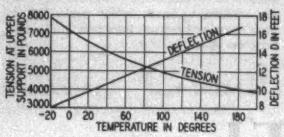


Fig. 1

The last 6 items are added to obtain temperatures without resorting to the graphical method. By plotting items 8 and 10 as ordinates against item 16 as abscissae, the stringing curves of the accompanying figure 1 are obtained.

Yours very truly,

H. J. McCracken, Jr. (A' 27)
Department of Water and Power,
City of Los Angeles, Calif.

To the Editor:

The method of calculating stringing curves proposed by H. J. McCracken, Jr., in table I of his "Letter to the Editor" (reproduced above), strikes me as being very ingenious. In reply to this letter, I would like to bring out the following points:

1. In my "example 1," the right-hand portion of the T_s' curve was plotted merely in order to find the maximum deflection, which occurs at wind load and 150 degrees Fahrenheit. In many problems I need only 2 points on the T_s' curve, as is the case in "example 2," for instance.

2. Mr. McCracken's value of T_1' is *nearly*, but not exactly, equal to the working tension. In table I of his letter, $T_1' = 8{,}672$ pounds, whereas the working tension is 8,650 pounds. However, this represents only a small error. In the case of "example 2" Mr. McCracken's method is even more accurate.

3. As it now stands, his method will work best in the case of long flat spans, worst in the case of very short steep spans.

4. For the first part of Mr. McCracken's calculations (wind load) my tables of functions cannot in general be used. To remedy this as well as the objection stated under 2, I would suggest that the wind-load calculations be carried out by graphical interpolation from values obtained from the tables of functions.

Very truly yours,

D. O. Ehrenburg
U. S. Bureau of Reclamation,
405 U. S. Custom House,
Denver, Colo.

Decrement Curves for Power Systems

To the Editor:

In the paper "Decrement Curves for Power Systems" by C. F. Dalziel in the February 1934 issue of Electrical Engineering, pages 331–8, the author presents a set of decrement curves intended to extend the range of application of the standard decrement curves, and one of the new factors introduced is the effect of resistance in calculating the magnitude and rate of decay of the fault current.

It would seem, however, that while this factor has been considered in relation to the a-c component, the effect on the rate of decay of the d-c component has been neglected, since the same time constant has been employed as in the case of the standard decrement curves where the direct component of fault current at any time t is given as

$$I_{dc} = \sqrt{2}\, i''_a e^{-t/0.15}$$

The initial value of the d-c component is, of course, determined by the point of the pressure wave at which the short circuit is applied, but thereafter it decays in an exponential manner corresponding to the time constant of the armature circuit, which is given by

$$T_a = \frac{x_2 + x_e}{2\pi f(r_a + r_e)}$$

where

x_2 = negative sequence reactance of machine

x_e = external reactance to the point of the fault

r_a = internal resistance of armature circuit

r_e = external resistance to the point of the fault

On figure 1 the writer has plotted the value of the d-c component at the end of the first half cycle expressed as a percentage of the initial value for various values of the ratio R/X, where

$R = r_a + r_e$

$X = x_2 + x_e$

This curve shows in a very striking manner the effect of resistance in reducing the peak value of the short-circuit current since even if the ratio R/X is as low as 0.2 the magnitude of the d-c component at the end of the first half cycle is reduced to 53

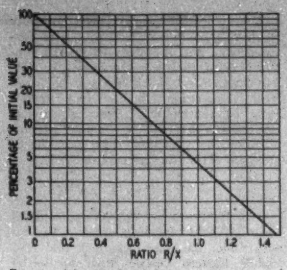


Fig. 1. Magnitude of d-c component at end of first half cycle

per cent of its initial value, while if the ratio R/X is 1.0 the magnitude of the d-c component at the end of the first half cycle is less than 5 per cent of its initial value and can be neglected.

It will be seen, therefore, that the effect of resistance on the rate of decay of the d-c component is very considerable, and the writer feels that the author's curves should be modified so as to take this effect into account.

Very truly yours,

W. H. Miller
139 Birchfields Road,
Followfield,
Manchester 14, England

To the Editor:

The curves given in "Decrement Curves for Power Systems," Electrical Engineering, February 1935, pages 331–8, were prepared to permit an estimate of the probable maximum and minimum short-circuit currents for various times after fault for 3 phase, line to line, and line to ground short circuits. Certain average machine and system constants were used in their preparation. Both the d-c time constant of the armature and the subtransient time constant were given average values, discussed by C. F. Wagner and S. H. Wright, "Calculation of Short Circuits on Power Systems," presented at the A.I.E.E. winter convention, New York, January 25–29, 1932. The values used were the same as those used by W. C. Hahn and C. F. Wagner, "Standard Decrement Curves," A.I.E.E. Transactions, volume 51, 1932, pages 353–61.

Mr. Miller's correction, introduced in his letter above, will affect the d-c component, and hence slightly reduce the maximum current curves only. This is a refinement, and could well be considered in decrement curves. However, since this time constant varies depending upon the type of fault considered, it will be necessary to prepare at least 2 sets of curves for estimating the maximum currents. At the time of constructing the curves, I did not think that such a refinement was justified, due to the great number of assumptions and approximations already made. It should be noted that the use of the published curves will result in safe values, and this correction will only reduce the maximum current curves slightly; therefore, pending the construction of more elaborate curves, I suggest that the curves be used as published. Special cases should then be reconsidered, using the actual time constants and resistances and reactances for the particular problem.

Very truly yours,

Charles F. Dalziel (A'33)
Associate in Elec. Engg. Dept.,
University of California, Berkeley

Confusion Exists in Rating of Low Loss Insulation

To the Editor:

May it be permitted through the medium of Electrical Engineering to call attention to a condition of confusion prevailing in the insulating material field. Although the efforts of the A.I.E.E. have resulted in good definitions of the electrical characteristics of insulating materials these have evidently not been put into practice by manufacturers of insulating materials.

In designing ultra-high frequency apparatus, requiring the best low loss insulating materials, it has been found that such confusion exists in the data published by the manufacturers that these data are completely valueless for comparative purposes. Whether this is due to carelessness on the part of engineers computing the values, or whether it is due to ignorance on the part of sales departments, is hard to say. In one case (see No. 3 in table I) it is clearly a mistake by the engineers making the test.

In cases where there are no special mechanical or thermal considerations the loss factor of a low loss insulating material may be used as a figure of merit. The loss factor $p' = k \tan \delta = k \cos \theta$; where k = dielectric constant and $\delta = 90 - \theta$. The term loss factor is proper as it takes in all variations of the material due to temperature and other physical and chemical factors. The loss per cubic centimeter may thus be expressed as:

$$p = 5.55\ 10^{-13} f e^2 k \tan \delta \qquad (1)$$

or

$$p = 5.55\ \ 10^{-13} f e^2 p' = A\ p' \qquad (2)$$

where f = frequency, e = voltage gradient = volts per centimeter, and A is a constant. For given conditions p' is the only variable in this loss equation and may thus rightly be called the loss factor.

In table I have been compiled values of power factor, dielectric constant and loss factor of the best commonly used low loss insulating materials. As may be seen from columns 5 and 6 representing, respectively, the loss factor as given by the manufacturer and the actual loss factor computed from power factor and dielectric constant, there is considerable variation. It is often impractical for the designer of electrical apparatus to make his own tests on the various materials, and one must rely on such data as furnished by the manufacturer of the insulating material. From this table it is easily seen that if one is to meet the exacting specifications laid down by modern requirements the data available are worse than valueless in that one may be led into making serious mistakes by following same. In interviewing the sales engineers of some of these manufacturers one is impressed by the fact that every one claims superiority for his product over all the others. Some manufacturers even publish comparative data of doubtful value due to its inexact and careless preparation.

Due to the growth of short-wave radio communication and new materials developed the above problems have become of increasing importance. Even the latest handbooks do not give reliable data on all materials. It seems therefore that this should be a welcome opportunity for the A.I.E.E. to compile and publish reliable comparative data. It may be stated as a mitigating circumstance for the manufacturers of insulating materials that in most cases the errors shown in the table are to their own disadvantage. It further illuminates how unfamiliar most engineers are with the proper use of the power factor. It would seem from this that the practice of stating the power factor in per cent should be entirely discontinued as it is here that most mistakes are made.

Very truly yours,

Magnus Björndal (A'25)
807 Summit Ave.,
Jersey City, N. J.

Table I

1 No.	2 Material	3 Power Factor 1000 kc. 17 deg C.	4 Diel. Constant	5 Loss Factor Given by Mfrs.	6 Correct Loss Factor	7 Source of Information
1	Isolantite	0.00181	6.1	1.05	0.011	Isolantite Bull. 100-F.
2	Mycalex	0.003	6.1		0.0183	"Mycalex the Ins." Bull.
3	Mycalex	0.0017	6.2	1.05	0.0105	Rt. Test. Lab. Report No. 163, 286; 6-2-32.
4	Mycalex	0.0063	6.1		0.0384	Nat. Phys. Lab., London.
5	Victron "AA"	0.0006	2.5	0.15	0.0015	*Insulation Engineer*, v. I, Dec. 1933, No. 2.
6	Victron "AA"	0.0008	3.0	0.24	0.0024	"
7	Victron "K"	0.0012	3.5	0.42	0.0042	"
8	Victron "K"	0.0015	4.0	0.60	0.006	"
9	Hard rubber			1.6	0.16	"
10	Bakelite			3.6	0.36	"
11	X1B rubber	0.00414	3.74	0.42*	0.0155	Am. Hard Rubber Co.
12	X2B rubber	0.00386	4.3	0.39*	0.0166	"
13	Bakelite Gr. XXX	0.035	5.0	0.18	0.175	Synthane Corp. Bull.
14	Pyrex	0.00418	4.9		0.0205	Std. Handbook for Elec. Engrs., p. 485
15	Mycalex	0.002 (100 kc.)	8.0		0.016	"

* Designated as "power factor loss" by the manufacturer, but apparently is the power factor in per cent.

Personal Items

C. A. Adams (A'94, F'13, member for life and past-president) Lawrence professor of engineering, Harvard University, Cambridge, Mass., has, with his co-authors J. C. Hodge and M. A. MacKusick, received honorable mention in connection with the award of the 1934 A.I.E.E. national prize for best paper in theory and research, for their paper "High Frequency Induction Furnaces." Professor Adams was born in 1868 in Cleveland, Ohio, and graduated from Case School of Applied Science in 1890 with the degree of bachelor of science. In that year he became a draftsman with the Brush Electric Company, and in 1891 joined the teaching staff of Harvard, where he has remained since that date. At Harvard University, he was first an instructor, becoming assistant professor in 1896, and professor in 1906. Since 1914 he has held the chair of Lawrence professor of engineering. From 1919 to 1921 he was also dean of the engineering school. In 1905 he received the degree of electrical engineer from the graduate school, and in 1925 the university bestowed upon him the honorary degree of doctor of engineering. Professor Adams has carried on an extensive consulting practice and has conducted numerous investigations on electrical machinery, being particularly active in the electric welding field. He has served the Institute in numerous capacities, and was its president 1918–19. Among the many committees on which he has served are the standards and electric welding committees, of which he has been a member during the Institute's year just ending.

E. H. Bancker (A'23, M'30) central station engineering department, General Electric Company, Schenectady, N. Y., has been awarded the 1934 A.I.E.E. North Eastern District prize for best paper, jointly with his co-author E. M. Hunter (A'28), for their paper "Distance Relay Action During Oscillations." Mr. Bancker was born at Brooklyn, N. Y., in 1896, and after receiving the degree of bachelor of arts from Williams College in 1916, attended Massachusetts Institute of Technology for graduate work, there receiving the degree of bachelor of science in 1918. In 1919 he entered the testing department of the General Electric Company. In 1920 he spent a few months as assistant in the laboratory at M.I.T., becoming head of railway control tests for the General Electric Company in that year. From 1922 to 1926, he was engaged on relay design and application in the switchgear engineering department of the company, having charge of the design of induction type relays. After several months with the Turners Falls Electric and Power Company, he returned to the General Electric Company in 1927, entering the central station engineering department, where he has since remained. In this position he has specialized in power system protection, and in evolving methods of calculating power system stability. Mr. Bancker previously presented a paper before the Institute.

E. M. Hunter (A'28) central station engineering department, General Electric Company, Schenectady, N. Y., has been awarded the 1934 A.I.E.E. North Eastern District prize for best paper, jointly with his co-author, E. H. Bancker (A'23, M'30) for their paper "Distance Relay Action During Oscillations." Mr. Hunter was born in Portsmouth, N. H., in 1902, going to Worcester Polytechnic Institute for his engineering training. That institute awarded him the degree of bachelor of science in 1926, and the degree of electrical engineer in 1930. Mr. Hunter spent 15 months on the test course of the General Electric Company at Schenectady between his junior and senior years in college, and after graduation in 1926, continued for a few months on the test course of the company at Pittsfield, Mass., and at Schenectady. Later that year he entered the turbine generator engineering department of the company in Schenectady. Since 1928 he has been in the central station engineering department. For graduate work at Union College, Mr. Hunter was awarded the degree of master of science in 1931. He has previously presented papers before the Institute.

H. F. Forbes-Roberts (A'25) Saskatchewan manager of the Montreal Engineering Company, with headquarters in Regina, Canada, has been awarded the 1934 A.I.E.E. Canada District prize for best paper, for his paper "The British National Grid System." Mr. Forbes-Roberts was born on the Isle of Wight, off the southwest coast of England, and was educated at St. Johns College there. He served as pupil engineer with John I. Thorney-croft Limited, and later as plant and erection engineer for Vickers-Petter Limited, which brought him to Canada in 1912. He wandered west to the prairies, and securing a franchise in Arcola, one of the smaller Saskatchewan towns, built an oil engine generating station and distribution system, and operated a small light and power business of his own. In addition, he traveled over Manitoba and Saskatchewan selling engineering equipment and central station supplies, and as the country was in its formative period, was responsible for many of the smaller plant installations. In 1927 he joined the Calgary Power Company when they commenced operations in Saskatchewan, and was engaged on the construction of their system there. In Saskatchewan this utility is known as the Montreal Engineering Company, and supplies some 50 centers with electrical service. He is now in charge of the company's operations in the province. This year he is president of the Regina Board of Trade.

C. K. Gieringer (A'35) development engineer, Liebel-Flarsheim Company, Cincinnati, Ohio, has been awarded the 1934 Middle Eastern District prize for initial paper for his paper "A New A-C Null Indicator." Mr. Gieringer was born in 1907 at Miamitown, Ohio. He attended the University of Cincinnati from 1925 to 1928, and was enrolled in the co-operative electrical engineering course. As a co-operative student he established his own contracting concern. In 1928 he moved to Arizona and attended the University of Arizona, studying business. He returned to the University of Cincinnati in 1930 and at the same time became a co-operative student employee in the research laboratory of the Detroit (Mich.) Edison Company. He received the degree of electrical engineer in 1932. During the ensuing 2 years he was a teaching fellow at the University of Cincinnati, receiving the degree of master of science in electrical engineering in 1934. Since 1934 he has been employed as development engineer of physical therapy apparatus for the Liebel-Flarsheim Company. He is a member of Eta Kappa Nu, Tau Beta Pi, Sigma Xi, and the Institute of Radio Engineers. The prize winning paper was written while he was a teaching fellow at the University of Cincinnati.

E. W. Kimbark (A'27, M'35) assistant in electrical engineering, Massachusetts Institute of Technology, Cambridge, has received the 1934 A.I.E.E. North Eastern District prize for his paper "Experimental Analysis of Double Unbalances." Mr. Kimbark was born at Chicago, Ill., in 1902. From Northwestern University he received the degree of bachelor of science in 1924, and that of electrical engineer in 1925. From 1925 to 1927 he was with the Public Service Company of Northern Illinois, Chicago, first as substation operator and later as assistant in the testing laboratories. From 1927 to 1929 he was instructor in electrical engineer-

E. W. KIMBARK

C. K. GIERINGER

H. FORBES-ROBERTS

L. A. S. WOOD

E. M. HUNTER

E. H. BANCKER

ing at the University of California, Berkeley, becoming assistant curator, division of power, of the Museum of Science and Industry, Chicago, in 1929. During 1932–33, he studied at Massachusetts Institute of Technology, Cambridge, receiving the degree of master of science in electrical engineering in 1933. The following year he was research assistant in electrical engineering at M.I.T., becoming an assistant in electrical engineering in 1934.

L. A. S. Wood (M'24) chief commercial lighting engineer, Westinghouse Electric and Manufacturing Company, New York, N. Y., has been elected president of the Illuminating Engineering Society, assuming office October 1, 1935. He was born in London, England, and was educated at City of London School and the University of London. In 1895 he became connected with the Edison and Swan United Electric Light Company, Ltd., London, and, specializing in illumination, later became special representative handling street lighting problems in Europe for the Union Electric Company of London. Mr. Wood came to the United States in 1911 in connection with the introduction of the flame carbon arc lamp, and was shortly afterwards appointed arc lamp expert for the Westinghouse company at East Pittsburgh. From 1915 to 1920 he was with the George Cutter Company, South Bend, Ind., becoming district sales manager. When this company was absorbed by the Westinghouse company, Mr. Wood was made manager of the street lighting department, and in connection with this work traveled extensively, maintaining his headquarters at South Bend. At the time of his recent transfer to New York he was manager of the exterior lighting section at Cleveland, Ohio. An Institute paper by him was published recently.

James Burke (A'93, M'03, F'13, and member for life) has retired from the Burke Electric Company, Erie, Pa., of which he was chairman of the board of directors, after more than 30 years as active head of the company. Mr. Burke was born in London, England, and was with the General Electric Company and its predecessors at Schenectady, N. Y., from 1889 to 1894. He then engaged in consulting engineering, but shortly accepted the position of technical director and chief engineer with the Bergmann Elektromotoren und Dynamo Werke, Berlin, Germany. He returned to the United States in 1902, and 2 years later the company bearing his name was formed. Mr. Burke is known for his ability as an inventor, having received a number of patents which include designs for a generator winding by which 3-wire service from a single machine was made possible and a motor for operation on either a-c or d-c supply. His society memberships include The American Society of Mechanical Engineers, the American Welding Society, of which he is a charter member, and the Edison Pioneers. Mr. Burke was a member of the standards committee of the Institute 1914–19, and of the electrical machinery committee 1917–27. He served on the U.S. National Committee of the International Electrotechnical Commission as representative of the National Electrical Manufacturers Association from 1914 to 1930, and as representative for the Institute 1930–32.

E. R. Northmore (A'07, M'13, F'28, and past vice president) superintendent of electrical distribution, Los Angeles Gas and Electric Corporation, Los Angeles, Calif., was recently presented with a parchment scroll in commemoration of 42 years continuous service with the company. Mr. Northmore went to California in 1876, and was employed as an apprentice by the Los Angeles Electric Company in 1893, becoming superintendent of distribution in 1902. He served the Institute as a vice president 1927–29, and as a member of the power transmission and distribution committee 1928–29.

F. B. Crosby (A'07) electrical engineer, Morgan Construction Company, Worcester, Mass., has been elected president of the Worcester Engineering Society. Mr. Crosby was a member of the Institute's committee on applications to iron and steel production (formerly iron and steel industry committee) 1914–34, serving as chairman 1923–26, and during the latter period was also a member of the meetings and papers (now technical program) committee. He is a past-secretary of the local Section, and is a member of the Association of Iron and Steel Electrical Engineers.

W. S. Barstow (A'94, M'99, F'12, and Life Member) retired former president of W. S. Barstow and Company, and member of Barstow, Tyng and Company, Inc., New York, N. Y., has received the honorary degree of doctor of science from Columbia University, New York, in recognition of his "long, devoted, and highly successful career as electrical engineer and organizer of engineering knowledge in its manifold applications to the public service and public welfare." Doctor Barstow is a representative of the Institute on the library board of United Engineering Trustees, Inc.

E. B. Meyer (A'05, M'13, F'27, and president) chief engineer, Public Service Electric and Gas Company, Newark, N. J., has been appointed a representative of the Institute upon American Engineering Council for one year, following the policy adopted 2 years ago of the president serving as a representative during his term of office. Mr. Meyer was recently elected to serve the New York Electrical Society for the year 1935–36 as its first vice president.

K. A. Hawley (A'09, M'12, F'35) who has been chief engineer for the Locke Insulator Company, Baltimore, Md., since 1922, is now with the newly formed Victor Insulators, Inc., at Victor, N. Y. Mr. Hawley is a member of the Institute's power transmission and distribution committee, having served on it since 1930, and recently presented a paper on insulators to the Institute.

W. J. Shackelton (A'12) development engineer, Bell Telephone Laboratories, Inc., New York, N. Y., has been appointed to represent the American Society for Testing Materials on the new sectional committee on electric and magnetic magnitudes and units. Mr. Shackelton has been a member of the Institute's instruments and measurements committee since 1930.

B. M. Brigman (M'28) dean, Speed Scientific School, University of Louisville, Louisville, Ky., has been appointed a member of the city planning and zoning commission by the mayor, the term expiring 1938. Since 1930 Dean Brigman has been a member of the Institute's committee on legislation affecting the engineering profession.

T. M. Keiller (M'34) for the past year superintendent of transmission and distribution for the El Paso Electric Company, El Paso, Texas, has been appointed to a similar position at Navasota with the Gulf States Utilities Company. Mr. Keiller has been connected with companies in the Stone and Webster group since 1922.

V. L. Hollister (A'08, M'32) consulting engineer, Hollister Engineering Company, Lincoln, Nebraska, has been named engineer for the Nebraska State Railway Commission. Mr. Hollister served on the Institute's power transmission and distribution committee 1928–29, and on the membership committee 1931–32.

H. L. Curtis (A'21, F'26) principal physicist, National Bureau of Standards, Washington, D. C., has been appointed to represent the American Society for Testing Materials on the new sectional committee

on electric and magnetic magnitudes and units.

Harvey Fletcher (M'23, F'30) physical research director, Bell Telephone Laboratories, Inc., New York, N. Y., has been elected to membership in the National Academy of Sciences. Papers on high quality transmission and auditory perspective have been presented to the Institute by him.

W. R. Thorson (A'26) former engineer with Burns and McDonnell, consulting engineers, Kansas City, Mo., has become general manager of the municipal light and power plant at Muscatine, Iowa, which is the largest municipally owned electric utility in that state.

J. D. Underhill (A'20) has been made vice president of The Okonite Company, the Okonite-Callender Company, and Hazard Insulated Wire Works, with headquarters at New York, N. Y. Mr. Underhill until recently was sales manager at New York.

J. M. Robertson (A'01) consulting engineer, Montreal, Que., Can., has been appointed by the Montreal Board of Trade as its representative on the commission that is to study the need of a sewage disposal plant for the city.

Sterling Beckwith (A'34) formerly connected with the Metropolitan Water District of Southern California, Los Angeles, is now engaged in a-c machine design in the electrical department of Allis-Chalmers Manufacturing Company, Milwaukee, Wis.

George Noble (A'34) formerly electrician in charge of Mountain Park Collieries, Ltd., Mountain Park, Alberta, Can., has accepted an appointment as electrical engineer for the Cadomin Coal Company, Ltd., Cadomin, Alberta, Can.

F. J. Somers (A'31) who has been with Television Laboratories, Ltd., San Francisco, Calif., is now with its successor, Farnsworth Television Incorporated, at Philadelphia, Pa.

Herbert Hoover (HM'29) Palo Alto, Calif., was granted the honorary degree of doctor of laws by Drake University, Des Moines, Iowa, at commencement exercises June 3, 1935.

R. A. Hopkins (A'19) salesman, Westinghouse Electric and Manufacturing Company, Los Angeles, Calif., was recently elected a vice president of the Los Angeles Electric Club.

H. L. Caldwell (A'07, F'20) engineer of distribution, operating division, Bureau of Power and Light, Los Angeles, Calif., was recently elected a vice president of the Los Angeles Electric Club.

J. G. Rollow (A'26, M'33) chief electrical engineer, Los Angeles Gas and Electric Corporation, Los Angeles, Calif., was recently elected to the executive committee of the Los Angeles Electric Club.

J. S. Jones (A'19, M'19, F'25) formerly assistant to president, Consolidated Laundries Corporation, New York, N. Y., is now with American Machine and Metals, Inc., New York.

W. H. Junkelman (A'27) who has recently been with RCA Photophone, Inc. New York, N. Y., is now commercial engineer for the New York (N. Y.) Edison Company.

F. M. Kinney (A'32) formerly in the electrical engineering department of The Hoover Company, North Canton, Ohio, is now electrical engineer with The Buckeye Portable Tool Company at Dayton.

C. G. Grimes (A'33) lieutenant, U. S. Navy, who has been electrical officer of the U.S.S. New Mexico, is now in the bureau of engineering of the Navy Department, Washington, D. C.

W. J. Tienken, Jr. (A'26) sales engineer formerly with the Electric Storage Battery Company, New York, N. Y., is now with the Morganite Brush Company, Long Island City, N. Y.

R. B. Steinmetz (A'26) is now district engineer for the Anaconda Wire and Cable Company at Boston, Mass., having previously been in the company's office at New York, N. Y.

F. J. Lyden (A'26) electrical engineer formerly with the Baldor Electric Company, St. Louis, Mo., is now in the welding division of J. D. Adams Company, Indianapolis, Ind.

M. K. Toeppen (A'21, M'21) who recently resigned as chief consulting engineer of the Michigan Public Utilities Commission, is now with the Federal Communications Commission at Washington, D. C.

William Bolster (A'33) former chief electrician with the United Fruit Company, New York N. Y., is now employed by the Sperry Gyroscope Company, Brooklyn, N. Y., as compass engineer.

N. L. Gregg, Jr. (A'34) formerly in the electrical drafting department, Newport News Shipbuilding and Dry Dock Company, Newport News, Va., is now with the Union Power Company at Mullens, W. Va.

Conrad Creim (A'34) Metropolitan Water District of Southern California, who has been at Banning, is now engaged in electrical maintenance at Hemet.

L. L. Robinson (A'31) recently became associated with the Gustav Hirsch organization in Columbus, Ohio, consulting engineers engaged primarily in telephone work.

H. G. Weston (A'30) telephone engineer formerly with C. A. McKee, New York, N. Y., is now with James O. Oliver and Company, Inc., New York.

D. W. Reeves (A'28) former superintendent of sales, Gulf States Utilities Company, Lake Charles, La., is now power engineer at Beaumont, Texas.

C. E. Soderbaum (A'24) former operating engineer, Motala Kraftwerk, Motala, Sweden, is now director of the Porjus Kraftwerk, Porjus.

R. E. McAdam (A'34) is now an instrument designer in the development department of the Eastman Kodak Company, Rochester, N. Y.

F. E. Snell (A'23) who has been assistant superintendent of power, Cleveland Railway Company, Cleveland, Ohio, has been appointed superintendent of power.

J. G. Kuhn (A'30) is now with Kinner Airplane and Motor Company, Glendale, Calif., as engineer.

J. S. Hagan (A'20, M'31) has engaged in consulting engineering practice in St. Louis, Mo.

H. H. Moody (A'34) is now employed in the geophysics department of the Continental Oil Company at Ponca City, Okla.

A. L. Kissel (A'26) is now a field engineer with Utility Consumers Service, Pittsburgh, Pa.

R. B. MacLaughlin (A'32) Acme Meter Service Corporation, has been transferred from Boston, Mass., to Pittsburgh, Pa.

M. G. Taylor (A'31) manager, Venezuela Power Company, Ltd., who has been at Barquisimeto, is now at Maracaibo.

J. C. Donahue (A'23) Rockland Light and Power Company, who has been at Middletown, N. Y., is now at Nyack, N. Y.

S. C. Fraser (A'30) is now president of Neon Sign Supply, Inc., Milwaukee, Wis.

Obituary

Sergius Paul Grace (A'03, F'21) assistant vice president of Bell Telephone Laboratories, Inc., New York, N. Y., died suddenly June 23, 1935. Doctor Grace was born at Farmington, Mich., on October 11, 1875. He graduated from the University of Michigan in 1896 with the degree of bachelor of science in electrical engineering, and started work that year for the Detroit (Mich.) Telephone Company, making important contributions to its problem of corrosion in underground cable sheaths. Between 1898 and 1900 he was chief engineer and operating manager of the People's Independent Telephone Company of New Orleans. After a few months as superin-

tendent of equipment for the Southwestern Bell Telephone Company of Texas, he became equipment engineer of the Erie Bell Telephone System in 1901, and becoming general superintendent of the Beaumont Independent Telephone Company of Texas later that year. In 1902 he became chief engineer of the Interstate Independent Telephone Company of New Jersey, later that year becoming assistant engineer for the American Telephone and Telegraph Company, whose headquarters were then at Boston, Mass. From 1902 to 1908, he was chief engineer of the Central District Telephone Company, Pittsburgh, Pa., and from 1908 to 1913 he was general superintendent of plant of the Central District company. During this period, when local telephone lines were being changed from open wires to aerial cables, Doctor Grace made many notable contributions to this development. In 1913 he became a consulting telephone engineer, at New York, N. Y., and the next year became chief telephone engineer for the Public Service Commission of the state of New York. From 1915 to 1920, he was assistant to the chief engineer of the New York Telephone Company and other companies of the Bell system. After a few months as assistant to the president of the Standard Chemical Company of Pittsburgh in 1920, he became advisory engineer to the general counsel of the New York Telephone Company. In 1921 he was appointed engineer on foreign wire relations for the American Telephone and Telegraph Company; in 1922, construction engineer, New York Telephone Company; later in 1922, general superintendent of by-products, American Telephone and Telegraph Company; in 1924, commercial development engineer of the Western Electric Company; in 1925, communication development engineer of the Bell Telephone Laboratories; in 1927, general commercial engineer of the laboratories; and in 1928 assistant vice president of the laboratories, which position he held until the time of his death. Doctor Grace was well known throughout the country for his lectures and demonstrations on the telephone system and its by-products. He was a past-president of the New York Electrical Society and of the Engineers Society of Western Pennsylvania. He was a member of the Engineers' Club of New York. He had been honored with the degree of doctor of engineering from the University of Michigan, and that of doctor of law from Notre Dame University. Doctor Grace had served the Institute as a member of its board of examiners, and on committees on education, meetings and papers (now technical program), and communication.

Richard Fleming (A'02) retired, Burlingame, Calif., died June 16, 1935. He was born in Ireland on May 23, 1866, and acquired his technical education by an extensive series of private courses. During the period 1886 to 1889, he was in various capacities in different central stations and street railway plants in different parts of the United States. Between 1889 and 1891, he was manager of the Olympia (Wash.) Light and Power Company, and assistant district engineer of the Edison General Electric Company at Portland, Ore., engaged on the installation of some of the first hydroelectric plants in the northwest. From 1891 to 1893 he was superintendent and chief engineer of the Rockford (Ill.) Electric and Manufacturing Company, designing and building dynamos and motors. In 1894 he was employed by the U.S. government in charge of electrical and mechanical work in fitting out a number of ships, including the battleship "Maine," and for the next 2 years was with the Fleming-Spence Electric Company as manager and engineer. In 1896, he entered the General Electric Company, West Lynn, Mass., remaining with the company until 1909, engaged on the design of arc lighting and other equipment; during this period he made pioneering inventions in connection with the enclosed flaming arc lamp. During 1909–10, he was a consulting engineer in New York, N. Y., engaged on the development of a gasoline-electric railway car. During 1911–13, he was plant manager of the Adams-Bagnal Electric Company, Cleveland, Ohio, and during 1913–14, was plant manager of Fairbanks-Morse Company, Indianapolis, Ind. During 1916–25, he was engaged in oil refining engineering in the development of an oil cracking process which was later used throughout the country. The Richard Fleming Company was organized for the furtherance of this work. In 1925 Mr. Fleming retired, residing at Burlingame, Calif., since that time. During the war (1917–18) he was inspector of smokeless powder plants for the U.S. government.

Joseph Showalter (M'21) who for the past 14 years had been sales engineer for the Canadian Westinghouse Company, Ltd., Toronto, Ontario, Canada, died June 5, 1935. Mr. Showalter was born April 25, 1880, at Gardner, Ill. His electrical and technical education was privately acquired. Between 1900 and 1902, he served the Diamond Meter Company and the Peoria Gas and Electric Company of Peoria, Ill., in various capacities, being in charge of the meter department during part of this period. Between 1902 and 1904, he was superintendent of the electrical and testing departments of the Duncan Electrical Manufacturing Company, instrument and meter manufacturers, Lafayette, Ind., and between 1904 and 1906 was engaged by the Western Electrical Manufacturing company, Berlin, Ontario, Canada, to design and manufacture a line of electric watthour meters. Between 1906 and 1909, he was engaged in electrical contracting, maintaining his headquarters at Berlin, Canada. In 1909, he became chief engineer for Ferranti Electrical Company, Ltd., Toronto, the Canadian branch of Ferranti, Limited, of England. He took this position when the Canadian branch was started, and was largely responsible for the development of a large business. In 1920, he left the Ferranti company to undertake practice as an electrical engineer. Shortly thereafter he became sales engineer of the Toronto office of the Canadian Westinghouse Company, remaining in this position until recently. Mr. Showalter had presented several papers before engineering associations and had served the Institute on its membership committee 1928–29.

Arthur Dudley Buzby (A'24) consulting engineer, Los Angeles, Calif., died May 26, 1935. Mr. Buzby was born June 30, 1889 at Montreal, Quebec, Canada. After 3 years of study at the school of science at Princeton University, he attending Valparaiso University, receiving the degree of civil engineer in 1911. He then took post graduate work in Massachusetts Institute of Technology for one year. During 1912–13, he was structural draftsman for Post and McCord, New York, N. Y., and during 1913–15 was bridge designer for the Erie Railroad. From 1915 to 1918 he was with the Chile Exploration Company and the Braden Copper Company, being successively, structural engineer, general designer, second assistant designing engineer, and principal assistant to the designing engineer. From 1918 to 1919, he was in the aviation service of the U.S. Signal Corps as experimental engineer, attached to the French Aviation Mission, in charge of design, construction, and development of combat planes. During 1919–20, he was again with the Chile Exploration Company and Braden Copper Company, resuming his previous duties. For several years following 1920 he was technical consultant for the Wellman-Seaver-Morgan Company, New York, N. Y., engaged on the design and application of a variety of mechanical equipment. He then became a consulting engineer at Jacksonville, Fla., being a member of the firm of DeSaussure and Buzby for several years. For the past few years he has been a consulting engineer at Los Angeles, Calif.

John J. Howard (M'21) electrical engineer, The Connecticut Company, New Haven, died June 3, 1935. Mr. Howard was born at New Haven, Conn., November 26, 1880, and graduated from the electrical engineering course at Yale University in 1903. Upon graduation, he entered the apprenticeship course of the Allis-Chalmers Company (then the Bullock Company) Cincinnati, Ohio, entering the testing department in 1904, being placed in charge of the testing department in 1905, and in 1906 becoming construction engineer on electrical apparatus for the company. In 1907, he became electrical inspector in the U.S. Navy Department. In 1911, he entered the employ of The Connecticut Company at New Haven, becoming assistant engineer in the engineering department, covering general electrical work in a street railway property operating in several cities in Connecticut. In 1917 he became electrical engineer for the company, holding this position until the time of his death, and being in responsible charge of electrical design and construction for the company.

Sumito Fukasawa (A'34) Tokyo, Japan, died December 31, 1934, according to information received recently at Institute headquarters. Mr. Fukasawa was born at Nagano-ken, Japan, October 19, 1905. He attended Iowa State College, Ames, receiving the degree of bachelor of science in electrical engineering in 1933. Previous to graduation, he spent several months as part time electrician at Guilford College,

N. C., and for a short time that year gained experience working as an assistant in the engine room of the Molly Pitcher Hotel, Red Bank, N. J. For a period starting in 1932, he was employed on work in the laboratory at Iowa State College. He recently had been engaged on the translation of an article on cable manufacturing.

DAVID RASMUSSEN (A'26) electrical designer, Elliott Company, Ridgway, Pa., died during April 1935. Mr. Rasmussen was born at Oxford, Ind., on Oct. 10, 1901. He was a graduate of Purdue University, West Lafayette, Ind. Following one year, 1924–25, as student engineer for the Duquesne Light Company, Pittsburgh, Pa., he became design draftsman for the company in 1925. In 1929 he became electrical designer for the Elliott Company, having held that position since that time.

Membership

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before Aug. 31, 1935, or Oct. 31, 1935, if the applicant resides outside of the United States or Canada.

Bertero, G. A., Brooklyn Edison Co., Brooklyn, N. Y.
Clevenger, C. M., c/o A. H. Ferris Co., Los Angeles, Calif.
Doolittle, J. B., Southwestern Bell Tel. Co., Kansas City, Mo.
Enderlin, M., (Member) Gibbs & Hill, New York, N. Y.
Griffith, R. C., General Elec. Co., Schenectady, N. Y.
Hazard, C. R., 733 N. W. Everett St., Portland, Ore.
Hildebrandt, D. B. (Member), Consumers Pwr. Co., Muskegon Hgts., Mich.
Inclan, L., Mexican Lt. & Pwr. Co., Mexico City, Mex.
Kilgore, R. R., Lincoln Elec. Co., Cleveland, Ohio.
Klauder, L. T., Rural Electrification Administration, Washington, D. C.
Lewis, D. A. (Member) Empire Gas & Elec. Co., Geneva, N. Y.
Lincoln, E. W., United Carr Fastener Corp., Cambridge, Mass.
Lippmann, B. A., 1921—66th St., Brooklyn, N. Y.
Miller, C. E., General Elec. Co., Schenectady, N. Y.
Sauter, O., Franklin Engg. Corp., New York, N. Y.
Sawle, R. T., English Elec. Co., St. Catharines, Ont., Can.
Scheffler, H., Mexican Lt. & Pwr. Co., Mexico D. F., Mex.
Sherman, W., Utica Gas & Elec. Co., Utica, N. Y.
Stansbury, C., (Member) Cutler-Hammer Inc., Milwaukee, Wis.
Ward, H. A., Interborough Rapid Transit Co., New York, N. Y.
Zuschlag, T., Magnetic Analysis Corp., Long Island City, N. Y.

21 Domestic

Foreign

Britton, J. R., Hawaiian Elec. Co., Ltd., Honolulu, T. H.
Chellam, S. V., Hydro Elec. Dept., Meltur Project, So. India.
Chu, C. Y., Association of Chinese Public Utilities, Shanghai, China.
Deering, J. E., British Post Office, London, N. 1, England.
Keoyios, L. M., Am. Farm Sch., Salonica, Greece.
Lazarieve, C., Compagnie des Lampes, Courbevoie, Seine, France
Proctor, J. A. M., Demerara Bauxite Co., Mackenzie, British Guiana, So. Am.

7 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as it now appears on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Bauer, Charles, 9 Royalton Place, Bloomfield, N. J.
Bock, F. S., 1642 W. Broad St., Richmond, Va.
Chiofalo, J., 203 Graham Ave., Brooklyn, N. Y.
Ghosh, K. C., c/o Compagnia Generale Di Elettricita, 34 Via Borgognone, Milan, Italy.
Golikoff, A., Main P. O. Gen. Del., Moscow, U.S.S.R.
Greene, F. M., 656—50th St., Brooklyn, N. Y.
Haddad, Raphael A., 500 Riverside Drive, N. Y. City.
Kimball, Gordon S., 154 Elmer Ave., Schenectady, N. Y.
Martinoff, V. M., 2150 Queen St., Toronto, Ont., Can.
Nelson, Charles J., 1515 N. Lotus Ave., Chicago, Ill.
Roselle, P. M., 2018 Chestnut St., Harrisburg, Pa.
Schellberg, Kenneth O., 4115—51st St., S., Seattle, Wash.
Schlosser, Walter H., Dominion Elec. Power, Ltd., Regina, Sask., Can.
Sillstrop, John P., Eldorado Towers, 300 Central Park West, New York, N. Y.
Smeaton, J. H., Rua Teixeira de Mello 49, Rio de Janeiro, Brasil, S. A.
Smedley, A. B., 82 Warner Ave., Hempstead, N. Y.
Vance, Paul E., c/o Marietta Mfg. Co., Point Pleasant, W. Va.
Verrier, E. J., Anglo Newfoundland Dev. Co., Grand Falls, Newfoundland.

18 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

CORROSION, CAUSES and PREVENTION. An Engineering Problem. By F. N. Speller. 2 ed. N. Y. and Lond., McGraw-Hill Book Co., 1935. 604 p., illus., 9x6 in., cloth, $7.00. A comprehensive review of the subject, especially with reference to the ferrous metals. The nature of corrosion, the influence of various factors, and the prevention of corrosion by air, water, steam, chemicals, and electricity are discussed.

DINAMOMASHINA V EE ISTORICHESKOM RAZVITII (Dynamo-Electric Machine in Its Historical Development). Documents and materials collected by D. V. Efremov and M. I. Radovskij; edited by V. Th. Mitkevitch, Academy of Sciences Press, Leningrad, 1934. 560 p., illus., 10x6 in., cloth, apply. Translations in Russian of the basic papers on the dynamo from 1832 to 1887.

A T M—Archiv für Technisches Messen. Lieferungen 39–44, Sept. 1934–Feb. 1935. Munich, R. Oldenbourg, illus., 12 x 8 in., paper, 1.50 rm. each. A review of methods and instruments use in technical measurements covering a wide field, classified and arranged so that the material may be collected in loose-leaf binders.

CUGLE'S TWO-MINUTE AZIMUTHS, Latitude 0° to 35°, Declination 0° to 23°, Same and Contrary Names. By C. H. Cugle. N. Y., E. P. Dutton & Co., 1935. 613 p., tables, 11x9 in. cloth, $5.00. By calculating this table to 2 minute intervals of time, the author has done away, in his opinion, with all necessity for interpolations in finding azimuths.

ANALYTISCHE GEOMETRIE der EBENE. (Sammlung Göschen 65.) By R. Haussner. 3 ed. Berlin and Leipzig, Walter de Gruyter & Co. 1934. 164 p., diagrs., 6 x 4 in., cloth, 1.62 rm. A brief introduction to plane analytic geometry, covering the usual undergraduate college course.

ANNUAL SURVEY of AMERICAN CHEMISTRY, v. 9, 1934. Ed. by C. J. West, National Research Council, N.Y., Reinhold Publishing Corp., 1935. 396 p., diagrs., 9x3 in., cloth, $4.50. A concise, comprehensive review of advances in pure and applied chemistry during 1934, including among the topics X-ray examination of materials and advances in electrochemical practice.

J. & P. TRANSFORMER BOOK being a Practical Technology of the Power Transformer. By S. A. Stigant and H. M. Lacey. 6 ed. Lond., Johnson & Phillips, 1935. 879 p., illus., 9x6 in., cloth, 12s 6d. A comprehensive exposition of power transformer theory and practice, designed to answer all the requirements of plant engineers. This edition has been revised and enlarged.

JOURNAL of the ROYAL TECHNICAL COLLEGE, v. 3, pt. 3, Jan. 1935, p. 326–396. Glasgow, Royal Technical College. Illus., 10x7 in., paper, 10s 6d. Records of research work recently carried out by the faculty and students of the college, including modifications of the cold-cathode Braun tube and stroboscopic examination of transitory torques.

Life and Letters of SEBASTIAN ZIANI de FERRANTI. By G. Ziani de Ferranti and R. Ince. Lond., Williams & Norgate, Ltd., 1934. 240 p., illus., 9x6 in., cloth, 12s 6d. This life of the noted pioneer electrical engineer is the work of his widow and his brother-in-law; many illustrations add to the interest.

MITTEILUNGEN aus den FORSCHUNGSANSTALTEN GHH-KONZERN, Bd. 3, Heft 8, April 1935. p. 199–222. Berlin, VDI-Verlag. illus., 12x8 in., paper, 2.70 rm. Includes a paper describing a new electric cable which is highly resistant to acid, alkalies, and other chemicals.

PRAKTISCHES HANDBUCH der GESAMTEN SHWEISSTECHNIK. Bd 2. Elektrische Schweisstechnik. By P. Schimpke and H. A. Horn. 2 ed. Berlin, J. Springer, 1935. 274 p., illus., 9x6 in., lea., 15 rm. A comprehensive account of welding technique, covering arc, resistance, and gas-electric, electric soldering and cutting, weld testing, etc.

S O S to the RESCUE. By K. Baarslag. N. Y. Oxford Univ. Press, 1935. 310 p., illus., 8x6 in., cloth, $2.50. A description of the use made of radio in a number of major disasters at sea, 1909–34, which is an addition to the history of radio.

THEORY of VIBRATIONS for ENGINEERS, an Intermediate Course. By R. B. Cole. Lond., Crosby Lockwood & Son, 1935. 263 p., illus., 9x5 in., cloth, 15s. An intermediate course in which the physical meaning of the mathematical equations is stressed and special attention given to methods of practical utility to designers of high speed machinery.

HETCH HETCHY, ITS ORIGIN and HISTORY. By M. M. O'Shaughnessy. Newbegin's Book Shop, 358 Post St., San Francisco, Cal. 134 p., illus., 12x9 in., cloth, $5.00. An account of the project for supplying water to San Francisco, from its inception in 1901 to its completion in 1934. The actual construction from 1912 to 1934 was directed by Mr. O'Shaughnessy. The book was published in a small edition, of which 300 copies are for sale.

MECHANICS of MATERIALS. By S. G. George and E. W. Rettger. N. Y. and Lond., McGraw-Hill Book Co., 1935. 483 p., illus., 9x6 in., cloth, $3.75. A textbook covering the essential topics of a first course in this subject, intended for students of engineering. Numerous complete examples are introduced to illustrate the application of theory.

PRINCIPLES of QUANTUM MECHANICS. By P. A. M. Dirac. 2 ed. Oxford, Clarendon Press; N. Y., Oxford Univ. Press, 1935. 300 p., tables, 10x6 in., cloth, $6.00. The first edition in 1930 won recognition as a contribution to modern physical theory; the new edition has been largely rewritten and thoroughly revised, including a chapter on field theory.

STRUCTURE and PROPERTIES of MATTER. By H. T. Briscoe. N. Y. and Lond., McGraw-Hill Book Co., 1935. 420 p., illus., 8x5 in., cloth, $3.55. An account of some of the facts and opinions concerning matter from the time of Aristotle to that of Bohr and Schroedinger, interpreting them from the point of view of the chemist.

TOOLS of TOMORROW. By J. N. Leonard. N. Y., Viking Press, 1935. 310 p., illus., 9x6 in., cloth, $3.00. A nontechnical discussion of modern developments in power resources and power distribution, the creation of new alloys, automatic machinery, and transportation and communication, and pointing to some lines along which striking progress may be expected.

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Front Cover

Nature furnishes the tower, with economy for the city of Seattle, Wash., incident to relocation of a portion of its Skagit River transmission line. Crossarms consisting of 2 8-inch 11 1/2-pound channels, latticed back to back, 18 inches apart, support 3 477,000 circular mil A.C.S.R. conductors on 15 foot spacings

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In This Issue—

CORRECTION—A correction on "Application of Electron Tubes in Industry," which paper appeared in the January 1935 issue of ELECTRICAL ENGINEERING, is published in the "Letters to the Editor" columns of the present issue. The correction concerns electron tube control for resistance welding (*page 1018*).

As this issue goes to press, the Institute's Pacific Coast convention is being held in Seattle, Wash., August 27–30 (and *not* September 27–30, as was stated erroneously on the cover of the August issue). A full report of the convention is scheduled for inclusion in the October issue.

REGISTRATION of engineers was discussed in an address in the August 1935 issue, pages 876–81, and a few additional comments by L. W. W. Morrow were published in that issue, page 899. In the "Letters to the Editor" columns of the present issue, Past-President A. W. Berresford analyzes several important aspects of registration, and urges that engineers, rather than nonengineers, should evolve the standards of registration (*pages 1014–6*).

SECTION officers frequently are confronted with the problem of providing high grade programs for their meetings, and interesting those in attendance sufficiently so that they will participate in discussion. A valuable suggestion for both relieving the work imposed on all concerned by these programs, and increasing their value to members, is contained in a "Letter to the Editor" in this issue (*pages 1016–7*).

THE most accurate methods of drawing and calculating magnetic fields in machinery windings are hard to understand and hard to use; easier methods of calculation are less accurate, and easier graphical methods are harder to analyze. The method of superposition, explained in this issue, is said to fill the gap between the more accurate and the simpler methods (*pages 959–66*).

DURING recent years, one of the most rapidly developing fields open to electrical engineers has been that of industrial electrochemistry. A long series of new products and processes indicates the tremendous activity going on, and a survey of the future shows that many further advances are to be made. Electrochemistry should prove to be one of the most attractive fields for the young engineer (*pages 920–3*).

INVESTIGATIONS of the effect of lightning on power transmission lines have been carried on continuously for several years by one group of investigators. Another paper in the series of reports on these investigations has been prepared. Data on overhead and buried ground wires are given and the amplitude of stroke surge currents is indicated (*pages 934–42*).

PURDUE University, West Lafayette, Ind., will be host for the Great Lakes District meeting of the A.I.E.E., October 24–25, 1935. The technical program, in which students will participate actively, and other features, including inspection trips, a television demonstration, and attendance at a football game, have been announced (*pages 1005–7*).

A MULTIHARMONIC electrostatic audiofrequency generator in which the harmonics are generated by the rotation of a shielded segmented disk adjacent to a stationary plate is described in this issue. Each harmonic is controlled independently, and any 2 or more may be combined to obtain complex wave forms (*pages 950–5*).

REPORTS were presented during the Institute's 1935 summer convention at Ithaca on 2 subjects of interest to the entire membership. One of these is a report of the A.I.E.E. publication committee (*pages 1009–10*). The other is a report on experiences with Section technical committees obtained by the Portland, Ore., Section (*page 1011*).

DELTA connected transformers sometimes are supplied with mid-taps, and loads can be taken off simultaneously at both full and half voltage. Equations and curves have been developed which facilitate the calculation of the maximum permissible load, even though the loading of the different windings is not uniform (*pages 931–4*).

LIGHTNING has been the subject of some 1,300 papers published from 1918 to date by the A.I.E.E. and other organizations. If enough orders are received, a comprehensive reference book containing all of these papers will be issued. Members interested are urged to act promptly (*page 1008 and page 8, advertising section*).

APPLICATION of electric railway motors necessitates the determination of speed-time and current-time curves. An electrograph has been developed in which these curves may be drawn on an oscillograph screen and many laborious calculations avoided (*pages 923–30*).

MEASUREMENT of impulse voltage obtained by noting the breakdown spacing of sphere-gaps may be rendered more dependable by the application of ultraviolet light. The improvement is especially marked for the smaller gaps and lower voltages (*pages 955–8*).

WAVE forms in the d-c side of rectifier circuits may be calculated with considerable accuracy by the application of the Fourier series. A knowledge of these wave forms frequently is desirable, and the accuracy of these calculations has been verified by oscillograms (*pages 977–84*).

LOCI of all voltages and currents in star-star (Y-Y) circuits follow circular paths when any self-impedance in the circuit is varied. A method of determining these loci is presented in this issue (*pages 970–6*).

CATHODE ray oscillograph measurements show that the "firing" time of an igniter type of mercury rectifier tube varies in a statistically systematic manner between successive operations (*pages 942–9*).

IN addition to the national and District prizes for 1934 Institute papers already announced, 2 additional Districts recently announced their awards (*page 1007*).

A Message

To the Institute Membership—

TOGETHER we stand at the threshold of another Institute year, looking forward from the point of vantage attained by our officers, directors, committee chairmen, and active members.

A perfect synchronism of the attitudes of our entire membership in a completely co-operative effort toward the continued growth and progress of our Institute would indeed be an ideal accomplishment.

You as individual mechanisms in this great professional society are the vitality of its every aim and purpose and therefore constitute the basis for its success.

Our job today, yours and mine, is to devote every ounce of energy toward building soundly for the future. Our usefulness will not attain a wide scope nor a higher degree of efficiency unless it be expanded along the lines of concurrent effort and co-operative functions.

The joy of personal accomplishment is regarded by some as the greatest of human joys, but unless our perspective be narrow, selfish, and egotistical, we cannot agree to this, preferring to make it secondary to the prime fact that it is most pleasurable to know that oneself has participated in the mutual accomplishment of some worthy effort.

Edward Bernard Meyer
A.I.E.E. President 1935–36

And so it is the co-operative action of the members that so materially aids and guides the board of directors of our Institute in effectively carrying on its work.

The extent of the contribution that can be made by any organization, such as the Institute, is determined by the soundness of its business policies. The furtherance of its aims to promote technological advancement and the best interests of its membership, is predicated upon its ability so to manage its affairs that it may foster uninterruptedly those activities that are consistent with the purposes for which it exists. It is important that its members be qualified technically if advances in the electrical art are to be made, but it is just as important that the members have knowledge of the administrative aspects of the Institute's affairs if they would be equally qualified to promote the well-being of the institution which concerns itself not only with technical matters but also with the improvement of the professional status of those engaged in electrical engineering.

It is a tribute to the profession that our individual engineers through their spirit of helpfulness and the development of mutual understandings have taken a broader view and accepted larger responsibilities not only on current engineering problems but in their applying themselves to the complex problems of modern society. They are cognizant of the growing demand for the application of engineering analysis to the social and economic aspects of our national existence.

The attention of the membership is directed to the problems that are ever before those who constitute the managing bodies of the Institute and to the studious effort that is constantly being made to give the various activities that make up the Institute's life the degree of emphasis that each deserves. It is all the more important that the individual members realize this and give serious thought to possible ways in which they may render assistance to their officers and committee heads.

Over and above all things which may be regarded as specific contributions, however, do we find the question of attitude as the one major responsibility. If the attitude of each member toward the aims and purposes of our society is all that it should be, we may go forward with complete confidence in our ability to deal constructively with any situation that may confront us in the future.

Industrial Electrochemistry Advances

By COLIN G. FINK
Columbia University, New York, N. Y.

Of the many fields of activity open to the young electrical engineer, one of the most fascinating and abundant in opportunities for important developments is that of industrial electrochemistry. A survey of the recent advances which have been made in this field shows the striking wealth of new products and new processes, many of these being of great commercial value. For the future, opportunities for the engineer to make new discoveries are even greater.

At the time of the harnessing of part of the vast power resources at Niagara Falls 40 years ago, "industrial electrochemistry" was born. Before that time the consumption of electricity in electrochemical processes was relatively insignificant. Today the total installed electric power for electrochemical industries in the United States alone amounts to over 3,000,000 kw—a very significant figure—enough power to light a good-sized tungsten lamp in every home in the whole country. About $^1/_2$ of the power is required by 2 of the electro-chemical products: aluminum metal and calcium carbide.

For many years the major electrochemical plants were segregated at Niagara Falls. Today there are half a dozen important electrochemical centers besides a score of smaller installations scattered throughout the United States. Charleston, West Va., boasts of the largest electrolytic alkali plant of the world; at Tacoma, Wash., is one of the large copper refineries of the American Smelting and Refining Company, besides 2 important electrolytic alkali-chlorine plants, one of the Hooker Electrochemical Company and the other of the Pennsylvania Salt Company; another center is Keokuk, Iowa, with its large dam across the Mississippi; then in Montana, at Anaconda and Great Falls, there are the electrolytic zinc and copper plants of the Anaconda Copper Company; and at Massena, N. Y., the major plant of the Aluminum Company. In most of these plants hydroelectric power is used, but steam power is competing successfully in several localities, notably in Tennessee and in California where rates are as low as 3 mills per kilowatt hour. Nevertheless, a number of new hydroelectric power centers are again offering inducements to manufacturers of electrochemical products: at the new Boulder Dam where 500,000 kw will soon be available; at Norris Dam in Tennessee; and at Coulee Dam in the State of Washington.

How is the remarkable development of the electrochemical industry within the past 40 years to be accounted for? Why has the electrical method become the preferred one? The answer is not hard to find. The electrolytic cell turns out products such as aluminum, magnesium, beryllium, and sodium that cannot be produced cheaply in any other way. The electric furnace has given birth to a long series of new products previously unknown: Acheson graphite, carborundum (silicon carbide), alundum, calcium carbide, tungsten metal, stainless steel, "18—8" chrome-nickel steel, ferronickel alloys with valuable magnetic properties, new malleable cast irons, etc. Finally, there are a number of chemical and metallurgical products that are made better, more cheaply, and of more uniform quality than by the older, straight chemical methods: thus, for example, all of the copper used in the electrical industries is electrolytic copper—of uniform purity and conductivity. Then there is electrolytic zinc 99.95 per cent pure; phosphorus made in the electric furnace; and electric carbon bisulfide, an important reagent for rayon manufacture.

New Products and New Processes

Considering only the last 3 or 4 years, many valuable additions to the long list of products and processes of the electrochemical industry may again be recorded. In the electric furnace field, T. F. Baily of Alliance, Ohio, has developed a new furnace for the production of steel direct from ore. The upper part of the furnace resembles a small shaft furnace. Reducing gases (largely carbon monoxide) pass upward through this heated shaft and finely divided iron ore particles pass downward. The particles thus are reduced to metal which drops into the electric furnace forming the base of the shaft. Here, with the aid of the electric arc, the metal droplets are converted into high-grade steel.

The rare metal columbium is now being used in electric furnace practice as an addition to the "18–8" chrome-nickel steel to render it more easily workable. This discovery emanates from the laboratories of Dr. F. M. Becket.

An essential reagent used in the manufacture of artificial silk, rayon, is carbon bisulfide. E. R. Taylor's electric shaft furnace first set up at Penn Yan, New York, 40 years ago, has been improved upon by C. C. Schwegler of the Dow Chemical Company at Midland, Mich. The inlet ports for sulfur vapor are located at or above the level of the electrodes and means are provided for counteracting any tendency on the part of the hot reaction zone to shift, a cause of considerable disturbance in the older types of furnace. The fundamental chemical reaction is relatively simple: Hot charcoal reacts

An address delivered at the annual joint meeting of the Institute's New York (N. Y.) Section and the New York Student Branch convention held in the Engineering Societies Building, New York, N. Y., April 26, 1935. Manuscript submitted April 19, 1935, released for publication June 15, 1935.

with sulfur vapor to form carbon bisulfide: $C + 2S = CS_2$.

Another recent development of particular interest to electrical engineers is the introduction of the high frequency furnace into the steel plant. Many tons of the finest alloy steels are now made in the high frequency furnace in direct competition with the arc furnace. Dr. E. F. Northrup of Trenton, N. J., is largely responsible for this development.

In the ceramic industries the firing of the ware is still being carried out in the old-fashioned fuel-fired kiln. However, large-scale tests are now under way substituting the much more efficient electrical means of heating. Here in this country R. E. Gould of Knoxville, Tenn., is in charge of these tests forming part of the program of the Tennessee Valley Authority.

A little over a year ago the Carbide and Carbon Chemicals Corporation received the much coveted McGraw-Hill "award for chemical achievement." This company is largely responsible for the creation of an entirely new chemical industry. The raw materials are coke and limestone. These are fed into a large box-type electric furnace, 3 phase and with 3 electrodes each over 3 feet in diameter. In the zone of the smothered arc, liquid calcium carbide is formed. After tapping this out of the furnace and allowing it to cool and solidify, it is brought into reaction with water to form the well-known acetylene gas used in welding and cutting. From this point on, the new industry develops: with the aid of catalysts, acetylene is interacted with hydrogen to form ethylene and then from this a vast variety of products—alcohols, solvents, gums, etc.—never before equaled in the history of chemistry. The new synthetic "resin" has been trade-named "vinylite." It has been made up into water tumblers, wall panels, phonograph records, floor tiles, translucent light fixtures, door knobs, denture castings, automobile steering wheels, etc.

A relatively small, yet important, new electric furnace product is cemented tungsten carbide originating in Germany but developed on an extensive scale in the United States. This carbide is used as a cutting tool and in hardness is next to diamond, the hardest material available to industry. Practically all of the oil well boring is now carried out by means of tungsten carbide in place of diamond. Furthermore, tungsten carbide tools have found world-wide application in the machine shops. They will cut the hardest steels.

Fused Electrolytes

The typical product of the fused electrolyte cell is aluminum metal; others of industrial importance are magnesium metal, sodium metal, and calcium metal. Recent additions to the commercial list are beryllium and lithium. Beryllium metal has found its chief application among the alloys. About $2^1/_2$ per cent beryllium added to copper produces an alloy that is highly corrosion-resistant, relatively hard—like tempered spring steel—nonmagnetic and nonsparking. This last property is particularly important in plants where inflammable vapors occur and where the spark of an ordinary steel tool has often caused a serious explosion. All kinds of beryllium-copper tools, chisels, scrapers, pry bars, hammers, etc., are now on the market and many thousands of beryllium-copper springs are in service today giving a remarkable, low-fatigue performance. Contact clips, pins, and plugs for electrical appliances constitute another important application of this beryllium-copper alloy. In comparison with the older bronzes, the life of these clips and plugs has been increased 10-fold.

In nature beryllium occurs widely distributed in the earth's crust. Beryl, a beryllium aluminum silicate, is the chief mineral. A relatively simple method of separating the beryllium from the other constituents of the ore has been worked out lately and is giving very satisfactory results.

Lithium metal, the other new fused salt cell product, has likewise found its chief application in the alloy field. A few tenths of one per cent of lithium, together with small percentages of other elements, develops steel-like properties in aluminum. The lithium-calcium alloy is a valuable scavenger. Upon adding it to molten steel or other metal it will combine with practically all undesirable impurities.

Aluminum metal has decked itself in a new coat. Anodically-treated aluminum has resulted in a wide variety of new products, many of which are highly colored and look very attractive, especially to the modern housewife. Aluminum mirrors have replaced silver mirrors for telescopes and have been found to be superior to these—an epochal event.

The electrical engineer has become very much interested within the last 2 or 3 years in one of the older products of the fused salt cell, namely, sodium metal. This is used in the new highway or sodium arc lamp, in itself a pretty illustration of applied electrochemistry. Sodium arc lamps have been made before, 30 years ago, but they would not start automatically as the new ones do. The present development has incorporated the hot cathode of the radio tube and the gas of the neon sign. Upon closing the circuit of the new sodium arc lamp the neon gas is ionized, becomes conductive and hot, causing the sodium metal to be vaporized and ionized, and thereupon the sodium arc is established. This 3 step starting of the arc results in the familiar "sun rise" effect in these new, highly efficient lamps.

Another new application of sodium metal of interest to engineers is based upon its high thermal conductivity. Hollow steel sections are filled with sodium metal and used for various machine parts. Thus the valves of aeroplane motors are "sodium" cooled.

Barium metal, which has been made by the fused salt process for many years, has also found important, if not the most important, application in the electrical field. The valuable function of barium as an electron emitter and getter in vacuum tubes is well known to most readers. Recently D. W. Randolph of the A. C. Spark Plug Company has reported on a nickel-barium alloy used as spark terminal. A uniform and quietly operating spark is obtained. M. A. Baernstein has found that the introduction of

barium compounds into the electric furnace arc results in a much more uniform and smoother performance of the arc.

Aqueous Electrolytes

Of greatest scientific importance was the discovery of heavy hydrogen, or "deuterium," by Dr. H. C. Urey and associates at Columbia University. This newcomer is a product of the electrolysis of water between nickel electrodes.

In the electrolytic alkali-chlorine industry an epoch-making application of chlorine gas is charging it into sea water and liberating tons of bromine—an important reagent in photography and in making "antiknock" gasoline. The large bromine plant is situated at Cape Fear, N. C.

In the electrolytic copper industry a noteworthy new product is the paper-thin copper sheet produced in endless lengths on a large revolving lead drum that serves as cathode. This was brought to commercial perfection by Shakespear, Levi and others of the Anaconda Copper Company. Very recently the thin copper sheet has been applied to paper and serves as an attractive wrapper for a wide variety of products.

For years the industry has been looking for a metal coating which would be resistant to the strongest of acids, muriatic, and at the same time easily applied. A short time ago this problem was tackled at Columbia University by a group including the author, and now with the assistance of Mr. Deren it has been possible to locate and develop the desired metal coating. It has been found that rhenium metal can be electrodeposited on copper, brass, and steel, and in that way protect them against muriatic acid attack. Aside from industrial applications rhenium plate is of special interest to jewelry manufacturers. Wrist bands which are rhenium-plated resist the attack of the acids in perspiration. Chromium, rhodium and even silver are attacked by perspiration whereas rhenium is not. Rhenium plate is remarkably free from pin holes, does not tarnish nor smudge. The present sources of rhenium metal are the slimes of one of the large electrolytic copper refineries. These copper cell slimes have given rise to a number of industries. Thus selenium, an essential metal in many of our modern photoelectric devices, is extracted from these slimes. Selenium and its sister metal, tellurium, are now being regularly recovered at electrolytic copper and electrolytic nickel plants. Tellurium is an important reagent in the electrolytic zinc industry.

Several laboratories have devoted considerable effort to the electrodeposition of alloys. The Bell Telephone Laboratories have electrodeposited magnetic alloys composed of iron, nickel, and cobalt. At the University of Minnesota, C. L. Faust and G. H. Montillon have developed a process for the deposition of nickel brasses. Brass as such has been commercially deposited on steel for the last 15 years. At Columbia University, the author and others have been depositing a silver-white corrosion-resistant alloy of cobalt and nickel; also a highly acid-resistant alloy of silver and lead, and another of tungsten and palladium. This field is a most fascinating one and offers great possibilities. The mechanical preparation of thin alloy sheets is often very difficult and tedious, whereas the electrodeposition of such sheets is usually relatively simple.

Electrochemistry of Gases

Of all branches of electrochemistry, that concerned with the discharge of electricity through gases is the most fascinating. However, due to the greater ease in handling solids and solutions, investigators usually avoid this branch of the science. From a practical point of view a number of circumstances have in recent years contributed toward a better acquaintance on the part of the engineer with gas reactions, gas transportation, gas recovery and generation, etc. Thus the use of gases in welding and cutting, gases in warfare, neon and other gases in electric signs, ozone generators, Cottrell precipitators, gas arcs, etc., have all helped to bring about a decided change in attitude on the part of the engineer. From an industrial point of view the recent developments in the sodium vapor and high-pressure mercury-vapor arcs deserve special mention. Important, too, are the researches of Dr. S. C. Lind at the University of Minnesota on various gas reactions initiated by radium emanations, and the researches of the Fixed Nitrogen Laboratory at Washington, D. C., under the direction of Dr. F. G. Cottrell on electrical methods of synthesizing nitric oxide. Electrical engineers will recall that in the corona discharge nitrogen is more readily ionized than oxygen—quite contrary to our early suppositions.

Many Unsolved Problems in Electrochemistry

Young students desirous of taking up a research problem often feel that "everything has been solved." This is far from the truth. Every new product or new process gives rise to a dozen new problems. The discovery of high frequency induction melting of steel and the appreciation of its commercial possibilities happened years before the first large furnace was in successful operation in the steel plant, and the delay was largely due to the many problems that had to be solved before the basic discovery was adaptable commercially.

Opportunities are greater than ever before and the possible new discoveries are unlimited in every branch of electrochemistry. An electric furnace is needed that will easily and efficiently convert ores into finished metal products; a new process is needed for the production of aluminum metal, one that is much simpler and cheaper than the present one; further development of the photovoltaic cell is needed so that it will readily convert large blocks of sun power into electric power; strong, low density alloys are needed that have a fatigue resistance equal to that of steel; a simple means of electrically controlling and directing rainfall—keeping it out of the cities—must be found; most urgently, there is needed a simple but efficient method of protecting steel products and steel structures against corrosion and thus save many millions of dollars now lost;

an electric source of illumination must be found suitable to human eyes, that will operate at 90 per cent and better in efficiency instead of less than 10 per cent, as at present; efforts are being made to find an electric heating unit that will operate a thousand hours or more in air at temperatures of 2,000 degrees centigrade (3,600 degrees Fahrenheit) or above; a simple process of producing large ingots of malleable titanium metal, one of the most prevalent constituents of the earth's crust (6,000 times as abundant as lead) must be found; the application of electric currents in the stimulation of the growth of living cells and the formation of many important organic compounds should be systematically investigated; dielectrics free from the short-comings of the many in use today must be found and developed; hundreds of new products are needed which were difficult or impossible to discover during the countless ages of the past with mechanical skill alone, but today readily possible through the combined power of electricity and chemistry. Truly the young electrical engineer looking for "worlds to conquer" will do well to survey the vast but little-explored domains of electrochemistry.

The Speed-Time Electrograph

The determination of speed-time curves and current-time curves as related to the duty cycles of electric railway motors may be greatly simplified by the use of an electrograph which has been developed, thereby making unnecessary the usual calculations which require considerable time. In this machine, the curves are drawn on an oscillograph screen. The equipment, which can also be used to obtain other characteristics, depends for its operation upon the similarity of equations in the mechanics of train movement and those involved in the electrograph circuit.

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IN electrical railway engineering work it is sometimes necessary to calculate and plot speed-time curves for scheduling purposes, current-time curves in estimating power requirements, speed-distance curves in connection with signal placing and current-squared-time curves in the selection of motors to perform a certain duty cycle. The usual procedure in plotting such curves is to "solve" the differential equations involving empirical quantities by a graphical point to point method. The appendix to this paper shows a sample set of such calculations.

While these calculations are not particularly difficult, the time involved is considerable and the accuracy depends to a large extent upon the judgment and care with which they are performed. In many cases, to insure reasonable accuracy, the curves must be checked, a task which is none too easy even with such standardized methods as are usually employed. The natural result is that these basic curves for electrical railway work are drawn only when absolutely essential, due to the time necessary and the consequent high cost of such calculations.

With the expectation that the development of any rapid electrical means of performing these calculations might increase their use an experimental "speed-time electrograph" has been built at New York University. The operation of this machine depends upon the similarity of the fundamental differential equations in the mechanics of train movement and the electrical equations involved in the speed-time electrograph circuit. The machine plots the speed-time curves for certain experimental runs up to the point selected by the operator and the distance traversed may be read directly. (Standard meters require a multiplying factor.) A current-time curve per motor may be plotted simultaneously and kilowatt-hours and amperes-squared-seconds read directly.

The speed-time and current-time curves are drawn on an oscillograph screen in the usual manner and may be preserved, if necessary, by photographing them. Since the usual results desired are obtained directly, there appears to be no reason for preserving these curves except where actual records of the train speed or motor current at certain times is desired or for checking work at a later date.

Figures 1 and 2 show 2 views of the experimental speed-time electrograph as set up in the laboratory.

Relation of the Fundamental Electrical and Mechanical Equations

Since the general similarity of electrical and mechanical equations and quantities has already been discussed in several papers[1, 2, 3] it seems unnecessary to more than briefly outline the particular conditions

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1. For all numbered references see list at end of paper.

which must be met in the speed-time electrograph.

In order to plot electrically both the speed of the train and the current per motor, 2 separate circuits are necessary. The current whose magnitude represents the speed of the train may be termed the "speed-current," while the small current representing actual current per motor will be called the "I-current."

From the mechanics of train movement[5,6]

$$T = 100W\frac{dV}{dt} + R + C \pm G \tag{1}$$

where

T = tractive effort per motor in pounds
W = total weight per motor in tons
$\frac{dV}{dt}$ = acceleration in miles per hour per second
R = train resistance per motor in pounds. This resistance will be a function of the speed of the train for any particular train
C = curve resistance per motor in pounds which depends, for any particular train, upon the degree of curvature of the track
G = grade resistance per motor in pounds, which for any particular train, depends upon the per cent grade. A plus sign precedes an up-grade while a minus sign precedes a down-grade

Fig. 1 (left). Front view of the experimental speed-time electrograph

Fig. 2 (below). Another view of the speed-time electrograph, taken from the side

The equivalent series circuit electrical equation is

$$E_T = L\frac{di}{dt'} + E_r + E_c \pm E_g \tag{2}$$

where E denotes a voltage rise and the subscripts indicate the items which are equivalent to those of equation 1. It will be noticed that E_r must vary with the current while E_c and E_g are fixed values for any particular condition of gradient and track curvature.

Since the speed V in miles per hour may be multiplied by a constant to obtain i, the speed-current in amperes

$$VK_v = i$$

also

$$TK_T = E_T$$

since tractive effort corresponds to electromotive force. t, the actual train time, is related to t', the electrical circuit time, in the same fashion, or

$$tK_t = t'$$

In order to have a repeating electrical circuit phenomena which may be traced on the oscillograph screen, it is necessary to have a stationary commutator the segments of which may be connected to one another and to the various circuits. A rotating brush changes the electrical connections in the same sequence during every revolution. The time for one revolution will determine the total electrical graph cycle time so that it is necessary to select a convenient maximum time for an actual train run so that

$$K_t = \frac{\text{Total electrical graph cycle time in seconds}}{\text{Total maximum time for a train run in seconds}}$$

If the graph cycle time is $^1/_{30}$ second, as it is for a commutator speed of 1,800 revolutions per minute, and the maximum actual time for a train run is 10 minutes, K_t becomes $^1/_{18,000}$.

The value of the inductance L corresponding to a certain train weight per motor may be calculated since

$$100W\frac{dV}{dt}K_T = L\frac{di}{dt'}$$

$$(dV)(K_v) = di \text{ and } dt(K_t) = dt'$$

so

$$\frac{(100W)(K_T)(K_t)}{K_v} = L \text{ in henries} \tag{3}$$

It may be pointed out that equation 3 allows considerable variation in the selection of the total screen time in terms of actual time since this may be changed to any period desired within the upper limit imposed by the maxium inductance available.

Elementary Theoretical Circuit

Figure 3 shows the usual speed-amperes and tractive effort-amperes curves for a 50-horsepower d-c traction motor. If these curves are used to plot a speed-tractive effort curve this may be plotted as shown in figure 4, the solid line marked "tractive

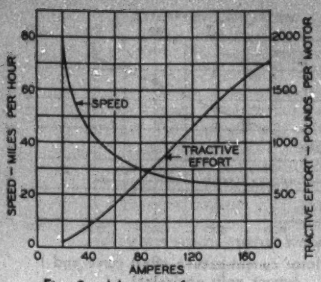


Fig. 3. Motor performance curves

D-C railway motor, hourly rating: 50 horsepower, 600 volts, 72 amperes, 900 rpm

Continuous capacity (85 degrees centigrade rise by resistance on stand test): 47 amperes on 300 volts; 51 amperes on 450 volts; 55 amperes on 600 volts

26 inch wheels; 20:47 gear ratio

effort per motor." The curve for "train resistance per motor" as calculated from the Davis formula[4] may also be plotted on the same figure. Since the speed-current is electrically equivalent to the train speed in miles per hour, and tractive effort or train resistance may also be plotted in equivalent volts, both sets of scales may be shown on the same diagram.

The elementary theoretical circuit diagram of the speed-current circuit is shown in figure 5. The circuit set up in this figure illustrates the theoretical circuit for the main wiring diagram, figure 7, and the sample results given later in the paper.

In order to duplicate electrically the control of the train, it is necessary to have 4 "control" circuits. In figure 5 these are lettered S, T, C, and B to signify start, run, coast, and brake, respectively. In each case the control circuit determines the value of E_T in equation 2 just as the control equipment on the train regulates the value of T in equation 1.

The circuits below the commutator segments P, V, W, and X are "grade" circuits. There must be as many grade circuits as there are different conditions of grade and curvature for a particular train run. Since the curve resistance voltage E_c may be set up as an equivalent grade voltage E_g, the 2 terms might have been combined in equation 2.

In figure 5 the inertia of the train is represented by the inductance L. As mechanical train resistance can only be represented by a voltage electrically, it may be considered that $-E_r$ (or $-E_r'$) is practically the voltage drop through a vacuum tube, the characteristic of which has been adjusted to approximate the train resistance curve of figure 4.

The area of the speed-current wave against time is equivalent to distance, and since this area can only be obtained by the variation of control and grade circuits in the correct sequence and at the proper instants, theoretically an infinite number of commutator segments would be necessary.

In starting an electric train the function of the electrical control equipment is to hold the starting current per motor practically constant during the starting period, which means that the tractive effort is constant during this time. (See figure 3.) In figure 4 this constant tractive effort (of 1,000 pounds) is marked E_t. This condition continues until the train has reached the speed at which this constant value of tractive effort intersects the "tractive

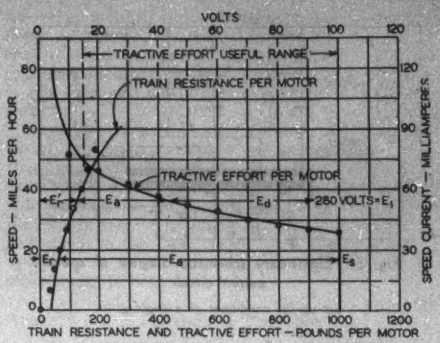


Fig. 4. Speed-resistance and speed-tractive effort curves

Solid lines show values plotted from figure 3
Plotted points show corresponding electrical values obtained

effort per motor" curve. In equation 1 this is equivalent to making T a constant, while in equation 2, E_T is a constant E_t.

In figure 5, the brush travels from left to right first making contact with the starting segment and completing the circuit *OPSMRO*. In this case the start is made on level tangent track, no grade voltage is necessary, and equation 2 becomes

$$E_t = L\frac{di}{dt'} + E_r = E_a + E_r \tag{4}$$

which is shown graphically in figure 4. As the speed-current increases the electromotive force available to overcome the back electromotive force of the inductance $\left(-L\frac{di}{dt'} = -E_a\right)$ becomes less as more voltage drop occurs through the vacuum tube "train resistance."

When the train has reached the lowest speed at which all motors may be connected for full line voltage the tractive effort becomes a function of the speed, as shown by figure 4, "tractive effort per motor." Returning to figure 5; as the brush continues to the right, circuit *OPTNMRO* is completed just before the starting circuit is opened thus keeping the series speed-current circuit intact. In this circuit E_1 is a constant electromotive force, while E_d is the difference in potential across a vacuum tube circuit. The voltage equation is

$$E_1 = E_d + E_a' + E_r' \tag{5}$$

where E_a' indicates $L\frac{di}{dt'}$. The equation is shown graphically in figure 4. Equation 5 may be rewritten

$$E_1 - E_d = E_a' + E_r'$$

which means that the electromotive force available for tractive effort is $E_1 - E_d = E_T$ for equation 2. For this type of curve E_T may be easily adjusted to fit the tractive-effort curve. When E_a' has become

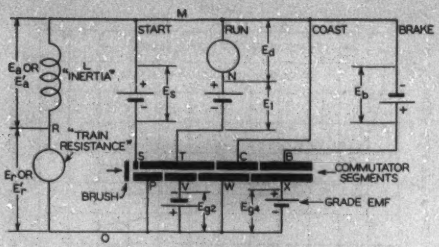


Fig. 5. Elementary schematic diagram of speed-current circuit

Set up for conditions of example given

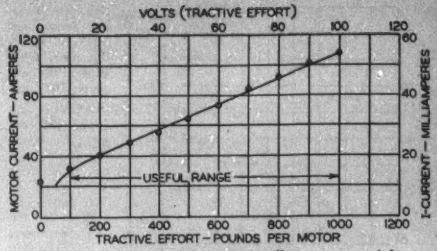


Fig. 6. Motor current-tractive effort curve and I-current, volts equivalent

Solid lines show plotted values from figure 3
Plotted points show corresponding electrical values obtained

zero, $E_T = E_r'$ which corresponds to the balancing speed of the train.

As the brush proceeds, it completes in succession circuits *OVTNMRO*, and *OWTNMRO*. In the former an "up-grade" voltage, E_{g2} is inserted and equation 5 becomes

$$E_d - E_d = E_T = E_a' + E_r' + E_{g2} \tag{5a}$$

The latter circuit is a repetition of equation 5 since the "train" is again on level tangent track.

At this point it may be assumed that the power is cut off and the train is to coast. (Level tangent track.) In the mechanical equation 1 this corresponds to making T, G, and C zero and the equivalent electrical equation becomes

$$L\frac{di}{dt'} + E_r' = 0 \tag{6}$$

This is accomplished electrically as the brush passes to circuit *OWCMRO* and disconnects the motor running circuit. The inductance takes the place of the inertia in the mechanical system and the speed-current starts to decrease. $\left(L\frac{di}{dt'} \text{ is negative.}\right)$

As the brush connects segment X, figure 5, circuit *OXCMRO* comes into play inserting a "down-grade" voltage, E_{g4} and equation 6 becomes

$$L\frac{di}{dt'} + E_r - E_{g4} = 0 \tag{6a}$$

and the speed-current increases as the "train" coasts downhill.

If the brakes are applied as the train coasts downhill the mechanical equation is

$$-B = 100\,W\frac{dV}{dt} + R - G \tag{7}$$

where $-B$ (braking force) takes the place of T in equation 1. Since this is usually assumed to be a constant for speed-time curves the electrical equation may be shown as

$$-E_b = L\frac{di}{dt'} + E_r - E_{g4} \tag{8}$$

which is the equation for the braking circuit *OXBMRO*. The speed-current goes to zero very quickly with this connection. It is interesting to note that if it were not for the valve action of the "train resistance" vacuum tube the "train" would "roll backward" if stopped on an "up-grade."

As the brush is revolving at a speed of, say, 1,800 rpm, this sequence of circuits is repeated continuously so that an oscillograph element placed in the circuit of figure 5 at point R draws the speed-time curve on the screen of the oscillograph. This curve is stationary if the brush and oscillograph mechanism are in synchronism. A magnetic type milliameter at the same point reads the average value of the current wave per brush cycle, which is proportional to distance.

Main Wiring Diagram

Figure 7 shows the speed-current circuit on the left and the I-current circuit on the right. The commutator is divided into an inside ring of "grade segments" and an outside ring of "control segments," which may be connected to the appropriate grade potentiometer voltages through the grade plugs or to the control circuits, respectively.

The circuit lettering for figure 7 corresponds to that of figure 5 so that the explanations for circuit functions apply directly to figure 7. In operation, all of the switches are, of course, closed, except the "test switch" and the switch protecting the distance milliameter and speed-current oscillograph element. Circuits necessary to eliminate commutator ripple are not shown. Voltmeters across all of the generators and voltmeters to set grade and control voltages have also been omitted to simplify the diagram. It is evident that each vacuum tube or group of vacuum tubes must be supplied with filament current from a separate transformer winding.

The voltage E_d of figure 5 may be adjusted in figure 7 by means of the grid voltages of the tubes, the resistances in series with the tubes, and by means of the resistance between points N and M. The tractive effort curve of figure 4 can be approximated to almost any accuracy desired if a sufficient number of tubes are used.

The function of the gas-filled grid-controlled "safety tube" in the circuit is to take the inductive "kick" as the speed-current is broken during the time the speed-time curve is being set up. This device

holds the voltage across the inductance to a low value and at the same time practically short-circuits the inductance so that the oscillograph speed-current goes to zero very rapidly, almost eliminating any "distance" error due to a continuation of current (by arcing at the brush) through the main circuit by inductive action. In this case the safety tube was set to operate at 100 volts reverse voltage, considerably higher than the voltage induced during the braking portion of the speed-time curve.

The train resistance voltage E_r (figure 4) may be approximated since the train resistance in pounds is given empirically[4] by an expression of the form

$$R = K_I + K_{II}V + K_{III}V^2$$

where V is speed in miles per hour and K_I, K_{II}, and K_{III} are constants. Electrically this becomes

$$E_r = E_p + ir + i^2r'$$

E_p may be set on the grade potentiometer, r may be adjusted with the resistance R in figure 7 and must include the resistance of the air core inductance, while the term i^2r' may be approximated with one or more vacuum tubes.

I-Current Circuit

On the right hand side of figure 7 the *I*-current circuit is shown. This circuit is controlled by the tractive effort voltage which is applied between the point M and the brush, acting through the 250,000 ohm circuit which is connected to the grid of the tube I_1 through the bias battery. The object in having the 2 vacuum tubes in series is to provide the proper characteristic (as shown in figure 6) between tractive effort voltage and *I*-current, with a negative grid control. This arrangement allows both tubes to operate on rated filament voltage. The curve of figure 6 could probably have been approximated much more closely by using more vacuum tubes.

In this experimental machine an "*I*-current plugging circuit" is necessary to reduce the *I*-current to zero when point M is not directly connected to point O by control circuits. In this case the "plugging circuit" sends a current through the 250,000 ohm grid control circuit for tube I_1 which makes the grid of this tube sufficiently negative to cut off all plate current.

It seems evident that since the *I*-current is determined by the tractive effort voltage at any instant, an oscillograph element placed in the circuit will draw the current-time curve. A magnetic type milliameter reads the average area, from which kilowatt-hours may be determined, and a thermal type instrument in the same circuit reads the root mean square value of current from which amperes-squared-seconds may be obtained.

Results for a Particular Test Run

The present machine is purely experimental since the commutator is divided into a relatively small number of segments providing a combination of test runs for experimental work. For practical calculations such a machine should have 300 sets of segments, thus allowing control and grade changes every 2 seconds for a 10 minute screen, or every second for a 5 minute screen.

The test run outlined in table I is for a light interurban car having 4 50 horsepower d-c motors. All figures shown in table I are summations from the starting point. For instance, the profile is shown by the figures opposite "Grade" in the table; the car runs from the starting point a distance of 4,500 feet on level tangent track, at which point it starts to climb a 1.373 per cent grade which extends to 10,267 feet from the starting point, etc.

The weight per motor is 6.188 tons. For the speed-current 1.5 milliamperes are equivalent to 1 mile per hour giving a value for K_v of 0.0015 while 1 volt is equivalent to 10 pounds per motor so that K_T = 0.1 giving a value of 2.29 henries, for the inductance to represent inertia with a commutator speed of 1,800 rpm. (Equation 3.)

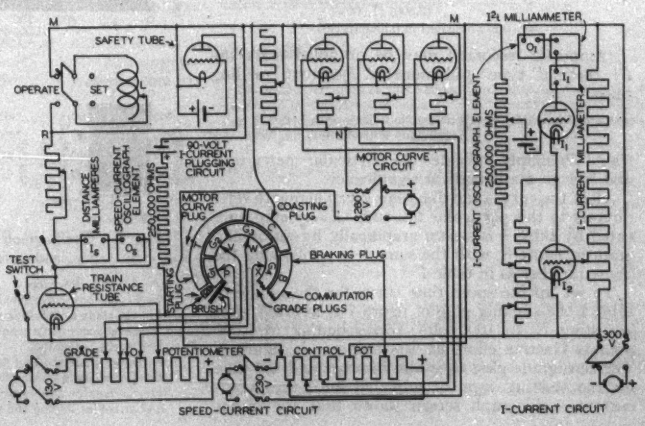


Fig. 7. Main wiring diagram

Set up for conditions of example given

Table I—Test Run

Starting current per motor, 108 amperes, which gives a normal acceleration rate of 1.48 miles per hour per second. (T = 1,000 pounds or E_s = 100 volts.) Normal braking rate 1.78 miles per hour per second. (B = 1,040 pounds or E_b = 104 volts.)

Step	A	B	C	D	E	F	G
Grade—volts	0	0	17 Up	0	0	19 Dn	19 Dn
Grade—per cent	0	0	1.373 Up	0	0	1.535 Dn	1.535 Dn
Distance—ma	0.565	7.67	17.5	23.4	31.5	33.6	34.1
Feet from start	332	4,500	10,267	13,729	18,481	19,713	20,006
I-current, ma	1.58			10.3			
Kw-hr at 600 v	0.316*			2.06*			
I^2t—ma	9.2			17.2			
(Amp.)² (Sec.)	203,136			709,056			
Time—ms	0.968	4.8	10.2	13.2	18.5	20.0	21.1
Time—seconds	17.4	86.4	183.6	237.6	333.0	360.0	379.8

* See text.

(Per cent grade) (12.38) = grade volts
(Distance milliamperes) (586.7) = distance in feet
(*I*-current milliamperes) (0.2) = kilowatt-hours at 600 volts
(I^2t milliamperes)² (2,400) = (amperes)² (seconds)
(Milliseconds) (18) = seconds

Root mean square current for the run = $\sqrt{\frac{709,056}{379.8}}$ = 43.2 amperes while the continuous rating is 55 amperes at 600 volts. Actual kilowatt-hours for the car on this run = (2.06 − 0.316/4)4 = 7.924.

A one per cent grade is equivalent to

$$(20)(W)K_T = (20)(6.188)(0.1) = 12.38 \text{ volts}$$

To convert distance milliamperes to feet from the starting point:

$$\text{Distance in feet} = \left(\frac{\text{amperes}}{K_v}\right)\left(\frac{t}{3,600}\right)(5,280)$$
$$= \frac{(\text{distance milliamperes})\ (600)\ (5,280)}{(1.5)\ (3,600)}$$
$$= (\text{distance milliamperes})\ (586.7)$$

where t is the maximum train run in seconds.

To compute kilowatt-hours at 600 volts for the relation of *I*-current to actual current shown in figure 6 (1 milliampere *I*-current is equivalent to 2 amperes motor current):

$$\text{Kilowatt-hours} = \frac{(I\text{-current in milliamperes})\ (2)\ (t)\ (600)}{(3,600)\ (1,000)}$$
$$= \frac{(I\text{-current in milliamperes})\ (2)\ (600)\ (600)}{(3,600)\ (1,000)}$$
$$= (0.2)\ (I\text{-current in milliamperes})$$

(Ampere)² (seconds) may be obtained from the I^2t thermal type milliammeter *I*-current reading since,

$$(\text{amperes})^2\ (\text{seconds}) = (I^2t \text{ reading in milliamperes})^2\ (2)^2\ (t)$$
$$= (I^2t \text{ reading in milliamperes})^2\ (2,400)$$

where I^2t simply indicates the particular meter read and has no mathematical significance.

All of the curves and diagrams given herewith refer directly to this particular test run. Every step indicated by table I is shown graphically by an oscillogram in figure 8, with the same letter following the figure number as in table I.

To set up the speed-time curve for the profile of table I the starting plug of figure 7 is inserted after adjusting E_s to 100 volts, corresponding to 1,000 pounds tractive effort at 108 amperes in figure 3. The zero grade plug G_1 is also inserted and the time for the starting segment adjusted until the speed-current oscillograph screen shows that the motor curve running speed has been attained (26 miles per hour). The oscillograph screen for this starting step is shown by figure 8*A*. The distance milliameter now reads 0.565 milliamperes showing that the car has traveled 332 feet. (See table I.)

The *I*-current oscillograph trace for this starting period is shown by figure 8*H* and the *I*-current milliampere meter reads 1.58 milliamperes which means 0.316 kilowatt-hours at 600 volts. The I^2t milliampere meter reads 9.2 milliamperes, which becomes 203,136 (ampere)² (seconds) as shown in table I, column *A*.

The motor curve plug is now inserted and segments added until the distance milliamperes become 7.67 corresponding to 4,500 feet. (See figure 8*B*.)

The G_2, 17 volts "up-grade" plug is inserted and

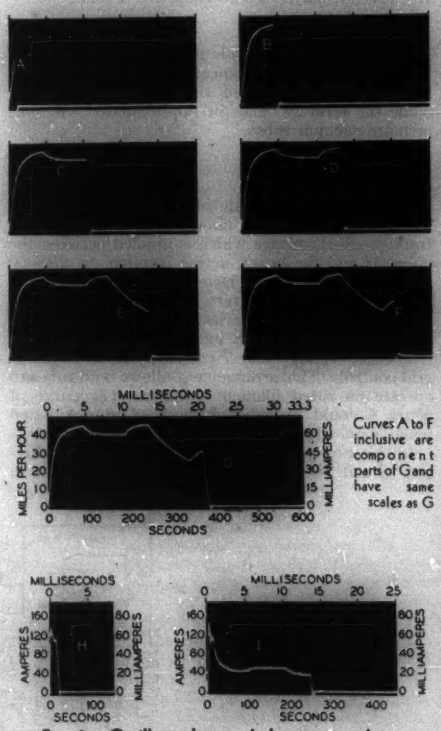


Fig. 8. Oscillograph record showing speed-time and current-time curves

A—Level starting step
B—Level motor curve running step
C—Up-grade motor curve running step
D—Level motor curve running step
E—Level coasting step
F—Down-grade coasting step
G—Down-grade braking step and complete speed-time curve
H—Current for starting step (8A)
I—Current for starting and running (8D)

more segments added until 17.5 milliamperes is read as "distance" and the screen shows the speed-time curve of figure 8*C*. Figure 8*D* shows the complete power running speed-time curve and figure 8*I* the *I*-current oscillograph trace of the current for one motor during the "power on" time.

The curve is completed as indicated by the steps shown by figure 8*E* and figure 8*F* and the complete speed-time curve as figure 8*G* which shows the total available screen time, for the test machine, of 10 minutes.

The scales shown on the oscillograms were added after printing the films to show the relation between the mechanical and electrical systems.

The root-mean-square current per motor for the run, as calculated under table I, is 43.2 amperes as compared with the continuous rating of 55 amperes at 600 volts.

Since the starting period kilowatt-hours in table I (column *A*) are for 600 volts and the motors are in series for approximately $^1/_2$ the starting period, this figure must be adjusted to 75 per cent of its present value or 0.237. As the total kilowatt-hours at 600 volts, column *D*, are also high by the same amount this must be reduced as shown under table I so that for 4 motors the total energy for the run is 7.924 kilowatt-hours.

Accuracy of the Results, and Conclusion

Table II indicates the results obtained with the electrograph and 2 sets of calculated values for this particular run.

Check *A* (see appendix for complete check *A*) is from a speed-time curve constructed in the usual manner using the maximum starting train resistance for straight line acceleration, while check *B* uses average speed resistance for starting.

Since no 2 calculated curves are exactly the same if the work is performed by 2 persons who are not collaborating, the "accuracy" of the machine seems rather difficult to determine. In general, however, the speed-time curves which have been obtained seem to be at least as accurate as the usual graphical solutions.

In table II the energy checks are almost identical with the electrograph results and the ampere-squared-seconds check rather closely with the exception of the check *B* value for column *D* which differs by 3.8 per cent.

While experience with energy and I^2t values has been rather limited, it would seem justifiable to suppose that reasonable accuracy may be expected.

In general the results have been surprisingly accurate considering the present approximations used for the various curves.

As might be expected the saving in time is considerable. The graphical solution on check *A* required some 6 or 7 hours. The electrograph calculations would probably require 10 or 15 minutes if the meters read directly in feet, kilowatt-hours, etc., but an extra period of 10 minutes was necessary to convert readings into the usual speed-time curve units.

In the experimental work, some difficulty was experienced with commutator ripple. However, this was easily eliminated by the use of proper chokes and condensers. While the rotating brush seemed to make very good contact on the rest of the segments, bad contact on the small starting segment caused low *I*-current readings. This should be eliminated by better commutator and brush design. Since the characteristic of a vacuum tube depends upon the grid voltage so long as the tube is not overloaded, no trouble was experienced in holding the curves as originally adjusted. As might have been expected iron core inductances proved unsuitable, due to eddy currents, hysteresis losses, and the changing value of the inductance during the cycle.

While the accuracy of the machine is, of course, limited to the accuracy of the meters, it might be pointed out that this inaccuracy was reduced to a minimum by using the same meters for both setting the curves and for final values.

From the results already obtained it is hoped that a machine may be built at the University which will include provisions for changing motors and gear ratios easily.

It may be pointed out that while the machine has been designed expressly for speed-time curve calculations it might be used for a variety of electrical calculations on test circuits.

Table II—Calculated Checks on Electrograph Results

Step	A	B	C	D	E	F	G
Time—Seconds							
Electrograph	17.4	86.4	183.6	237.6	333.0	360.0	379.8
Calc. check *A*	17.6	88.0	184.4	238.0	331.0	360.0	381.1
Calc. check *B*	17.4*	86.5	181.5	235.0	332.0	356.0	378.0
Energy—Kilowatt-Hours at 600 Volts**							
Electrograph	0.316			2.060			
Calc. check *A*	0.317			2.044			
Calc. check *B*	0.314			2.060			
Amperes-Squared-Seconds							
Electrograph	203,136			709,056			
Calc. check *A*	205,636			704,440			
Calc. check *B*	203,000			736,000			

* Average speed train resistance used.
** Not adjusted for series connection—see text.

Appendix

The usual method of calculating and plotting speed-time curves is illustrated by the curves of figure 9, the 3 "general formulas" which follow, and the calculations of table III, all of which are for "check A" discussed in the body of the paper.

General Formulas

$$\frac{T - R - G}{100W} = \frac{T - R - G}{618.8} = A, \text{ in miles per hour per second} \quad (9)$$

$$\Delta t = \Delta V/A, \text{ in seconds} \quad (10)$$

$$\Delta s = \left(\frac{2V + \Delta V}{2}\right)(\Delta t)\,(1.467), \text{ in feet} \quad (11)$$

Under "general formulas," above, 3 equations are listed which apply to every step shown in the solution. Equation 9 is the same as equation 1 in the body of the paper except that the term for the curve resistance *C* has been omitted, since, in this check run, the calculations are for straight track only. In equation 1 the term $100\,W\frac{dV}{dt}$ represents the force necessary to overcome the inertia for both

Table III—Calculations of Check "A"

Between Points	Speed $V+\Delta V$	T (Avg)	R (Avg)	G	A (Avg)	Speed ΔV	Time Δt	Time $t+\Delta t$	Distance ΔS	Distance $S+\Delta S$	I^{2*}	I^2
a, b	26.0	1000	88*	0	1.474	26.0	17.63	17.63	336	336	108	11,664
b, c	30.0	850	94	0	1.220	4.0	3.28	20.91	135	471	83	6,889
c, d	35.0	575	111	0	0.750	5.0	6.67	27.58	318	789	62	3,884
d, e	40.0	375	132	0	0.393	5.0	12.72	40.30	700	1,487	49	2,401
e, f	45.0	238	156	0	0.132	5.0	37.76	78.06	2,350	3,837	40	1,600
f, g'	46.0	188	172	0	0.026	1.0	38.68	116.74	2,580	6,417		
f, g	45.5							88.00		4,500	39	1,521
g, h	42.0	213	163	170	−0.194	− 3.5	18.05	106.05	1,159	5,659	45	2,025
h, i	40.0	275	149	170	−0.071	− 2.0	28.13	134.18	1,690	7,349	49	2,401
i, j	39.5	300	143	170	−0.021	− 0.5	23.80	157.98	1,388	8,737	50	2,500
j, k	39.5	312	142	170	0.000	0.0	26.40	184.38	1,530	10,267	50	2,500
k, l	42.0	275	148	0	0.205	2.5	12.20	196.58	729	10,996	45	2,025
l, m	44.0	225	159	0	0.107	2.0	18.76	215.34	1,183	12,179	41	1,681
m, n'	46.0	200	170	0	0.048	2.0	41.30	256.64	2,730	14,909		
m, n	45.5							238.00		13,729	39	1,521
n, o	41.0	0	160	0	−0.259	− 4.5	17.40	255.40	1,103	14,832		
o, p	36.0	0	136	0	−0.220	− 5.0	22.74	278.14	1,284	16,116		
p, q	30.0	0	113	0	−0.183	− 6.0	32.90	311.04	1,590	17,706		
q, r'	24.0	0	90	0	−0.145	− 6.0	41.30	352.34	1,637	19,343		
q, r	26.7							331.00		18,481		
r, s'	32.0	0	99	−190	0.147	5.3	36.01	367.01	1,552	20,033		
r, s	31.0	0						360.00		19,713		
s, t	0.0	−1040†	58	−190	−1.468	31.0	21.10	381.10	480	20,193		

* At end of Starting Period. ** For $V + \Delta V$. † Braking Force Per Motor.

Starting kilowatt-hours at 600 volts = (17.63) (600) (108) ÷ (1,000) (3,600) = 0.317
Starting I^2t = (17.63) (108)[2] = 205,636
Total kilowatt-hours at 600 volts = 2.044 (from area under current curve)
Total I^2t = 704,440 (from area under current-squared curve)
Total kilowatt-hours for 4 motors = (2.044 − 0.317/4)4 = 7.859

translation and the rotation of wheels and axles, motor armatures, etc. The grade resistance G is 20 pounds per ton per motor for every one per cent of grade while curve resistance is usually taken as 0.6 of a pound per ton per motor for every degree of curvature. The train resistance per motor is plotted before hand, as in figure 4, from any one of several empirical formulas which have been developed for this purpose, or from actual test curves for a particular car or train.

Equation 10 simply states the relation that the time necessary for a certain change in velocity in miles per hour is equal to the change in velocity divided by the acceleration in miles per hour per second.

In equation 11 the change in distance (from the starting point) is given by the average speed multiplied by the change in time and by a constant to give the distance in feet.

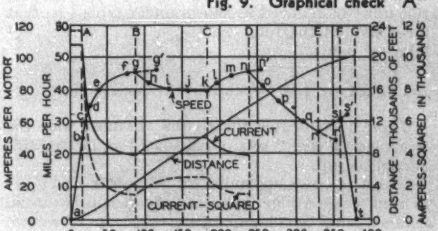
Construction of Curves

To illustrate the construction of the curves of check A the first few steps may be explained. For a starting current of 108 amperes the tractive effort per motor will be constant at 1,000 pounds until the car speed has reached a value of 26 miles per hour, from figure 3. The train resistance for this period is usually assumed to be the resistance at the end of the period (to allow for initial starting resistance) which is 88 pounds per motor, from figure 4. For level straight track G is zero. ΔV then, is first taken as 26 miles per hour and equation 9 gives the acceleration to be 1.474 miles per hour per second. Equation 10 gives the time for this change in velocity to be 17.63 seconds and equation 11 shows that the car has progressed 336 feet. This may be plotted as shown by the straight line drawn between points a and b on the speed-time curve of figure 9.

For the next step a change in velocity is assumed. For great accuracy ΔV should be as small as practical consideration will permit. If $\Delta V = 4$ miles per hour then the average tractive effort during this period, from figure 3, is 850 pounds and the average train resistance per motor is 94 pounds, from figure 4. Δt and Δs are calculated as before and the total time is, of course, $t + \Delta t$ where the total time t up to the point b is 17.63 seconds. Line bc on the curve may now be plotted.

As these calculations are performed, step by step, the speed-time and distance-time curves are drawn. This process is continued until the point g' on the speed-time curve gives a distance greater than the distance from the starting point to the first change in grade. Table I (in the paper) shows this to be 4,500 feet, so a line B drawn to cross the distance curve at 4,500 feet intercepts the speed-time curve at g, so values for step fg are read from the drawing and the time indicated by line B is 88 seconds.

Fig. 9. Graphical check "A"



From the profile outlined by table I the car now goes up a 1.373 per cent grade so G becomes:

(1.373) (20) (6.188) = 170 pounds

and the calculations are performed as before.

Continuing in this process the distance curve finally shows the stopping point for the run has almost been reached. A braking force, in this case 1,040 pounds to correspond to the electrograph conditions, is used with a minus sign as T in equation 9 and the car is brought to a stop at the point t.

The current per motor may be obtained for each speed from figure 3 and I^2 may be calculated. Both curves are then plotted as shown in the figure. From these curves the kilowatt-hours at 600 volts and the (amperes)[2] (seconds) may be calculated as shown below the listed calculations of table III. The kilowatt-hours at 600 volts have been calculated to check the electrograph results. These figures must be adjusted as explained in the paper to obtain actual kilowatt-hours for the car.

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Loads on Delta-Connected Transformers With Mid-Taps

Mid-taps on the secondaries of a 3-phase delta-connected transformer bank enable loads to be supplied simultaneously at full voltage and half voltage. Although the nonuniform loading of the different windings makes an exact determination of the maximum permissible loads difficult, equations and curves have been developed to facilitate these calculations. A rating factor is included which permits the rating of the transformer bank to be expressed in terms of the maximum current in any portion of the windings. Equations for voltage regulation with balanced loads and similar transformer units have been developed.

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It is sometimes advantageous to supply simultaneously 2 3-phase loads, one at half voltage and the other at full voltage, from a transformer bank with delta connected secondary having mid-taps. When this connection is to be used, it is necessary to determine the amount of 3 phase loads which can be carried safely at one voltage, provided the amount of load to be carried at the other voltage is known. Consideration should also be given to the voltage regulation, since it is evident that the regulation for a given 3 phase bank loaded to capacity in this manner will not be as good as if it were loaded to capacity normally.

It is difficult to determine exactly the maximum load permissible with this connection, because of the nonuniform loading of the various windings of the transformers. However, the equations and curves presented in this paper include a rating factor which permits the rating of the transformer bank to be expressed in terms of the maximum current in any portion of the transformer windings. Two sets of curves are given for determining simultaneous loading. The curves of one set (figure 3) are based upon the maximum current in any portion of the winding being limited to rated current. The curves of the other set (figure 5) are based upon a maximum current of 110 per cent rated current, and upon the additional restriction that the copper loss will not exceed that at rated load.

Previous papers have analyzed the problem for the special case where the power factors of the 2 loads are equal. In this paper the solution has been generalized to include the effect of different power factors for the 2 loads.

Voltage regulation is considered briefly, and general equations are given for the voltage regulation for this type of connection, for the case where the load on the 3 phases is balanced and the bank is made up of similar units. A table shows the results of calculations made for 3 typical transformer banks.

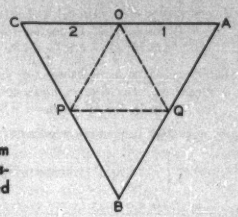

Fig. 1. Schematic diagram of delta-connected transformer with load connected to half voltage taps

Figure 1 shows the schematic diagram for the type of connection under consideration. In this diagram the dotted lines represent the half voltage delta formed by the mid-taps of the secondary windings.

Determination of Allowable Loadings

If 2 balanced 3 phase loads of any power factors are connected to a transformer bank in this manner, the load currents of the full and half voltage loads are not in phase with each other. The kilovolt-ampere capacity of the bank that can be utilized will depend upon the permissible percentage of rated current which can be carried in any portion of the windings, the relative amounts of full and half voltage load, and the power factors of the 2 loads.

The vector diagram of the currents flowing in the secondary windings of the transformer bank is shown in figure 2. Since the circuit is symmetrical and the loads are assumed to be balanced 3 phase loads,

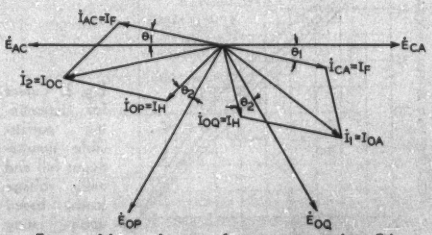

Fig. 2. Vector diagram of currents in winding CA

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the vector diagram, for simplicity, is shown only for the one phase, AC. In the diagram:

I_F = scalar value of winding current due to full voltage load.
I_H = scalar value of winding current due to half voltage load.
ϕ_1 = power factor angle of full voltage load.
ϕ_2 = power factor angle of half voltage load.

With the voltage CA used as a reference, the following equations, written in complex form, give the currents in the various portions of the winding CA:

$$I_{OA} = I_F(\cos\phi_1 - j\sin\phi_1) + I_H(0.5 - j0.866)(\cos\phi_2 - j\sin\phi_2)$$
$$= I_F\cos\phi_1 + 0.5\,I_H\cos\phi_2 - 0.866\,I_H\sin\phi_2 - j(I_F\sin\phi_1 + 0.5\,I_H\sin\phi_2 + 0.866\,I_H\cos\phi_2) \quad (1)$$

$$I_{OC} = -I_F(\cos\phi_1 - j\sin\phi_1) + I_H(-0.5 - j\,0.866)(\cos\phi_2 - j\sin\phi_2) = -I_F\cos\phi_1 - 0.5\,I_H\cos\phi_2 - 0.866\,I_H\sin\phi_2 + j(I_F\sin\phi_1 + 0.5\,I_H\sin\phi_2 - 0.866\,I_H\cos\phi_2) \quad (2)$$

I_P = current in primary winding

$$= \frac{1}{a}\left[\frac{I_{OC} - I_{OA}}{2}\right] \text{ where } a = \text{ratio of transformation}$$
$$= \frac{-2I_F\cos\phi_1 - I_H\cos\phi_2 + j(2I_F\sin\phi_1 - I_H\sin\phi_2)}{2a} \quad (3)$$

From the vector diagram of figure 2 it can be seen that:

$$I_{OA} = I_{OC} \text{ when } \phi_1 = \phi_2 \quad (4)$$
$$I_{OA} > I_{OC} \text{ when } \phi_1 > \phi_2 \quad (5)$$
$$I_{OA} < I_{OC} \text{ when } \phi_1 < \phi_2 \quad (6)$$

Equations 4, 5, and 6 show that for all cases, except for the particular case when the power factors of the 2 loads are equal, the current in one half of each secondary winding is larger in magnitude than the current in the other half. Since the current in the primary winding, as shown by equation 3, is $^1/_2$ the vector difference of the 2 secondary currents, it follows that the portion of the secondary winding carrying the greatest current will be the limiting factor in determining the safe loading for the transformer. If the current in this portion of the winding is limited to its rated value, the other half of the secondary winding and the entire primary winding will carry less than rated current. Since, then, practically $^3/_4$ of the copper in the transformer will carry less than rated current, the maximum hot-spot temperature in the windings will be lower than if all portions of the windings carried rated current. Hence, the loading of the bank can be increased somewhat above that based upon rated current in the half of the secondary winding carrying the greatest current. The amount of increase will be that which will raise the maximum hot-spot temperature of the windings to the same point as would be found if the transformer were carrying normal rated load. The determination of this allowable increase for any particular loading of a given transformer bank is, of course, difficult, if not practically impossible. In case it cannot be determined, a conservative rating should be used, such as one based upon rated winding current, or one with but little allowance made for decreased loading of other portions of the windings.

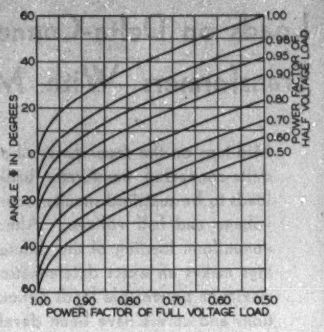

Fig. 4. Curves for determining difference between power factors of full and half voltage loads

A Factor for This Increase in Loading

The equations which follow for determining the permissible loadings of the transformer bank for various conditions contain a factor A by means of which the permissible loading may be based upon a value of current greater than rated current. If I_R is the rated current of each half of the secondary winding, and if AI_R is the permissible current which may be carried in either half of the winding, where A is the increased rating factor previously mentioned, equations 1 and 2, respectively, may be expanded and equated to AI_R.

$$I_{OA} = A\,I_R$$

or

$$I_F^2 + I_H^2 + I_F I_H[\cos(\phi_2 - \phi_1) - \sqrt{3}\sin(\phi_2 - \phi_1)] - A^2 I_R^2 = 0 \quad (7)$$

$$I_{OC} = A\,I_R$$

or

$$I_F^2 + I_H^2 + I_F I_H[\cos(\phi_2 - \phi_1) + \sqrt{3}\sin(\phi_2 - \phi_1)] - A^2 I_R^2 = 0 \quad (8)$$

These scalar equations are the basic equations for use in determining permissible full and half voltage loadings on the transformer bank. If the full voltage load is known in terms of the rating of the bank, that is

$$I_F = PI_R$$

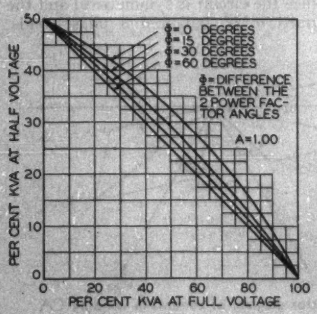

Fig. 3. Curves for determining permissible simultaneous full and half voltage loads, based upon rating factor of 1.00

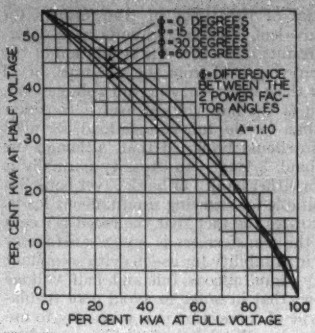

Fig. 5. Curves for determining permissible simultaneous full and half voltage loads, based upon rating factor of 1.10

where P is the ratio of full voltage load to the rated kilovolt-amperes of the bank, and PI_R is substituted for I_F in equations 7 and 8, then these equations can be solved for I_H. If Φ = the difference between the 2 power factor angles, that is

$$\Phi = (\phi_2 - \phi_1) = (\phi_1 - \phi_2)$$

then I_H may be expressed as follows

$$I_H = \frac{I_R}{2}\left\{\frac{-P(\cos\Phi + \sqrt{3}\sin\Phi) + \sqrt{P^2(\cos\Phi + \sqrt{3}\sin\Phi)^2 - 4(p^2 - A^2)}}{}\right\} \quad (9)$$

or if I_H is known in terms of I_R

$$I_F = \frac{I_R}{2}\left\{\frac{-2P_1(\cos\Phi + \sqrt{3}\sin\Phi) + \sqrt{4P_1^2(\cos\Phi + \sqrt{3}\sin\Phi)^2 - 16P_1^2 + 4A^2}}{}\right\} \quad (10)$$

where

$$2P_1 = \frac{I_H}{I_R}$$

From these equations it can be seen that the permissible loading which can be placed on either the full or half voltage delta, providing the load on one is known, depends upon the difference in power factor angles and the value of the factor A. The curves of figure 3 have been computed using equation 9 but have been converted to a kilovolt-ampere base. They show the permissible simultaneous loads which can be carried on the transformer bank. The curves of figure 3 are based upon a value of unity for the rating factor A. That is, the values of permissible loading taken from these curves will be such that in no part of the windings will the current exceed rated value. The curves of figure 4 can be used to determine quickly the difference in power factor angles for any 2 power factors.

The curves of figure 5 are similar to those of figure 3. They are based upon a value of 1.10 for the rating factor A, and upon the additional restriction that the copper losses in the bank will in no case exceed the rated full load copper loss. The necessity for this restriction can be seen by considering the case where the known load on the full voltage delta is near the bank rating. For example, if the load on the full voltage delta is 90 per cent of the bank rating, the permissible half voltage loading based upon equation 9 will be such that the copper loss will be considerable in excess of the rated full load copper loss. The curves of figure 5 are shown only in order to give the relative increase in rating as the factor A is increased. The value of 1.10 used here for the rating factor is of course an arbitrary figure and it cannot be said that this figure will be a safe value for any transformer bank. In any case of doubt, the curves of figure 3 should be used.

Voltage Regulation

The determination of the voltage regulation of the full and half voltage loads for this type of connection involves the use of the 3-winding equivalent circuit of the single-phase transformers making up the bank. Consider the single-phase transformer AC of the bank shown in figure 1, the equivalent circuit for which is shown in figure 6. This equivalent circuit is determined from simple short-circuit impedance tests on the transformer. The currents in the primary winding and in each half of the secondary winding of the transformer can be determined by means of equations 1, 2, and 3, and the regulation may be determined by making use of the following relationships.

$$V_{OC} = E_p - I_pZ_p - I_{OC}Z_{OC} \quad (11)$$

$$V_{OA} = -E_p + I_pZ_p - I_{OA}Z_{OA} \quad (12)$$

$$V_{AC} = \frac{V_{OC} - V_{OA}}{2} = E_p - I_pZ_p - \frac{(I_{OC}Z_{OC} + I_{OA}Z_{OA})}{2} \quad (13)$$

$$V_{OQ} = \frac{V_{OA} + V_{OC}\left(\epsilon^{\frac{j\pi}{3}}\right)}{2} = \frac{-E_p + I_pA_p - I_{OA}Z_{OA} + (E_p - I_pZ_p - I_{OC}Z_{OC})\left(\epsilon^{\frac{j\pi}{3}}\right)}{2} \quad (14)$$

where

E_p = primary impressed voltage in direction AC
V_{AC} = voltage of full voltage delta
V_{OQ} = voltage of half voltage delta
$\epsilon^{\frac{j\pi}{3}}$ = an operator rotating a vector 60 degrees forward

and

all impedances and voltages are referred to the primary

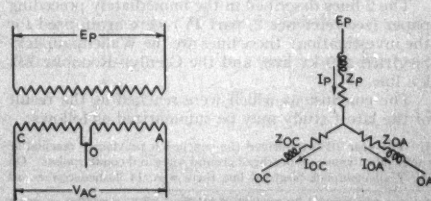

Fig. 6. Diagram of single-phase transformer AC of figure 1, and its equivalent circuit when used as a 3-winding transformer

The equivalent 3-winding circuits were determined for 3 different distribution transformers of recent manufacture. The transformers were of the low impedance type. Table I shows the calculated full-load voltage regulation of 3 3-phase banks made up of the types of transformers for which the equivalent 3-winding circuits were determined. The results show that the regulation of the banks when carrying load from the mid-taps, in all cases is poorer than when carrying full voltage load. The regulation of the half voltage load is considerably greater than for the full voltage load, for all 3 banks. It also should be noted that, although the regulation of bank 3 loaded to capacity normally is greater than for either bank 1 or bank 2, yet bank 3 is much more suitable for carrying simultaneous loads. This well illustrates the fact that the rated per cent impedance of the transformers is not a satisfactory measure of their suitability for use in delta secondary banks to carry simultaneous full and half voltage loads. It shows that in order to avoid poor regulation for this type of connection it is necessary to use transformers having the 2 halves of the secondary windings properly interlaced.

If this connection is to be used for an installation where the voltage regulation cannot be excessive, it is apparent that it is necessary to determine the 3-winding constants of the transformers and then calculate the regulation.

Table I—Calculated Full Load Voltage Regulation of 3 Banks of Transformers, for 2 Loading Conditions

	Bank 1	Bank 2	Bank 3
Transformer			
Number	3	3	3
Size, each	50 kva	25 kva	50 kva
Voltage	2,170/240/120	2,170/240/120	2,170/240/120
Type	Core	Core	Shell
Normal Load[1]			
Regulation	1.65%	1.7%	1.95%
Simultaneous Loads[2]			
Regulation			
Full voltage delta	2.6 %	2.9%	2.05%
Half voltage delta	5.5 %	6.5%	3.1 %

1. Normal load: 100 per cent rated kilovolt-amperes at 0.8 power factor.
2. Simultaneous loads: 50 per cent rated kilovolt-amperes of full voltage load; 32.5 per cent rated kilovolt-amperes of half voltage load; both loads at 0.8 power factor.

Lightning Investigation on Transmission Lines—V

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Continuing an investigation of lightning effects on power transmission lines, a recent study confirms previously reached conclusions as to the effectiveness of overhead and buried ground wires. Also, direct stroke surge currents of from 2,000 to 100,000 amperes in tower structures were measured with the surge crest ammeter, and total stroke currents up to 220,000 amperes were indicated. Values for the rate of build-up of direct stroke currents and values of potentials in the tower were obtained. Negative polarity clouds were found to be the source of almost all direct strokes.

THE investigation of lightning effects on transmission lines which has been carried on for several years and has been reported in previous A.I.E.E. papers[1,2] was continued in 1934. The present paper is the sixth of a series reporting the results of this investigation.

The 2 lines described in the immediately preceding paper (see reference 2, part IV) were again used for the investigation; these lines are the Wallenpaupack-Siegfried 220 kv line, and the Glenlyn-Roanoke 132 kv line.

The conclusions which were reached as the result of the latest study may be summarized as follows:

1. The year 1934 confirmed the conclusion previously reached as to the effectiveness of overhead ground wires and counterpoises. On the Wallenpaupack-Siegfried line there were 14 flashed towers, all of which were on the section without overhead ground wires. On the whole Pennsylvania-New Jersey interconnection (346 miles) there were 12 tripouts, 11 of which were due to flashover on the 37 miles of Wallenpaupack-Siegfried line without ground wires and 1 of which occurred on the section of the Bushkill-Roseland line between Bushkill and the Delaware River, which has overhead ground wires. However, on this section no particular effort has been made to secure low tower footing resistance.

2. If a stroke current emerges from a line conductor, flashover of the line insulation will follow.

3. Conventionally placed overhead ground wires 10 to 20 feet above the line conductor at the towers have been found in practice effectively to shield the conductors from direct strokes.

4. If a ground wire or tower is struck and the tower footing re-

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1. For all numbered references, see list at end of paper.

sistance is high enough, insulator flashover will follow due to the high potential of the tower structure.

5. A counterpoise (buried ground wire) serves effectively to reduce ground current density at the tower base and hold down tower potential, thereby preventing insulation flashover.

6. Readings of direct stroke surge currents in tower structures were obtained with the surge crest ammeter, and showed a range from 2,000 to 100,000 amperes.

7. Probable stroke currents ranged from 2,500 to 220,000 amperes.

8. Difference of potential in the tower from top to bottom has not exceeded 100,000 volts, but the whole tower may be raised above ground by a voltage equal to the flashover of the line insulation.

9. In 2 years 97 per cent of all direct strokes to 2 transmission lines were from negative polarity clouds.

10. For an isokeraunic level of 30 to 40 storms per year, records of 42 strokes per 100 miles per year were obtained.

11. From a cathode ray oscillogram of conductor potential under direct stroke conditions, the direct stroke current building up from the line structure appeared to increase approximately in accordance with the relation:

$$i = 300t^{0.84}$$

in which t is time in microseconds and i is current in amperes. This means that in 4 microseconds a current of 8,000 amperes would be reached and in 8 microseconds a current of 200,000 amperes would be reached. Insulator flashover takes place in 4 to 8 microseconds.

Line and Measuring Equipment

The 2 lines used for the investigation are the Wallenpaupack-Siegfried 220 kv line of the Pennsylvania Power and Light Company, and the Glenlyn-Roanoke 132 kv line of the Appalachian Electric Power Company (American Gas and Electric Company's system). These lines were described in the preceding paper of this series (see reference 2, part IV). In addition to the equipment previously described, the Pennsylvania line had all 4 legs of 150 towers (out of a total of 314 towers) equipped with surge crest ammeter[3] magnetic links, also links were installed on the counterpoise wires at about 8 towers. Figure 1 illustrates the equipment used at a typical tower on this line.

The Glenlyn-Roanoke line had 150 towers (out of a total of 267 towers) equipped with magnetic links on all 4 legs, in addition to a number of links on the counterpoise wires. A crater lamp oscillograph[4] was installed on this line at Roanoke. Figure 2 illustrates the arrangement of equipment at a typical tower.

Lightning Currents in Towers and Strokes

The surge crest ammeter is adapted to the measurement of both oscillatory and unidirectional surges.[3] During the 1933 and 1934 lightning seasons, records from this instrument have indicated lightning stroke surge currents in tower structures to vary from strictly unidirectional polarity surges to an extreme case of 44 per cent oscillation, that is, the second half cycle was 44 per cent in amplitude of the first half cycle. In general, the higher current lightning surges were of unidirectional polarity, and the lower surges tended toward some degree of oscillation. Additional measurements and study are required before a good interpretation of these results can be made. There are a number of considerations which must be weighed carefully as having possible significance in connection with the indicated oscillations. Particularly, the recently indicated complexity of the stroke mechanism must be borne in mind.[5,6,11] A lightning flash may consist of one or more main strokes, each of which is preceded by a leader stroke. The single stroke and the first stroke of a number of successive strokes are preceded by a leader stroke of different character than the leader stroke preceding subsequent main strokes. Within this complicated mechanism may lie the explanation of the indicated oscillations.

Table I summarizes the readings taken on the Wallenpaupack-Siegfried line during the years 1933 and 1934, both for individual tower currents and for probable stroke currents. The latter figure is made up by adding the currents in all the towers affected by a stroke. Where more than one tower is involved, data are given under the heading "tower current" for only the tower with the highest current. The maximum current in one tower recorded on this system in the 2 years was 51,000 amperes and the maximum stroke current was 107,000 amperes. As many as 7 towers have been affected by 1 stroke.

In table II are summarized similar data for the Glenlyn-Roanoke line for the years 1933 and 1934. The maximum current in one tower recorded for this system during 1933 and 1934 was 100,000 amperes. The maximum stroke current was 220,000 amperes.

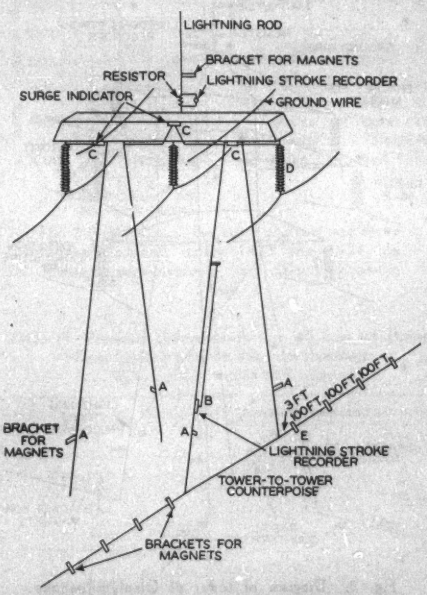

Fig. 1. Diagram of tower of Wallenpaupack-Siegfried 220 kv line, illustrating location of measuring and recording equipment

On 2 occasions as many as 8 towers were involved in 1 stroke.

All currents recorded on the Wallenpaupack system were of negative polarity. On the Glenlyn system there was 1 positive polarity tower current of 7,600 amperes in 1933, and in 1934 2 positive polarity tower currents: 1 of 36,000 amperes and 1 of 100,000 amperes. The probable stroke current in these 3 cases was 7,600, 36,000 and 193,000 amperes, respectively, of positive polarity. All other current readings on this line were of negative polarity.

In figure 3 are drawn some cumulative curves for tower currents and stroke currents, based on the data of tables I and II. It will be seen from these curves that only about 10 per cent of the tower currents are greater than 60,000 amperes, and about 10 per cent of the stroke currents greater than 100,000 amperes.

Potential Difference Across Vertical Section of Tower

The lightning stroke recorders shunted across 40 feet of the height of the tower leg on the Wallenpaupack-Siegfried line recorded voltages from 3 kv to more than 50 kv. In the latter case, the film of the instrument flashed over. About 90 per cent of the voltages were under 40 kv. The range and distribution of these potential differences for 1933 and 1934 are given in table III. Figure 4 shows a cumulative curve based on the data of table III.

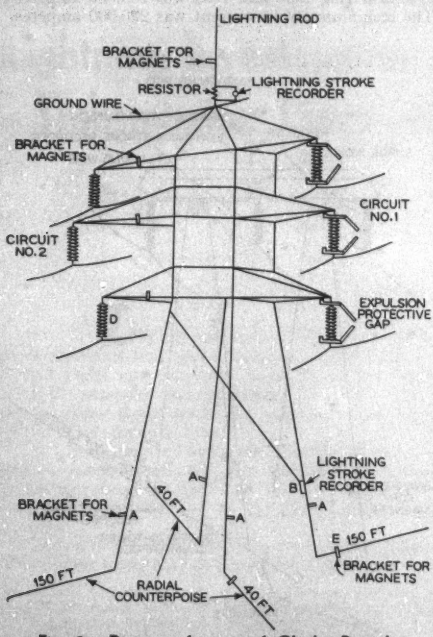

Fig. 2. Diagram of tower of Glenlyn-Roanoke 132 kv line, illustrating arrangement of measuring and recording equipment. Lightning stroke recorders not in use on this line in 1934

Table I—Tower and Stroke Currents
Wallenpaupack-Siegfried 220 Kv Line

Range of Current Amp.	Number of Occurrences: Tower Currents* 1933	Tower Currents* 1934	Probable Stroke Current 1933	Probable Stroke Current 1934
1,000– 5,000	4	4	4	4
5,001– 10,000	3	5	3	1
10,001– 20,000	7	2	6	4
20,001– 30,000	0	0	1	2
30,001– 40,000	6	2	3	0
40,001– 50,000	2		4	1
50,001– 60,000	1		1	0
60,001– 70,000			0	0
70,001– 80,000			1	0
80,001– 90,000				0
90,001–100,000				0
100,001–110,000				1
Total	23	13	23	13

* Where more than one tower is involved, data are given in this table for only the tower with highest current.

All current records are of negative polarity, that is, top of tower negative with respect to ground.

As shown in table III, field data pertaining to voltages across the tower structure during the flow of lightning currents show that these potentials are a very small portion of the total voltage required for insulator flashover. A maximum of 100 kv from tower top to ground is indicated and the great majority are below 50 kv., and many too low to be measurable (below 5 kv). Measurements of potentials on line conductors show direct strokes giving potentials limited only by insulator flashover. The rate of rise of potential is not rapid, however, requiring in one case 5 microseconds to flash over.

Polarity Relation in Direct Strokes

In almost all cases of direct strokes to transmission lines the lightning current apparently flows up the tower, i. e., in conventional terminology the tower base is positive and the tower top negative in polarity. Of 109 stroke records accumulated with the surge crest ammeter, which is an ideal indicator of direction of current flow, 106 records show upward flowing current. Assuming that upward flowing direct stroke currents in tower legs are discharge currents between a negative polarity cloud area and a positive polarity induced charge at the ground, the percentage of negative cloud strokes is 97 and positive cloud strokes 3. An observer[5] recently reporting stroke cloud polarities obtained from general field studies and not associated with transmission lines gives approximately 80 per cent for negative clouds and 20 per cent for positive clouds. These figures are for strokes between earth and cloud. Accumulated totals of 7,128 field changes, including both cloud-to-cloud and cloud-to-ground strokes,

gave 63 per cent from negative clouds and 37 per cent positive.

As 37 per cent of the total field changes were from positive polarity clouds and only 20 per cent of the field changes associated with cloud-ground strokes were from positive clouds, it is strongly indicated that many positive cloud strokes are the cloud-to-cloud or cloud-to-space type. This is in accordance with observations pertaining to the extensive ramification of streamers from positive clouds.[5,6]

Table II—Tower and Stroke Currents
Glenlyn-Roanoke 132 Kv Line

Range of Current Amp.	Number of Occurrences: Tower Currents* 1933	Tower Currents* 1934	Probable Stroke Current 1933	Probable Stroke Current 1934
1,000– 5,000	0	2	0	2
5,001– 10,000	8	3	7	3
10,001– 20,000	9	7	10	2
20,001– 30,000	4	11	2	10
30,001– 40,000	0	15	1	11
40,001– 50,000	0	5	1	7
50,001– 60,000	1	2	0	1
60,001– 70,000	1	3	1	0
70,001– 80,000		0	0	3
80,001– 90,000		0	0	2
90,001–100,000		2	0	1
100,001–110,000			0	1
110,001–120,000			1	1
120,001–130,000				1
130,001–140,000				2
190,001–200,000				1
200,001–210,000				0
210,001–220,000				2
Total	23	50	23	50

* Where more than one tower is involved data are given in this table for only the tower with highest current.

All current records are of negative polarity, except 1 in 1933 and 2 in 1934.

Now the 20 per cent positive polarity cloud-ground strokes compared with only 3 per cent positive polarity strokes which get on the transmission line, show the line to be much more susceptible to negative polarity strokes. The authors have pointed out[7] how this circumstance fits in with the directive effects of a conducting projection above the plane of the seat of the positive charge. The transmission line acting as such projection above the positive charge on the earth serves as an origin from which the stroke builds up to the cloud. Laboratory tests using small scale models indicate that under these conditions all negative cloud strokes within a distance of 10 to 20 times the height of the line will emanate from the line and build upward to the seat of the negative electrification in the cloud. The excellent photographs,[8,9] recently obtained with the Boys camera have recorded this building up of the main stroke. A preliminary stepped streamer of very long time formation apparently provides initial ionization for the starting of the initial main stroke. The location of this preliminary ionization may, of course, determine the point of contact of the stroke at the tower top, on the ground wire, or on the conductor. Cases of direct strokes to conductors which are apparently well shielded by overhead ground wires may be caused by line excitation controlling the direction of the preliminary ionizing streamer. The Boys camera photographs have confirmed early observations[10] that many strokes are made up of repeated discharges through the same breakdown channel, and another investigation[11] has shown such strokes frequently to strike the transmission line.

The 109 records of lightning stroke currents referred to above were obtained on 130 miles of line over a 2 year period of time. This gives an expectancy of 42 strokes per 100 miles per year for the territory traversed by the lines, which is in an isokeraunic region of 30 to 40 storms per year.

Analysis of Various Cases of Direct Strokes to Transmission Lines

The complete electrical mechanism of the lightning stroke, insulator flashover, and line tripout is, of course, complicated. Accumulated data have, however, shown that the really significant elements are not many and fit together in a very simple way.

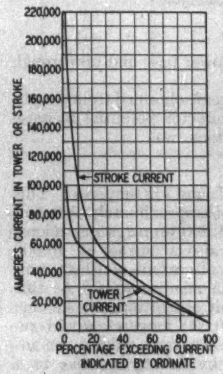

Fig. 3 (left). Cumulative curve of tower and stroke currents recorded during 1933 and 1934, on Wallenpaupack-Siegfried and Glenlyn-Roanoke lines

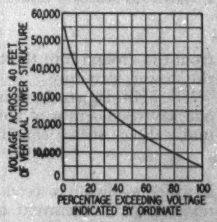

Fig. 4 (above). Cumulative curve of voltage across 40 feet vertical of tower on Wallenpaupack - Siegfried line during 1933 and 1934

Table III—Potential Difference Across 40 Feet of Tower, From Lightning Stroke Recorder Readings
Wallenpaupack-Siegfried 220 Kv Line

Range of Volts	Number of Occurrences: 1933	1934	Total
1,000– 5,000	4	2	6
5,001–10,000	10	7	17
10,001–15,000	15	9	24
15,001–20,000	2	5	7
20,001–25,000	6	1	7
25,001–30,000	3	2	5
30,001–35,000	4	1	5
35,001–40,000	1	5	6
40,001–45,000	2		2
45,001–50,000	0		
50,001–55,000	1		
Total	48	32	8

Majority of voltage records negative, that is, top of tower negative with respect to bottom.

Case I.—Stroke to a Tower, No Ground Wires Present. When a lightning stroke builds up from a tower top with no ground wire present, the entire current feeding into the extending streamer tip, proceeding at approximately 150 feet per microsecond,[8] flows from the ground into the tower base and up through the tower structure.

Table IV—Field Record Illustrating Direct Stroke to a Tower. No Ground Wires Present

Wallenpaupack-Siegfried 220 Kv Line

Tower Number	Footing Resistance Ohms	Tower Current(A)Amp.	Tower Potential Kv	Across-Tower Potential (B) Kv	Insulator Assembly-Phase: Surge Indicator Operation (C)	Insulator Assembly-Phase: Flash Marks(D)	Line Trip-Outs	Short Circuited Phase (F)
*WT*27-6	58	−36,000	2,100	50	*Y*	*Y*	Yes	*Y*
*WT*28-1	45	− 3,000	135	64	*Y*	*Y*		

A, B, C, D indicate data recorded by instruments located as shown on figure 1. *F* indicates data recorded by magnetic oscillograph.

The lightning stroke current, obtained from a cathode ray oscillogram of conductor potential increase under direct stroke conditions, was

$$i = 300e^{0.9t}$$

in which t is in microseconds and i in amperes. This relation gives a current of approximately 700 amperes and a rate of rise of 600 amperes per microsecond at 1 microsecond, also a current of 16,000 amperes and a rate of rise of current of 13,000 amperes per microsecond at 5 microseconds. At this rate the extreme upper limit of lightning stroke current of approximately 200,000 amperes would require 8 microseconds to reach crest value. An insulator flashover at 1,800 kv due to a stroke to a tower of 50 ohms footing resistance would be reached in about 6 microseconds. This is slow compared with the time length (0.1 microsecond) of the tower structure.

At the tower base the ground current density is highest, and a potential difference appears depending upon this density and the ground resistance. The tower structure therefore is elevated in potential above ground potential by this amount while the conductors remain at practically ground potential. A voltage instantaneously equal to stroke current times tower footing resistance builds up across each insulator assembly. This potential combined with the normal excitation voltage of each conductor gives the total insulator assembly stress. As these potentials are combined with respect to polarity, a negative tower potential added to a positive conductor potential will give maximum insulator assembly stress and the phase in this condition will flash over first. One assembly flashover reduces the tower potential just as much as connecting $^1/_2$ the conductor surge impedance across the tower footing resistance would. This reduction in tower potential may be sufficient to prevent other insulator assemblies flashing over, and if so, only a single-phase flashover is obtained. If the stroke current, however, is sufficiently high again to increase the tower potential in spite of the lowered impedance to ground, additional assemblies will flash over. As tower potentials are usually negative for direct strokes to the tower, flashover will occur on the conductor having positive polarity excitation at the time of the stroke. Insulator flashover may occur at adjacent towers if the potential carried along the flashed conductors is sufficiently high. A specimen field record of such an occurrence obtained on the Wallenpaupack-Siegfried line[12] during the season 1933 is given in table IV.

These data indicate a stroke to tower *WT*27-6. At this tower 36,000 amperes flowed in the tower structure, the tower base being positive and the tower top negative in polarity. On this basis the assumption is made that a stroke occurred between the tower top and a negative polarity cloud. The measured tower footing resistance of 58 ohms gives a tower potential of 2,100 kv. The laboratory flashover of the 16 unit string ranges from 1,650 on the $1^1/_2 \times 40$ microsecond wave to 1,900 kv on the 1×5 microsecond wave. These values are exceeded by the 2,100 kv tower potential. The across-tower potential of 50 kv (from top to bottom of tower) is obviously a negligible proportion of the insulator flashover voltage. The surge indicator on *Y*-phase tower arm at 27-6 and flashover marks showed flashover to have occurred on this insulator assembly. Also, the surge indicator and flashover marks on *Y* phase of adjacent tower 28-1 showed insulator assembly flashover. The current in this tower structure was just high enough to leave a record on the surge crest ammeter, 3,000 amperes. Accompanying this lower tower current, however, was an across-tower potential of 64 kv, more voltage than at the tower where the lightning disturbance occurred. Keeping in mind the abrupt flashover of the insulators at approximately 1,800 kv, the nature of this across-tower voltage is readily apparent. Similar voltages are obtained across conduc-

Table V—Field Record Illustrating Direct Stroke to a Conductor. No Ground Wires Present

Wallenpaupack-Siegfried 220 Kv Line

Tower Number	Footing Resistance Ohms	Tower Current(A)Amp.	Tower Potential Kv	Across-Tower Potential (B) Kv	Insulator Assembly-Phase: Surge Indicator Operation (C)	Insulator Assembly-Phase: Flash Marks(D)	Line Trip-Outs	Short Circuited Phase (F)
*SR*8-1	34	−12,000	408	74	*W*	*W*	Yes	*W*
*SR*8-2	23	− 8,000	194	58	*W*	*W*		

A, B, C, D indicate data recorded by instruments located as shown on figure 1. *F* indicates data recorded by magnetic oscillograph.

tors leading to the insulator string in laboratory flashover tests. This is a traveling wave phenomenon and the wave steepness at tower 28-1 was sufficient to give 32 kv across the 40 feet of tower structure adjacent to the insulator assembly flashed over and spanned by the lightning stroke recorder connections. As the tower height is about 80 feet, the total across-tower potential is estimated at 64 kv. A line trip-out occurred with this disturbance and magnetic oscillographs indicated the flashover to be on *Y* phase. On tower 27-5, adjacent to 27-6 on the side opposite to 28-1, which was also equipped with measuring instruments, no records were obtained.

Such a disturbance record strongly indicates a stroke to a tower followed by a single-phase flashover caused by high tower potential, followed by flashover on the same phase at an adjacent tower caused by high conductor potential. Such an interpretation is also generally confirmed by many other records.

Case II.—Stroke to a Conductor, No Ground Wires Present. If, as frequently occurs, the lightning stroke to a line having no overhead ground wire emerges directly from the conductor, flashover invariably occurs. In this case the current feeds along the conductor into the stroke. Conductor potential will rise just as though the stroke were passing to ground through a resistance equal to $^1/_2$ the surge impedance of the conductor (approximately 200 ohms). This is, of course, a high resistance and will require only a moderate lightning current to give flashover even on the highest voltage lines. Insulator assemblies on adjacent towers on the phase struck are quite certain to flash over. The stroke currents now feed up through the tower structures. Again, additional assemblies may flash over, but are not quite so likely to do so, as the stroke current has been divided between 2 towers.

In the case of a stroke directly to a conductor, the conductor potential due to the stroke is invariably high enough so that line excitation is not a factor in flashover. However, the excitation will determine whether or not trip-out follows and may also be a factor in determining which conductor is struck, as previously mentioned.

An example of a field record obtained in the case of a direct stroke to a conductor on the Wallenpaupack-Siegfried line during 1933 is given in table V.

In this case all records obtained show the disturbance to be about the same at both the adjacent towers involved, *SR*8-1 and *SR*8-2. Surge indicators and flashover marks showed flashovers to have occurred on *W* phase at both towers. The line tripped out and short-circuit current indicated flashover on *W* phase. Tower currents and footing resistances gave tower potentials well below insulator flashover. Across-tower potentials were of low magnitude as compared to insulator assembly flashover voltages, but are still quite reasonable as voltage differences resulting from insulator flashover waves traveling to ground through the tower structure. This stroke quite certainly built up from *W* phase conductor in mid-span, probably nearer to *SR*8-1 than *SR*8-2. Current feeding into the point of emergence of the stroke from both directions raised the conductor to flashover potential at both towers. Only 10,000 amperes stroke current or 5,000 amperes conductor current were required. Flashover by lightning stroke current was followed by short-circuit power current, and trip-out resulted. This case is typical of measurement results obtained for strokes to a conductor.

Case III—Stroke to a Tower With Ground Wires. The case of a direct stroke to a tower of a line equipped with overhead ground wires is very much the same as without ground wires, especially when tower footing resistances are low. The ground wire, of course, assists in holding down the tower potential at the stroke. The current flowing into the stroke feeds in through the ground wire from both directions as well as up through the tower structure. As a result, the resistance drop at the tower footing is reduced in proportion to this decrease in tower footing current. Assuming a surge impedance of 250 ohms in both directions for the ground wire and a footing resistance of 50 ohms, the ground wire will carry a portion of the total stroke current at least as great as the inverse ratios of these resistances. The more slowly the feed-in current to the stroke builds up, the greater will be the portion of current carried by the ground wire. It is believed that in many cases these ground wire currents are very much higher than might be indicated by comparison of ground wire surge impedance and footing resistance at the tower struck. In other words, the ground wire serves effectively in holding down structure potentials because it provides for the feeding in of stroke current through several adjacent tower footings.

Table VI—Field Record Illustrating Direct Stroke to a Tower. With Ground Wire Present

Glenlyn-Roanoke 132 Kv Line

Tower Number	Footing Resistance Ohms	Tower Current(A) Amp.	Tower Potential Kv	Expulsion Protective Gap Operations Circuit No. 1	Trip-Outs
78*R*	12	−16,600	200	Top phase	
79*R*	12	−86,000	790	All 3 phases	Circuit 2
80*R*	5	−36,000	180	Top phase	

A indicates data recorded by instruments located as shown on Fig. 2.

A specimen field record obtained during 1934 from the Glenlyn-Roanoke line pertaining to this case is given in table VI.

Towers adjacent to the consecutive towers listed in the table showed no evidence of having participated in the disturbance. The stroke was located at tower 79*R* and tower potential at this structure was high enough to operate all 3 expulsion protective gaps[18] on circuit 1, and to flash over insulators on circuit 2. The gaps prevented an outage on circuit 1. On circuit 2 at least one insulator assembly of a

10 unit string flashed over, trip-out of this circuit resulting. The 1 × 5 microsecond wave flashover for 10 units is 920 kv and the $1^1/_2 \times 40$ microsecond wave flashover is 820 kv. As the tower potential was 790 kv, a very slow wave is indicated. The lightning currents feeding in over the ground wire and the flashed conductors divided in adjacent towers about inversely as footing resistances.

Case IV—Stroke to Ground Wire. A stroke building up from near mid-point on the ground wire is fed by currents flowing in from both directions. Here the potential of the ground wire will be something less than $^1/_2$ the stroke current times the surge impedance of the ground wire. Reflections returning from adjacent tower footings where resistance is low will act to hold down ground wire potential, and more effectively the slower the building up of current feeding into the stroke. The effectiveness of conventionally spaced ground wires in reducing insulator flashovers has long been recognized. Many strokes have built up from these wires and flashover to line conductors has apparently not occurred. This is in spite of the fact that a value of 50,000 amperes is reasonable for many strokes. One-half this current with a 500 ohm surge impedance and no reflections would give a ground wire potential in excess of 12 million volts. Some coupling effect with the line conductors would, of course, reduce the insulator stress below this value. The inference, however, that ground wire potentials are effectively reduced by reflections from adjacent tower footings before flashover voltages to the conductors are reached appears inescapable. Only one microsecond is required for the returned reflection in the extreme case of 1,000 foot tower spans. A record of a specimen mid-span stroke to a ground wire on the Glenlyn-Roanoke line during the 1933 season is shown in table VII.

Table VII—Field Record Illustrating Direct Stroke to a Ground Wire

Glenlyn-Roanoke 132 Kv Line

Tower Number	Footing Resistance Ohms	Tower Current (A) Amps.	Tower Potential Kv	Across-Tower Potential (B) Kv	Expulsion Protective Gap Operations Circuit No. 1	Trip-Outs
103*R*	4	−16,400	65	50	None	None
104*R*	13	−20,400	265	80	None	
105*R*	16	0	0	10	None	

A, *B* indicate data recorded by instruments located as shown on figure 2.

In this case the nearly equal division of current between towers 103*R* and 104*R* and the very similar across-tower potentials, point to a direct stroke at mid-span on the ground wire. The tower footing resistances were sufficiently low to hold down tower potentials below expulsion protective gap operation and insulator flashover. No disturbance to line operation resulted from this stroke and no line damage was traced to it. On a surge impedance basis, assuming 500 ohms for the ground wire, a current of 20,000 amperes should give a ground wire potential of 10 million volts, sufficient potential to flash over to a conductor. Obviously, the rate of current rise was slow enough to permit repeated reflections from tower footing to eliminate to a considerable extent the surge impedance of the ground wire.

The Counterpoise (Buried Ground Wire)

The most significant way in which the counterpoise functions to prevent line flashover is by reducing current density in the earth at the tower base. In this way the voltage drop at the tower base is reduced and the tower structure is held down to values below insulator flashover.

An excellent record illustrating the functioning of the counterpoise was obtained on the Wallenpaupack-Siegfried line during 1934. The record is shown in table VIII.

The stroke is assumed to have built up from the overhead ground wire near tower *WT*12-3. The concentration of the tower leg currents at the tower side connected to the counterpoise is quite evident. Figure 1 shows how the counterpoise is connected to the legs at these towers. Before the installation of the counterpoise 3 of these tower footing resistances were approximately 80 ohms, a value which with the current shown in table VIII would give tower potentials well over insulation flashover. The across-tower potentials were low. Apparently no flashovers occurred between the overhead ground wire and conductors, even though large currents flowed from tower to tower and the ground wires were but 16 feet away from the line conductors.

Effective Location of Overhead Ground Wires

In table IX is summarized a comparison of faults on double circuit lines on 2 systems, that of the Victoria Falls and Transvaal Power Company, South Africa,[14] and that of the New York Power and Light Corporation. Following is a brief description of these lines. The Victoria Falls line is 63.5 miles long of double circuit. The spacing between conductors in each circuit is 12 feet and the horizontal distance between circuits is 23 feet. There is one center ground wire 18 feet above the top conductors. The record for this line in table IX is for the 8 years, 1926 to 1933, inclusive. In 1930, 2 additional ground wires were attached to the top cross arm of towers 120 to 140 inclusive, one over each circuit. Also, in the same year, one additional ground wire was attached to the top cross arm over the South circuit on towers 141 to 164, inclusive. The additional ground wire or wires covered about 12.5 per cent of the total number of towers, which is 361. The insulation of these lines consists of 9 disks having a dry flashover of 350 kv root mean square in suspension, and 11 disks with a dry flashover of 420 kv root mean square in strain. These are equivalent to about 6 and 7 $5^3/_4$ inch disks, respectively.

The New York Power and Light Corporation por-

tion of table IX covers 8 110 kv double circuit lines, a total of 316 miles. The spacing between conductors varies from 8 to 13 feet and the horizontal spacing between circuits from 17 to 28 feet. 98 miles of line have one central ground wire 8 feet above the top conductor. The remaining 218 miles have 2 ground wires 7 and 8 feet above the top conductor and 20 to 36 inches apart. The record is for the better part of 4 lightning seasons, beginning June 1931 and ending July 1934. The insulation on these lines consists of 7 to 11 disks.

It will be noted that the double circuit faults on both sets of lines tend to be fairly even on top, middle, and bottom conductors. The single circuit faults, however, are very high on the top conductor, lower on the middle, and lowest on the bottom for the Victoria Falls line; while for the New York Power and Light Corporation line the single circuit faults are highest on the bottom conductor and lowest on the top conductor.

These figures indicate fairly good shielding on the New York Power and Light Corporation line and poor shielding on the Victoria Falls line. The majority of the single circuit faults are probably due to strokes making direct contact with the conductors. On the Victoria Falls line the major portion has only one ground wire. Many strokes evade the ground wire and make contact with the conductors, especially the top conductor. The high ground wire has poor coupling with the conductors and gives poor induced stroke protection.

On the New York Power and Light Corporation lines the ground wires are closer to the conductors. The coupling with the conductors is good and the induced stroke protection good. This arrangement is effective in reducing direct strokes to the conductors, particularly to the top conductor. Most of the flashovers involve more than one conductor and both circuits, and the numbers on top, middle, and bottom conductors tend to average up.

It is essential in order to protect such double circuit lines to have 2 overhead ground wires, 1 over the conductors of each circuit, in order to prevent direct contact of the stroke with the conductors. Heights of 10 to 15 feet above the top conductor at the towers seem to be ample, based upon practical experience.

For prevention of flashover when the stroke makes contact with the ground wire or tower top, the tower footing resistance must be low, so that the product of the lightning current in the tower and footing resistance will not exceed the insulator flashover. On the Pennsylvania Power and Light Company's 220 kv line the critical resistance is about 12 ohms, and on the South African 132 kv line[14] the critical resistance appears to be about 7 ohms.

For single-circuit horizontally arranged lines 2 ground wires are usually installed, placed midway between the vertical planes through middle and outside conductors, or in some cases near the outside conductors. These appear to shield the conductors from direct contact with the stroke, and if the footing resistance is low enough, flashover is prevented in case of contact with the ground wire or tower. Ground wires 10 to 20 feet above the conductors at the towers appear to be amply high, based upon operating experience.

For lines without overhead ground wires, the stroke usually hits the conductor between towers and flashover nearly always results. The tower footing resistance has no effect on flashover in such cases except where the stroke makes contact with the tower. It is almost hopeless to try to prevent flashover of such a line, unless some auxiliary means are used, such as expulsion protective gaps.

Table VIII—Field Data Illustrating Effect of Counterpoise on Distribution of Direct Stroke Current in Tower Legs

Wallenpaupack-Siegfried 220 Kv Line

Tower Number	Tower Footing Resistance, Ohms	Tower Leg Currents (A): Legs Connected to Counterpoise, Amp.	Tower Leg Currents (A): Free Legs, Amps.	Across-Tower Potential (B) Kv	Remarks
WT11-5	1.4	− 2,200	0	None	No trip-out or damage to the line resulted from this stroke
WT12-1	1.4	− 12,200	− 3,500	16	
WT12-2	1.4	− 13,900	− 4,000	16	
WT12-3	1.4	− 24,400	−14,300	64	
WT12-4	1.3	− 5,400	− 1,000	None	
WT12-5	1.7	− 18,900	− 3,200	6	
WT12-6	1.4	− 2,300	0	14	
		− 79,300	−26,000		
		− 26,000			
		−105,300	Total stroke current		

A, *B* indicate data recorded by instruments located as shown on figure 1.
Figure 1 shows how the counterpoise is connected to the legs at the above towers.

Table IX—Single and Double Circuit Faults

Victoria Falls and Transvaal Power Company (132 Kv) and New York Power and Light Corporation (110 Kv) Transmission Lines

Conductor	Victoria Falls: Single Circuit	Victoria Falls: Double Circuit	New York Power and Light: Single Circuit	New York Power and Light: Double Circuit
Top	43	26	8	41
Middle	17	30	12	38
Bottom	13	32	13	36
Total	73	88	33	115

Victoria Falls and Transvaal Power Company data from 63.5 miles of double circuit line. Eight years record from 1926 to 1933, inclusive.
New York Power and Light Corporation data from 316 miles of double circuit line. Three and one-half years record from 1931 to 1934.

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Firing Time of an Igniter Type of Tube

The time interval required for ignition or "firing" of an igniter type of rectifier tube is found to vary in a statistically systematic manner between successive operations. When in continuous operation with igniter rod potential gradients greater than a critical value the median firing time is an inverse exponential function of the gradient in the rod. If the gradient be reduced gradually below the critical value the firing time rapidly approaches infinity, corresponding to failure to ignite at all. Temperature rise of the rod caused by continuous operation of the tube results in a marked reduction in resistance, critical gradient, and median firing time.

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TO THOSE engaged or interested in the development of the igniter type of mercury rectifier tube or in its applications, it may be useful to know how much time may be expected to elapse between the application of the initiating impulse to the igniter rod of the tube and the establishment of the arc between cathode and anode, and how this time is affected by conditions of operation. The cathode ray oscillograph measurements here described have shown that an ignition time of the order of a few microseconds ordinarily may be expected, but that it varies over a rather wide range for moderate and low impulse gradients along the igniter rod.

A Westinghouse tube, type *KU*-637, having a continuous average current rating of 5 amperes with convection cooling, 20 amperes if fan-cooled, and a surge current rating of 1,000 amperes, was used for the tests. It is of glass and metal construction, of the general shape illustrated by figure 1. The over-all length is about 12 inches and the diameter 5 inches. There are 3 electrodes: a graphite anode at the top, a mercury pool cathode at the bottom, and an igniter rod, of carborundum or similar material, the lower end of the rod being immersed in the pool to a depth of a few millimeters. The rod of the particular tube used has a d-c resistance of 80 ohms when cold and 20 to 40 ohms when heated by continuous operation. Its length between the supporting bracket and mercury level is 23 millimeters, and its diameter about 3 millimeters; it tapers to a point at the lower end, but most of the tapered length is immersed so that the diameter is practically constant over the length external to the mercury.

In evaluating the results of these tests it must be recognized, of course, that the particular tube used was one of the earlier ones of its kind (it was received in March 1934) and that manufacturing details probably have changed since that time, although the principles of construction and operation are the same. The quantitative results here reported apply, of course, only to the particular geometry and materials used in the tube tested, but the results should be helpful in interpreting the behavior of other tubes having principles of operation similar to this one.

For the particular tube used:

1. The only time element of importance in the ignition process is that between application of the voltage impulse and the initiation of an arc between the mercury pool and the bracket holding the rod. The arc between cathode and anode forms immediately, closing the anode circuit in a small fraction of a microsecond after the arc first strikes to the bracket.

2. The time required for the arc to strike to the bracket varies from cycle to cycle, the variations following a simple statistical law.

3. When in continuous operation with igniter rod potential gradients greater than a critical value (about 85 volts per centimeter in these tests) the median time varies as an inverse exponential function of the voltage gradient in the rod; one series of tests indicates a median time of $1^1/_2$ microseconds and another about 3 times that for a gradient of 150 volts per centimeter.

4. As the rod gradient is reduced below the critical value the median time required for ignition rises rapidly, but not abruptly, toward an infinite value corresponding to failure to fire at all.

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2. For all numbered references see list at end of paper.

5. Because the shift between the nonfiring condition and that of a finite median firing time is not an abrupt one, the phase position at which ignition occurs in response to a gradually growing igniter-rod voltage, such as a 60 cycle sine wave, should vary from cycle to cycle, as it does in fact.

6. The resistance of the rod, the critical gradient, and the median firing time for a given gradient all decrease substantially as the tube and the rod heat up in continuous a-c operation. The rod resistance and critical gradient decrease to about $^1/_3$ to $^1/_2$ of the cold values, and it seems likely that the logarithm of the median critical-gradient firing time decreases in a similar ratio.

7. The statistical nature of the time relation leads to intermittent operation, that is, occasional failure to ignite at all, if the rod gradient be small or of very short duration. For any given igniting circuit it should be possible to calculate the per cent flicker if the statistical law governing the rod behavior be known, and also to predict the extent of time variation in ignition. With rod gradients in the neighborhood of 150 volts per centimeter the probability of flicker is extraordinarily small if the duration of the firing impulse is as much as 10 or 15 microseconds.

8. With rod gradients in the neighborhood of 300 volts per centimeter, the lower limit of time for ignition, and therefore the minimum energy required for ignition, is determined by the relative values of resistance and inductance in the igniting circuit.

9. If very prompt ignition be desired, either to reduce energy demand or for other reasons, it is necessary to keep the inductance of the igniting circuit small, that is, a matter of a few microhenries, the upper limit depending on the resistance of the igniting circuit and the speed of response wanted.

10. Ignition occurs satisfactorily with connections to the mercury pool and the bracket reversed, the bracket then serving as the cathode. No time tests were made with these reversed connections.

11. The results of these measurements, together with tests made by others on backfires in mercury rectifiers[3] and reignition of a-c atmospheric arcs,[4] suggest the existence of a statistical type of relation between ignition time and gradient for any spark or arc kindling process. In the present study the microscopic effects of mercury level variation must contribute to the statistical variability of firing time; but it is not at all certain that this is an important cause of the time variations, because indirect evidence suggests statistical behavior when the arc originates between the rod and the fixed metal bracket.

Ignition Process

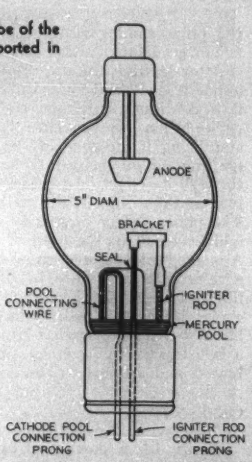
Ignition of the arc within the tube depends on the existence of a considerable potential gradient in the rod at the junction with the mercury surface. It consists of 2 distinct operations: one the initiation of an arc between the cathode pool of mercury and the metal bracket that supports the rod, the other the establishment of the arc path to the anode. Test results show that the only appreciable time element is that between the application of voltage to the rod and the initiation of the arc from the mercury pool to the bracket.

Tiny sparks can be observed at the junction of the mercury and igniter rod when the gradient is almost but not quite large enough to initiate the arc. Even when the gradient is produced by a steady direct current these sparks dodge erratically about the rod-mercury junction. As the gradient becomes larger the sparks become less yellow and more brilliantly white, until finally an arc forms at the junction. The lower terminal of this arc, a hot spot cathode, moves away from the rod along the surface of the pool, while the upper terminal travels upward along the rod with extreme rapidity; when it reaches the metal of the supporting bracket the rod of course is short-circuited by the arc. Ignition of this arc across the rod occurs with current in either direction; if the upper end of the rod be the more negative terminal the arc originates there, the cathode moving away from the rod along the metal of the bracket, and the other end of the arc traveling rapidly down the rod to form an anode on the mercury pool. If voltage impulses be applied to the igniter rod with the anode disconnected, these formations along the rod and bracket easily may be observed. With reverse gradients almost sufficient for ignition the same kind of erratically dodging sparks appear at the junction of the rod with the fixed metal of the bracket as those normally observed at the junction with the slightly agitated mercury pool surface; movements of the liquid at the junction cannot be considered the controlling influence in the shifting of the sparks.

Test Procedure

During the tests for determining the time required for ignition the tube was operated continuously on alternating current, with an average current of about half the normal rating. The circuit arrangement, illustrated in figure 2, was designed primarily for convenience in applying an igniting impulse of controllable magnitude and phase position. During

Fig. 1. A 2.5 ampere tube of the type used in the tests reported in this paper



each half cycle in which the anode is negative the capacitor of the igniting circuit is charged through the mercury rectifier tube to the peak of the 440 volt wave (see figure 3). The grid of the grid-controlled gas-filled rectifier tube swings positive at some controllable moment in the succeeding positive half cycle; the grid-controlled tube becomes conducting at once so that capacitor potential appears across the noninductive resistor and igniter rod in series. The potential gradient in the rod is determined by

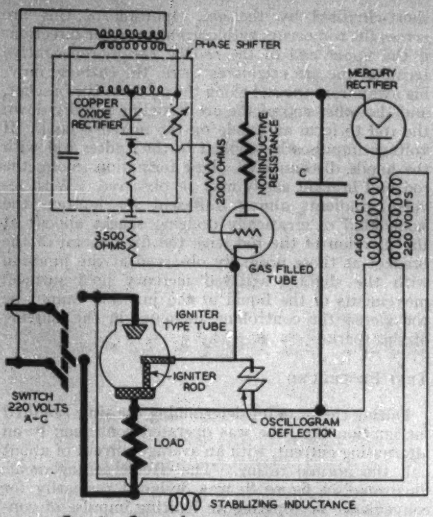


Fig. 2. Circuit for measuring ignition time

the proportioning of these 2 resistances; with sufficient gradient, ignition occurs.

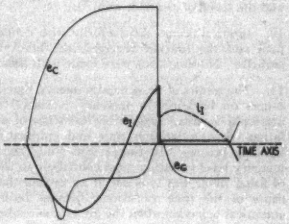
After ignition the arc drop between cathode and anode is small and approximately constant; current flow continues until the end of the positive half cycle, when the sequence begins again. A small stabilizing inductance in the power supply to the igniting circuit helped to reduce flicker, possibly through its effect on transient interactions between load and igniting circuits at the moment of ignition. The phase shifter ordinarily was adjusted to cause ignition at about the peak of the positive half cycle. A peaked grid voltage was desired in order to insure a nonconducting state in the grid-controlled gas-filled tube at the beginning of each inverse half cycle; it was obtained by having the phase shifter battery charge through a copper oxide rectifier and a resistance; the voltage from the resistance was biased and applied to the controlling grid.

Oscillograms

Figure 4*A*, a slow-speed cathode-ray oscillogram, illustrates the over-all form of the condenser discharge current in the rod. Discharge was completed in a little more than 200 microseconds in the operation recorded by this oscillogram; the time varied for different values of capacitance and igniting circuit resistance. Figure 4*B* contains 3 high speed records of the rising portion of rod current, showing that it grows very rapidly to an intermediate value, hesitates there for a few microseconds, then proceeds upward to a maximum. The hesitation occurs at the current value determined by the combined resistance of the noninductive resistance and rod; the abrupt progression upward occurs when the arc strikes to the bracket, short circuiting the rod and permitting a larger current to flow. The useful function of the igniting circuit is completed as soon as the current starts to rise from the intermediate level. Such current records permit determination of the ignition time, but a more satisfactory measurement is obtainable from records of the voltage across the rod, illustrated by figure 4*C*. The rod voltage rises abruptly at the moment the grid-controlled tube discharges and vanishes abruptly when the bracket arc initiates, so that the duration and height of the rise in the rod voltage, as recorded by the oscillograph, measure the time required for ignition at a given voltage. Records of this kind were made at brief intervals, the tube remaining in continuous operation throughout entire sets of tests. The temperature of the base of the tube was recorded from time to time; it was found to remain practically constant for the duration of each series of observations. The oscillograph film was advanced slightly, and the position of the electron beam's trace shifted slightly, magnetically, between successive observations, giving rise

Fig. 3. Cyclic variations of current and voltage

e_c = voltage across capacitor
e_i = voltage across igniter type tube
e_g = grid voltage of grid-controlled gas-filled rectifier tube
i_i = current in igniter type tube



to the type of record illustrated by figure 4*D*, each film accommodating many voltage traces.

The 3 separate voltage traces of figure 4*C* illustrate the variability of the ignition time. Although the rod voltage values for the 3 records are not markedly different, ignition took place in 1.1, 3.6, and 1.4 microseconds, respectively. Much larger variations in firing time occurred at lower ignition gradients; near a critical low value of gradient ignition often occurred after the trace passed beyond the limits of film exposure, and sometimes not at all, giving rise to flickering of the tube.

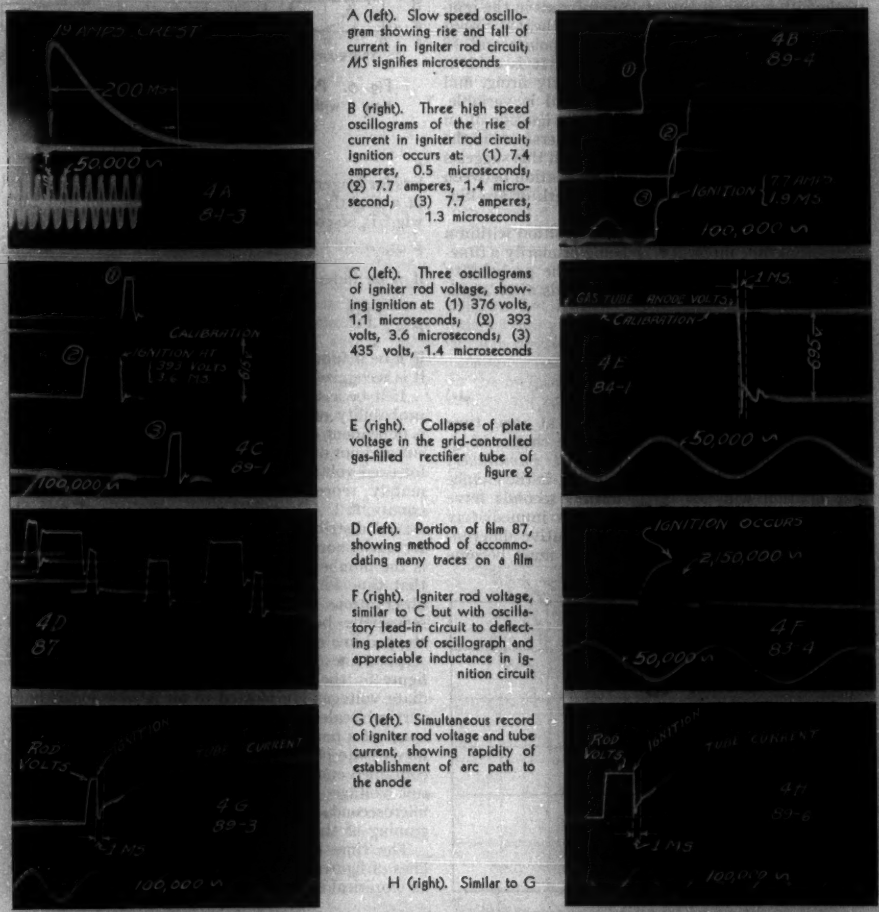
Figure 4*E* illustrates the extreme rapidity of the collapse of the voltage of the grid-controlled tube when the grid swings positive. The irregular oscillations after collapse probably are caused by successive reflections in the lead-in wires to the oscillograph plates. Figure 4*F* is an oscillogram similar to figure 4*C* (rod voltage) except that the lead-in circuit was highly oscillatory and the resistance in series with the igniter rod slightly inductive. Both of these conditions had to be corrected before satisfactory measurements could be made. The frequency of the oscillations of figure 4*F* agrees approximately with the value calculated from the length and construction of the oscillograph lead-in circuit, and the relatively slow

rate of rise of the igniter rod voltage with the inductance of the resistance as estimated from its dimensions.

The rapidity of the transfer of the arc from the bracket to the anode is indicated by figures 4*G* and 4*H*, oscillograms that measure simultaneously the igniter rod voltage and the anode current. The rod voltage was brought to the electrostatic deflection plates, and the anode current was passed through a magnetic deflecting coil on the oscillograph. Since anode current is zero before ignition, and rod voltage practically zero after ignition, the 2 measurements do not conflict. The anode current, measured by the slowly rising portion of the trace, begins in much less than a microsecond after the rod voltage begins to drop. The gradual rather than abrupt increase of anode current is caused by the presence of a little inductance in the load circuit.

Statistical Variations in Ignition Time

Values of the noninductive resistance were calculated to give approximately 450, 350, 250, and 200 volts on the igniter rod, and a series of records was made with each value of resistance. The resulting over-all range of ignition time observed was from a few tenths of a microsecond to 90 microseconds. The igniter rod voltage varied to some



A (left). Slow speed oscillogram showing rise and fall of current in igniter rod circuit; *MS* signifies microseconds

B (right). Three high speed oscillograms of the rise of current in igniter rod circuit; ignition occurs at: (1) 7.4 amperes, 0.5 microseconds; (2) 7.7 amperes, 1.4 microsecond; (3) 7.7 amperes, 1.3 microseconds

C (left). Three oscillograms of igniter rod voltage, showing ignition at: (1) 376 volts, 1.1 microseconds; (2) 393 volts, 3.6 microseconds; (3) 435 volts, 1.4 microseconds

E (right). Collapse of plate voltage in the grid-controlled gas-filled rectifier tube of figure 2

D (left). Portion of film 87, showing method of accommodating many traces on a film

F (right). Igniter rod voltage, similar to C but with oscillatory lead-in circuit to deflecting plates of oscillograph and appreciable inductance in ignition circuit

G (left). Simultaneous record of igniter rod voltage and tube current, showing rapidity of establishment of arc path to the anode

H (right). Similar to G

Fig. 4. Cathode ray oscillograms, typical of those upon which the results presented in this paper are based

extent within each series, possibly as a result of changes in the resistance of the rod resulting from inconstant temperature. The temperature measured by a thermometer in contact with the base of the tube just outside the pool changed very little, but there may have been variations of temperature distribution within the tube. Average values of rod voltages as measured from the oscillograms were 453, 377, 276, and 198 volts for the 4 series (recorded on oscillograph films 86 and 87).

Figure 5 shows the results of the 453 and 198 volt series of tests; not all of the lower voltage observations are indicated, for in some instances ignition occurred beyond the limit of the time scale used in the figure. Both these sets of observations were made with a capacitance of 4 microfarads in the ignition circuit. The series resistance in the rod circuit was 54 ohms for the lower voltage points and 18 ohms for the higher voltage points. It is evident that (1) the higher voltage favors early firing, and (2) at each voltage the time required is variable. Similar variability of time required for ignition of an arc has been observed in mercury rectifiers[2] and in the reignition of a-c atmospheric arcs.[3] All this suggests the existence of a statistical type of relation between ignition time and gradient for any spark or arc kindling process.

Suppose pdt is the probability of ignition within a differential time interval dt, p being primarily a function of igniting gradient. If P be the probability that ignition occurs later than t seconds after application of gradient,

$$-dP = P \cdot pdt \tag{1}$$

or

$$-d \log P = pdt \tag{1a}$$

for the chance of ignition occurring at *some* time later than t is by definition P, and the chance of ignition in the particular interval dt *immediately following* t is pdt; their product, $P \cdot pdt$, is the chance that ignition will not occur until t seconds have passed, but will occur in dt seconds immediately thereafter. This is of course the negative differential change in P, negative because P must become

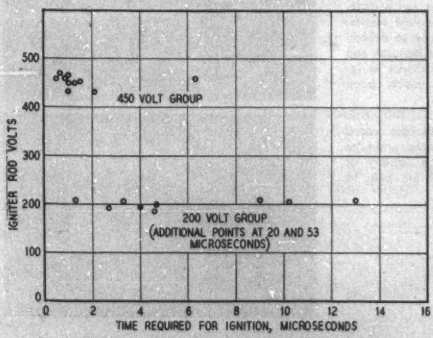


Fig. 5. Variability of time required for ignition

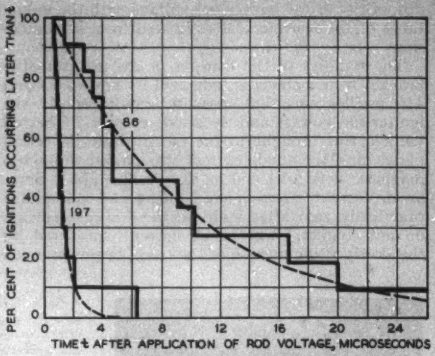


Fig. 6. Per cent of ignitions occurring later than time t, with rod gradients of 86 and 197 volts per centimeter (films 86 and 87)

less for longer times. The solution for P, approached in a slightly different manner by Slepian and Ludwig,[2] is of course

$$P = \epsilon^{-pt} \tag{2}$$

if p be independent of time, and

$$P = \epsilon^{-\int_0^t pdt} \tag{3}$$

if p be a function of time. In deriving these forms it is recognized that $P = 1$ when $t = 0$.

If it be assumed as a first approximation that the probability of firing in a very brief interval of time is dependent only on the magnitude of the rod gradient and not on its duration, the distribution of points for each voltage group in figure 5 should be approximately representable in a manner suggested by equation 2. Graphical representation of the observed distribution is accomplished by determining for each moment of time the ratio m/M, where m is the number of observations requiring longer than that time for ignition, and M the total number of observations at that voltage. If the number of observations be finite, such treatment produces a stepped line rather than a smooth curve. Two such stepped lines appear in figure 6, for the 2 voltages of figure 5; the same data with 2 additional intermediate voltages are plotted to an inverse logarithmic vertical scale in figure 7. The stepped lines converge at a point slightly to the right of where $t = 0$, for in spite of precautions taken the igniting circuit contained enough inductance to make the rise of the rod voltage require an appreciable fraction of a microsecond, and time was measured from the beginning of the rise.

The time distribution described by the stepped lines of figures 6 and 7 can be well approximated by an empirical relation of the form

$$p = \frac{1}{t_0} \epsilon^{F/F_0} \tag{4}$$

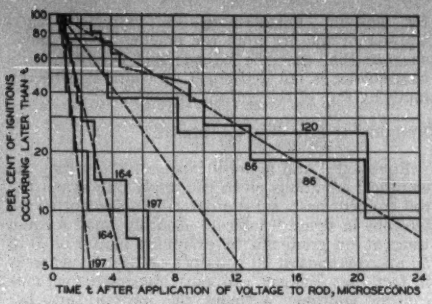


Fig. 7. Per cent of ignitions occurring later than time t; logarithmic per cent scale. Potential gradients 86, 120, 164, and 197 volts per centimeter (films 86 and 87)

giving

$$\log_e P = -\frac{t}{t_0} e^{F/F_0} \tag{5}$$

where F is the voltage gradient along the rod in volts per centimeter, and t_0 and F_0 empirical constants. The dotted lines on the figures represent this empirical relation, time being measured from an effective or equivalent zero placed 0.65 microsecond from the left of the figure, and t_0 and F_0 having the values 72 microseconds and 41 volts per centimeter. The dotted lines are straight or curved rather than stepped because they represent the behavior to be expected from a great many observations. In judging the correspondence between the stepped and empirical curves it must be borne in mind that there were relatively few (8 to 19) observations in each group, so that very close correspondence would be a remarkable accident. The agreement is quite satisfactory except for the series taken with a gradient of 120 volts per centimeter. This particular series included fewer observations than any of the others and appears, even on the basis of a cursory inspection of the data, to be unrepresentative.

Figure 8 represents the behavior in a subsequent series of tests (recorded on film 88) for which the ignition times were substantially longer than for those leading to figures 6 and 7. Zero time adjustment (1.2 microseconds) was made before preparing the figure. Records of the voltage calibration corresponding to figure 8 were destroyed accidentally after the first measurements were made from the oscillograms, so that it has not been possible to make a positive subsequent check of the gradient magnitudes; but the weight of evidence, based partly upon relative time and voltage sensitivities of the oscillograph, appears to justify the correctness of the values marked. If they are correct, the change in the median time by a ratio of about 3 to 1 between figures 7 and 8 must be attributed to variations in ambient temperature or duty cycle of the tube. The resistance of the rod is quite sensitive to operating conditions and may affect the ignition time. The 3 voltage groups of figure 8 seem to be consistent with each other in that they follow the same kind of a law as those of figure 7, the empirical constants being 195 microseconds and 45 volts per centimeter.

Median Time Versus Rod Gradient

Equation 5 can be adapted to express the median ignition time t_m as a function of the rod gradient by letting $P = 1/2$, as follows:

$$t_m = t_0 e^{-F/F_0} \log_e 2 \tag{6}$$

$$= 0.693 t_0 e^{-F/F_0} \tag{7}$$

This form lends itself well to representation of the median time on a logarithmic scale, as in figure 9. The 7 points circled there mark median times selected by drawing the best straight lines through the original logarithmic stepped curves (figures 7 and 8) prior to the selection of any empirical law and the solid lines drawn through the points represent the corresponding general relation between voltage gradient and median time. With the one exception of the series at 120 volts per centimeter, discussed earlier, these median times fit an exponential law very well indeed; there is no uncertainty at all as to the placement of either of the 2 heavy lines. Various other types of relationship between voltage gradient and median time were tested, but the exponential law fits the data much better than any other besides being in agreement with the relationship found by Slepian and Ludwig[2] to exist between back-fire frequency and voltage in mercury rectifiers, a somewhat similar physical situation.

The curves of figure 9 also describe the variations in the reciprocal of p, the momentary ignition probability, for combining equations 4 and 6,

$$\frac{1}{p} = \frac{t_m}{0.693} \tag{8}$$

The significance of the constants F_0 and t_0 appears from a study of these curves in the light of equation

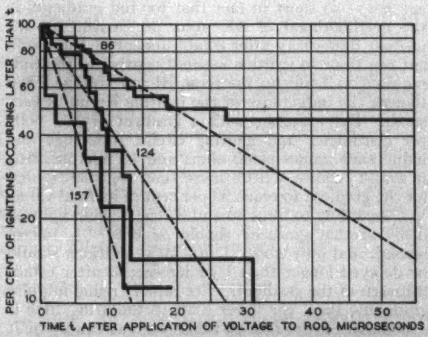


Fig. 8. Per cent of ignitions occurring later than time t; logarithmic per cent scale. Potential gradients 86, 124, and 157 volts per centimeter (film 88)

6; F_0 is the reciprocal of the slope of the straight line through the observed median times, and t_0 is proportional by the factor 0.693 to the median time expected at zero gradient if the empirical law were still valid there.

It is interesting to observe that the slopes are nearly the same for the 2 contrasting sets of observations. In a complete and correct theory F_0 probably would be independent of operating conditions. The 3-to-1 time factor between the 88 series and the 86–87 series probably is related to the fact, observed in the course of the tests, that after the rod became hot from continuous operation it would ignite at a much lower gradient than when cold, besides having a much lower resistance. Resistance and required gradient when hot were both between $^1/_3$ and $^1/_2$ of their values when cold.

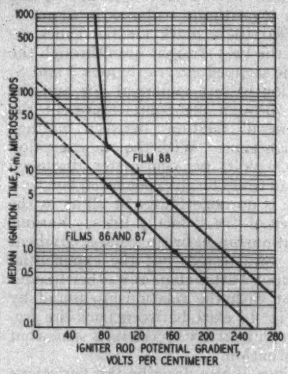


Fig. 9. Dependence of median ignition time on rod potential gradient

Energy Required for Ignition

The median time becomes very short as the voltage rises—so short in fact that for rod gradients in the neighborhood of 300 volts per centimeter the median time delay after establishment of the gradient but prior to ignition is small relative to the time required to build up the required rod voltage, even though the inductance of the igniting circuit is very small. For example, with a gradient of 300 volts per centimeter and igniting circuit resistance and inductance values of 40 ohms and 10 microhenries, it would require a little more than $^1/_2$ microsecond for the gradient to reach 90 per cent of its final value. Yet according to films 86 and 87 the median ignition delay at that gradient should be only $^1/_{30}$ microsecond, and only about 1 in 35,000 ignitions should be delayed longer than $^1/_2$ microsecond after establishment of the gradient. For rapidly rising impulse gradients, then, the lower limit to the firing time is dependent on the rate at which current can be built up in the igniting circuit, and the energy required to establish the magnetic field in the inductance may be an important part of the total energy demanded for ignition. Furthermore, the extremely rapid transfer of the arc from the bracket to the anode suggests that once the cathode spot is initiated, its continuance is not dependent on continuing energy input by way of the igniting circuit.

Ignition at Low Rod Gradients

Equation 6 and figure 9 expose the fact that the empirical equations given can apply only when the rod gradient has a substantial value. The dotted extensions in figure 9 indicate absurdly small median times at low gradients, for example a matter of 20 to 50 microseconds at 40 volts per centimeter, whereas in fact that gradient can exist indefinitely without causing ignition. Actually the median time becomes rapidly larger in the 88 series as the gradient is reduced gradually from 85 to 80 volts per centimeter as indicated by increasingly marked flickering of the tube and ultimate failure to fire at all. It is conceivable that each one of the tiny sparks observed around the rod contributes a chance of ignition, the likelihood of a sufficiently intense spark occurring depending on voltage gradient in the rod, and that at sufficiently low gradient sparks do not occur at all.

An analytical approach to the behavior at low voltages may be made on the basis of the longest-time curve (86 volts per centimeter) of figure 8, which does not describe a linear logarithmic distribution except for very short times. This logarithmic stepped line and the corresponding straight dotted line are redrawn in figure 10 to a scale which takes in all of the observed ignition points of that series. The stepped line runs off to the right and ultimately becomes horizontal, for in many instances ignition did not occur at all. An empirical curve to fit these data also should become horizontal at some definite level corresponding to the likelihood of failure to ignite, thus specifying the amount of flicker to be expected. A representative dotted curve of the required type has been drawn in figure 10.

Frequency of flicker and the shape of the curve of figure 10 were related closely to constants of the igniting circuit, for whenever ignition was delayed more than a score or so microseconds there was in the circuit used an appreciable drop in the capacitor potential and so in rod gradient. The rate of decay was determined by the values of resistance and capacitance in the igniting circuit, that is,

$$F = F_1 e^{-t/(RC)} \tag{9}$$

The time constant RC was about 360 microseconds for the observations upon which figure 10 is based. Delayed ignition under such circumstances makes p, the momentary ignition probability, vary with time, necessitating analysis according to equation 3 rather than equation 2. In preparing the figures, the part of the upper median time curve (figure 9) that lies above and to the left of the bend was co-ordinated with the dotted curve on figure 10, by means of equation 9 and a graphical integration according to equation 3. That is, the upper line of figure 9 is drawn so as to predict a time distribution in accord

with the observed facts of delayed ignition and flicker as described by figure 10. In general, if the median time curve and the circuit constants be known the per cent flicker can be predicted in this way. The data upon which this analysis is based are insufficient to do more than suggest the general type and location of the upward swing to be expected in the median time curves. This upper part of the curve presumably governs the observed variability in the phase position of ignition for applications[1] in which the igniter rod voltage is always some definite fraction of the sinusoidal anode voltage.

It is conceivable, of course, that the momentary ignition probability p decreases with time regardless of decay of gradient, through some such mechanism as the building up of a deposit on the mercury surface by recurring sparks. Such behavior would account satisfactorily for the appearance of flicker at moderately low gradients, but it seems that even then a more or less well-defined critical gradient must exist. It is simpler to attribute the appearance of flicker to a gradual decrease in p that results from decay of capacitor potential and so of rod gradient.

Median Firing Time at Critical Gradient

Firing time can be expressed as a function of the excess of gradient above the critical value F_c, as follows:

$$\log_e P = -\frac{t}{t_1} e^{(F-F_c)/F_0} \tag{10}$$

which is the same as equation 5 if

$$t_0 = t_1 e^{F_c/F_0} \tag{11}$$

Then also

$$t_m = 0.693 t_1 e^{F_c/F_0} e^{-F/F_0} \tag{12}$$

where $0.693t_1$ is the median time at the critical gradient, that is, $0.693t_1 = 22$ or 23 microseconds for the 88 series of figure 9. The critical gradient was not determined for the 86–87 series; it was less, but probably not a great deal less, than for the 88 series, as evidenced by the lower values to which rod gradient could be reduced before severe flicker set in. When the rod was cold the critical gradient was in the neighborhood of 300 volts per centimeter, and casual observations indicated a median time measurable in seconds rather than microseconds. All this suggests a relationship approaching a direct proportionality between the critical gradient and the logarithm of the median firing time for the critical gradient, but the evidence is suggestive only and is offered merely as a guide to further study.

Causes of Variability in Firing Time

It has been suggested that the agitation of the liquid mercury surface at the rod junction may be an important factor in causing the observed statistical variability in firing time. Such agitation certainly exists all of the time, and has at least 2 immediate effects: (1) a gross effect, that of varying the gradient in the rod as a whole because of increases and decreases in effective rod length; and (2) variations in microscopic details at the points of current transfer.

Certainly not more than ±10 per cent variation occurs regularly in effective rod length, corresponding to about ±2 millimeter change in liquid level. If the lines of figure 9 were to be considered as representing a nonstatistical relation between firing time and gradient for the mean liquid level, a ±10 per cent variation in effective length would scatter the observations made at 86 volts per centimeter of the 86–87 series between 4 and 8 microseconds with the greatest concentration of points near the median.

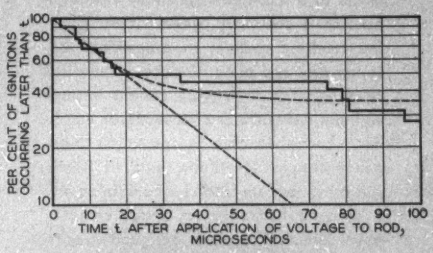


Fig. 10. Time distribution of ignition at a low rod gradient (86 volts per centimeter)

Actually 14 observations ranged between 1 and 50 microseconds with the concentration greatest near zero time. Neither the range nor type of statistical distribution accord with expectation if variability be attributed to the gross effect of variation in liquid level.

Effects of variations of mercury level on microscopic distribution of gradient, as between grains of the rod, is probably a contributing factor to the statistical nature of the results. The extent of the contribution could be estimated by oscillographic measurements with reversed rod polarity to determine firing time at the rod-bracket junction, where the geometry of the junction is fixed. No such tests were made, but there was qualitative similarity in operating behavior with normal and reverse polarity, as to magnitude of cold critical gradient, easily observed variability of time required for the rod to fire when cold, flicker when in steady operation near or slightly below the warm critical gradient, and spark behavior. There is enough such indirect qualitative evidence to require for the present the maintenance of an open mind as to whether or not variations in liquid level play an important part in causing statistical variations in firing time.

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3. Reignition of Metallic A-C Arcs in Air, S. S. Attwood, W. G. Dow, and W. Krausnick. A.I.E.E. Trans., v. 50, Sept. 1931, p. 857–70.

An Electrostatic Audio Generator

Design and operating features of a multi-harmonic electrostatic audio frequency generator are described in this paper. The harmonics are generated singly by the rotation of a shielded segmented disk adjacent to a stationary wave pattern plate; the resulting changes in capacitance between disk and plate produce a sinusoidal charging and discharging current through an input resistance of a vacuum tube amplifier. Each harmonic is controlled independently in amplitude and in phase, and provisions are made for combining any 2 or more harmonics to obtain complex wave forms. Although designed specifically for psychological tests, the device should prove useful in any work requiring a flexible audio frequency supply of small capacity.

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PRODUCTION of current variations from definite periodic changes in capacitance is a relatively new approach to the old problem of tone or wave synthesis.[1-4] If a potential be applied across 2 parallel metal plates separated by a dielectric, the capacitance thus formed will become charged to $Q = CE$, where Q is the charge, C the capacitance of the plates, and E the potential across the plates. The expression for charging current, $i = dq/dt$, becomes $i = E\,dc/dt$ when the capacitance is caused to change by moving the plates. If the capacitance be given a definite periodic variation such as

$$c = \frac{1}{2}[C_0(1 + \sin \omega t)]$$

then

$$i = E\frac{dc}{dt}$$

$$= E\frac{d}{dt}\frac{1}{2}[C_0(1 + \sin \omega t)] = \frac{1}{2}E\,C_0\,\omega \cos \omega t]$$

A periodic variation in capacitance may be obtained by several methods. Perhaps the most direct method is that of rotating a segmented metal disk or drum relative to a designed fixed plate. It is possible to cause a capacitance variation also by simply rotating a segmented dielectric disk between 2 properly designed stationary metal plates. Rotating steel disks are employed in the generator herein described. When, however, a sinusoidal capacitance variation is desired, the problem resolves itself into one of constructing a specially shielded arrangement with a suitable circuit so that the capacitance will be directly porportional to the coincident area of the 2 adjacent plates. The addition of resistance to the circuit and the possibility of fringing flux must be given consideration in the design.

Fig. 1. End view of generator rotor showing revolving segments, one stationary wave-pattern-plate support, and portion of phase shifting arrangement

Design Features

After a period of experimentation the authors found a relatively simple arrangement that seemed to have a wide range of adaptability. Although the apparatus herein discussed was designed primarily for use in a psychological laboratory, it by no means is limited to this field. The following specifications were assumed, to allow for maximum flexibility:

1. A sufficient current capacity to produce an audible tone.
2. The complex tone to include any or all of the first 16 harmonics.
3. Each harmonic to be relatively free from stray components, that is, it must be as nearly a pure sine wave as possible.
4. Individual magnitude control of each harmonic in 2 per cent steps.
5. A 360 degree individual phase control of each harmonic.

A paper recommended for publication by the A.I.E.E. committee on electrophysics, and scheduled for discussion at the A.I.E.E. Great Lakes District meeting, West Lafayette, Ind., Oct. 24–25, 1935. Manuscript submitted May 16, 1935; released for publication July 8, 1935.

The authors wish to acknowledge the assistance of the following: Carl E. Seashore, Don Lewis, G. F. Corcoran, and J. L. Potter, all of The State University of Iowa, Iowa City.

1. For all numbered references see list at end of paper.

6. Arrangements for setting 5 wave forms in advance, so that tests may be made rapidly.

Rotor Construction. The circular rotating disks (see figure 1) are made of ground steel $^1/_{16}$ inch thick and are 15 inches in diameter. On each side of the disk is shellaced a layer of commercially manufactured heat insulating material made up of thin aluminum foil rolled smoothly and fastened to a layer of heavy paper; the paper insulates the foil from the steel disk. The segments were cut radially and every other one was removed before the shellac dried. For the fundamental frequency 6 segments are employed, 12 for the second harmonic, 18 for the third, etc. Each disk accommodates 2 harmonics, one on each side. The 8 disks are mounted on a one inch shaft which turns in 3 self-aligning ball bearing units. The rotor is driven by a $^1/_3$ horsepower synchronous motor. Any rate of rotation up to 2,400 rpm can be obtained by means of proper pulley or gear ratio.

Amplitude Control. The magnitudes of the waves, and thus the intensities of the individual harmonics, are controlled by varying the potentials on the rotating aluminum segments. Each segmented disk is

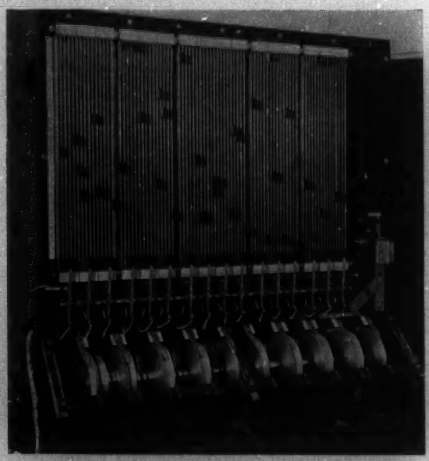


Fig. 2. Front view of generator showing amplitude control panel with sliders and switches, and phase control drums

connected to a slip ring. The carbon brushes bearing on these slip rings are connected directly to switch levers on a potential panel (see figure 2). The potential panel is made up of 50 resistances of 1,000 ohms each. Each resistance unit is connected between 2 of the 51 copper cross bars. The resistances may be seen on the back of the panel in figure 3. The total 50,000 ohm resistance bank is connected in series with a 50,000 ohm variable resistance and a continuous potential of 135 volts; 5 sliders are used for each harmonic. The switch levers are moved in tandem by a master lever at the right side of the panel as shown in figure 2. Arrangement is made to disconnect the input lead when the slider is in the lowest or zero potential position.

Wave Pattern Plate. The wave pattern plate is designed so that when the rotating segments move parallel to it, the coincident area increases and decreases sinusoidally. This causes the capacitance between the plates to change in like manner.

Assume that the segments S of the rotor in figure 4 move over the parallel wave pattern plate P in the direction indicated by the arrow. When the segment S moves through a physical angle θ' one electrical cycle will be generated. Assume also that the current produced by rotating the segments in a plane parallel to P is to be $I_0 \sin \omega t$. Then in a simple series circuit with negligible resistance and with a constant potential E across the condenser plates P and S

$$i = \frac{dq}{dt} = E\frac{dc}{dt} = k_1\frac{dA}{dt} = I_0 \sin \omega t$$

and therefore

$$\frac{dA}{dt} = k_2 \sin \omega t$$

or

$$\frac{dA}{dx} = k_3 \sin x$$

From the construction shown in figure 4,

$$\Delta A = \frac{y(\Delta x + \Delta x')}{2} \text{ (approximately)} \tag{1}$$

From similar triangles formed by the radial lines

$$R\Delta x' = \Delta x(R - y) \tag{2}$$

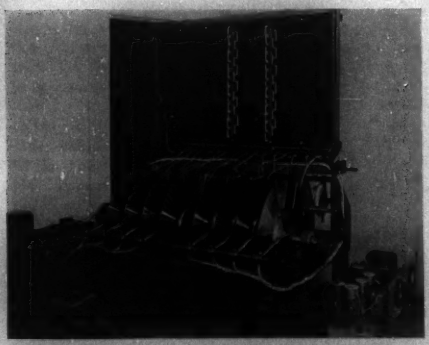


Fig. 3. Rear view of generator showing 50 1,000 ohm resistors, rotor, stationary plates, and brush and slip ring assembly. The amplifier is shown on the right and the synchronous driving motor on the left

Substituting the value for $\Delta x'$ from equation 2 into equation 1

$$\frac{\Delta A}{\Delta x} = y - \frac{y^2}{2R} \text{ (approximately)}$$

Then

$$\frac{dA}{dx} = y - \frac{y^2}{2R} = k_3 \sin x$$

Solving the resulting quadratic equation in y yields,

$$y = R - (R^2 - 2Rk_3 \sin x)^{1/2} \tag{3}$$

To determine k_3, or more conveniently $2Rk_3$, let $x = 90$ degrees. Then y reaches its maximum value, H, since $\sin x = 1$. Substituting these values in equation 3 gives

$$H = R - (R^2 - 2Rk_3)^{1/2}$$

from which

$$2Rk_3 = 2RH - H^2$$

Hence the final expression for y becomes

$$y = R - [R^2 - (2RH - H^2)\sin x]^{1/2} \tag{4}$$

(Expression for plate designs for use with rotating drums were developed by Culver,[2] and for inverted pattern plates by Lyon.[1]) The relationship between electrical and physical degrees is given by $x = \theta/S$, where θ represents the physical degrees and S the number of segments on the given rotor.

An example of the application of equation 4 to the design of the pattern plate for the second harmonic follows. The values used are: $H = 2$ inches, $R = 6.75$ inches, $S = 12$. The relationship between the electrical degrees, which were laid off on a dividing head, in terms of the physical degrees becomes

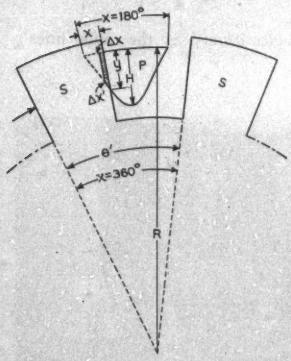


Fig. 4. Diagrammatic representation of the generating elements, for obtaining mathematical relationships

$\theta = x/S = x/12$. Values of y were calculated from equation 4 in steps of 10 degrees. The symmetry of the arrangement makes it unnecessary to compute any values of y for values of x greater than 90 electrical degrees. Figure 5 shows the actual shape of this plate as plotted from the data calculated.

Plate P is shellaced on a layer of paper insulation and mounted on a sheet iron support which is free to move for phase shifting. The sheet iron arc has a hole in the center to admit the connection of the conductor leading to the amplifier. Only one plate was necessary for each of the first 6 harmonic units. An average of 15 plates per unit was used for the remaining 10 higher harmonic units. The wave pattern plates for each unit were mounted on a single support. The use of multiple plates for the higher harmonics has 2 advantages: First, it reduces the effect of mechanical errors which increases when the segments and the plates become narrower; and second, the increased current output makes possible the use a lower input resistance which in turn reduces the distortion.

Phase Control. Phase displacement (see figure 1) is accomplished by moving the plate holder supporting the wave pattern along a circular arc. The motion is obtained by winding a cord on a hand operated drum located below the amplitude control

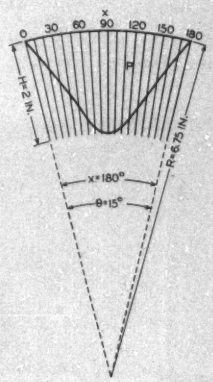


Fig. 5. Shape of sinusoidal wave pattern plate for second harmonic as obtained from equation 4

panel (see figure 2). The physical angle of rotation varies from 60 degrees for the fundamental frequency to $3^3/_4$ degrees for the sixteenth harmonic while producing a change of 360 electrical degrees in each instance. For convenience and accuracy of adjustment the drums are varied in diameter so that about 290 degrees of rotation of each drum corresponds to 360 electrical degrees.

While the present machine has only 1 generating unit for each harmonic, there is ample room for 2 or 3 or even more complete units around the periphery. With several such adjustable units, the phase as well as the magnitude values for several complex patterns, can be set in advance.

Electrical Circuit. The conductors from the stationary wave pattern plates are connected through switches to the grid side of a 10,000 ohm amplifier input resistance as shown in the schematic circuit diagram, figure 6. The other end of the input resistance is grounded through the potential controls. Since the frame is grounded, the steel disks and stationary plate supports keep the individual units thoroughly shielded from each other and from exter-

nal disturbances. Since the wave pattern plates are held about 0.3 inch from the rotor, the pattern plate may be considered as being in the same plane with its shield, inasmuch as the thickness of the insulating paper is only 0.01 inch. The wave pattern plate is, therefore, practically at ground potential since the drop across the input resistance is negligible, being on the order of 50 microvolts. The feeble capacitance currents are amplified through a specially designed amplifier which feeds an output of 2 watts into a 500 ohm impedance line with only 50 microvolts across the 10,000 ohm input resistance.

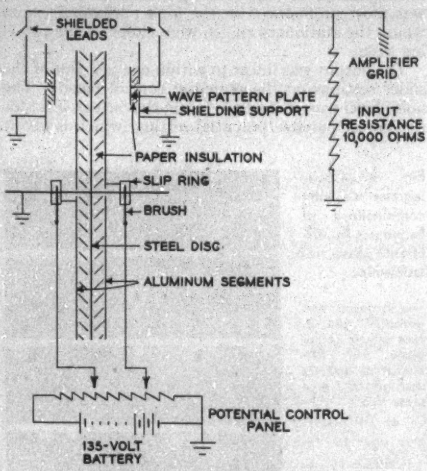


Fig. 6. Schematic circuit diagram of one rotor disk with its accompanying pair of harmonic generating units

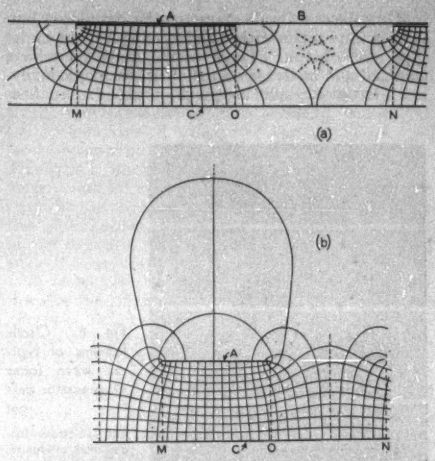


Fig. 7. Maps of the electrostatic field between stator and rotor (a) with shielding disk, and (b) without shielding disk

Electrostatic Flux Distribution

A generalized form of the electrostatic field between the rotor and the wave pattern plate holder is shown in figure 7*a*. The segments are shown as if moved in a plane instead of in a circle; *A* represents a segment, *B* the steel disk, and *C* the pattern plate holder. Both *B* and *C* are at ground potential. The distance *MN* embraces the generating flux for one cycle. The pattern plate extends $^1/_2$ cycle. Since the pattern plate is practically in the same plane as the holder, *C*, the flux distribution on it may be considered the same as on the holder. Directly under the segment *MO* the flux is distributed evenly and is relatively dense. Near the edge of the segment the flux density quite sharply becomes diminished. Since the boundary of the holder is of greater extent than that of the pattern plate, the edge effect has little or no influence on the flux distribution in the vicinity of the pattern plate. Thus the distribution shown by figure 7*a* makes the coincident-area principle of design quite reliable. It is true that the lack of uniformity that does exist causes a certain amount of distortion in the resulting current wave; analyses, however, show that these distortions are small.

In order that all harmonic units would generate currents of the same magnitude, it was found necessary to place the wave pattern plates for the higher harmonics closer to the disks. As the segments become narrower a greater percentage of the flux from *A* goes to the steel disk *B*. To compensate for this the plate *C* must be moved closer to the rotor.

Figure 7*b* shows the field distribution without the use of the shielding plate *B*. Under these conditions there is no sudden change in flux density. Considerable flux comes around from behind segment *A* as well as from the edges and fills in between the segments. This arrangement would be highly unsatisfactory, but is shown here to point out the need of an adequate shielding system. Some improvement could be made by placing the plates closer together, but this would increase the distortion caused by vibration. Furthermore, the steel disk acts as a good shield between adjacent units.

Performance Characteristics

Performance tests included analyses of the individual harmonics for freedom from higher frequency components, a measurement of intensity variation over a series of waves, a check on linearity between the output and the setting on the potential control board, measurement of noise level, and a measurement of change in intensity caused by phase shifting.

Wave Form. Oscillograms of the individual harmonics were taken with a high quality galvanometer type oscillograph. These oscillograms then were enlarged and analyzed on a Henrici harmonic analyzer. Detailed results are given in table I. Analysis

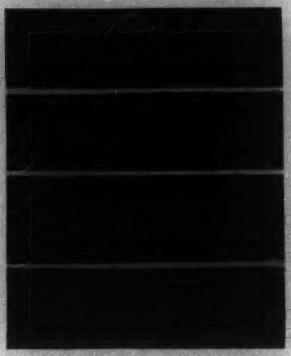


Fig. 8. Oscillograms of typical wave forms of generator output

Top to bottom: fundamental, and fourth, sixth, and fifteenth harmonics

was made for 5 components in each of the 8 lower harmonics and for 3 components in each of the 8 higher harmonics. In the lower harmonic group the stray component with the greatest magnitude was the second component of the third harmonic, which had an intensity 26 decibels below that of the fundamental component. The average intensity of the stray components of the first 8 harmonics was 37 decibels below the fundamental. In the upper harmonic group the worst was 22 decibels below the fundamental component, while the average was 30. The presence of this small percentage of stray components was caused largely by the summation of mechanical errors in plate tracing and cutting, faulty alignment of stationary plates relative to the rotors, and some departure from the flux distribution assumed in designing the wave pattern plates. All of the waves were viewed on a cathode ray oscillograph which showed them to be smooth and well defined. Some typical oscillograms are shown in figure 8. Combinations of 2 waves in different phase relationships are shown in figure 9.

Table I—Results of Wave Shape Analysis of Generator Output

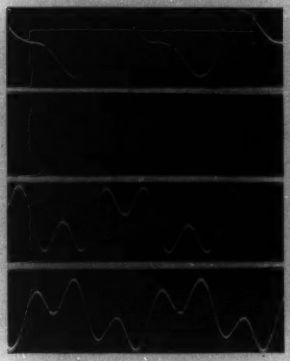
Generated Harmonic	Frequency, Cycles per Second	Average Intensity of Stray Components, Decibels Below Fundamental	Maximum Intensity Variation in a Series of Analyses, Decibels	Maximum Intensity Variation During 360° Phase Shift, Decibels
1	178	42	0.10	0.22
2	356	42	0.10	0.32
3	534	37	0.12	0.32
4	712	33	0.21	0.36
5	890	38	0.21	0.30
6	1,068	32	0.30	0.34
7	1,246	40	0.34	0.40
8	1,424	32	0.36	0.46
9	1,602	33	0.30	0.38
10	1,780	30	0.21	0.28
11	1,958	35	0.28	0.30
12	2,136	31	0.44	0.41
13	2,314	26	0.48	0.30
14	2,492	27	0.50	0.48
15	2,670	23	0.44	0.22
16	2,848	32	0.48	0.40

Intensity Variations. The greatest variation in intensity over a series of waves of a given harmonic was 0.50 decibel. The average maximum variation among the 16 harmonics was 0.30 decibel. Individual variations are shown in table I. These variations were caused for the most part by a slight misalignment of the rotating disks, which defect was most pronounced in the higher harmonic units where the stationary plates were closer to the rotating disks.

The output was linear to within one per cent of the slider settings on the potential control panel. The noise level was 40 decibels below the output level for the lowest possible potential setting, which is about

Fig. 9. Oscillograms showing combinations of harmonics in different phase relationships

Top to bottom: harmonics 1 and 2, same with 90 degree phase shift, harmonics 1 and 3, same with 60 degree phase shift



70 decibels below that for the setting normally used.

When the stationary condenser plates are moved along their supporting arcs in order to shift the phase, changes in intensity result if the plates do not move parallel to the disks. The average change in intensity caused by phase shifting over 360 electrical degrees was 0.35 decibel for the 16 plates. These values are given in the last column of table I.

Applications

The machine just described should have a wide range of application. While its use may be limited to frequencies of the audible range, 16 harmonics is by no means the limiting number. Given the analyzed results of any periodic wave form with harmonic constitution within the limits of the generator and that wave readily may be synthesized. By special plate designs and compact arrangements of rotors, different types of musical instruments might well evolve. A simplified arrangement could be used for demonstration purposes in classes studying electrical wave patterns. Known complex tones can be sent through communication channels or amplifiers to study phase and other distortions.

Additional applications readily will suggest themselves to workers in the audio frequency division of the communication field.

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Effect of Ultraviolet on Breakdown Voltage

The effect of ultraviolet light upon the breakdown voltage of sphere gaps subjected to impulse voltages is considered in this paper. It is shown that, especially for the smaller gaps and corresponding lower voltages, more accurate voltage measurements result when ultraviolet light is used. Photoelectric emission from the surface of the spheres is believed to be the cause of the improved accuracy. Without ultraviolet light, variations in the number of free electrons affect the result.

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THERE is always a continual demand for better methods and means for measuring unknown values. Naturally, the measurement of high voltages is no exception, and the sphere gap has retained its position as the accepted method mainly because of its advantages over other methods which have been proposed. Among the sphere gap's disadvantages, is its time lag when measuring impulse voltages. It was observed before the tests described in this paper that the sphere gap seemed inaccurate and was erratic when used to measure steep front impulse voltages of the order of 10 kv using 6.25 centimeter spheres.

It was found that by illuminating the spheres with a carbon arc light the readings became less erratic and presumably more accurate, confirming the observations of others.[1,2] The arc light was later displaced by a quartz-tube mercury-vapor lamp. This type of illumination was found to be more convenient and fully as satisfactory. Since in ordinary daylight the sphere gap behaved as described above, the illumination from the ultraviolet portion of the mercury vapor lamp spectrum was assumed to be affecting the spark-over.

It is well known that ultraviolet radiation influences the breakdown voltage of spark gaps. The effects on 6.25 centimeter sphere gaps at close spacings have been studied quantitatively, and the data are presented in this paper to emphasize the importance of considering the matter of irradiation when sphere gaps are used for measuring impulse voltages. From these data, the conclusion may be drawn that the use of ultraviolet light is warranted, especially for the lower potentials and smaller gaps, by the increased accuracy of measurement which results.

The following data apply to the 6.25 centimeter spheres which were used throughout this entire test. A quartz-tube mercury-vapor lamp was used to illuminate the spheres and its power input, which was 35 watts, was kept constant to provide constant light output. The surge generator was of the conventional type and the George cathode ray oscillograph was used to record and measure the spark-over voltage.

METHOD OF TEST AND RESULTS

Curves of the breakdown spacing of 6.25 centimeter spheres versus relative light intensities are

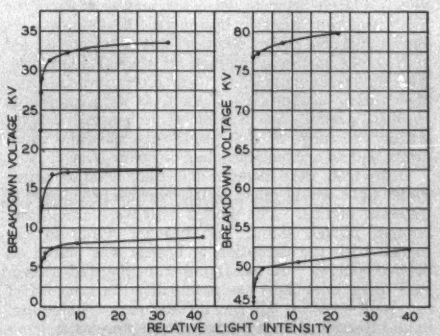

Fig. 1. The effect of different light intensities from a quartz-tube mercury-vapor lamp on the breakdown voltage of 6.25 centimeter bronze sphere gap

Each curve represents a different magnitude of impulse voltage wave

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1. For all numbered references, see list at end of paper.

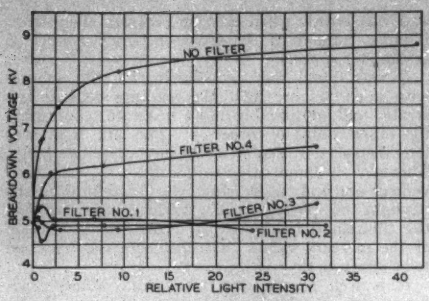

Fig. 2. The effect of different light frequencies from a quartz-tube mercury-vapor lamp on the sphere gap breakdown voltage

Filter No.	1	2	3	4	No. Filter
Cut-off frequencies of the filters, in Angstroms	3,340	2,920	2,540	2,380	2,250

presented in figure 1; the curves show the increase in length of gap required with increase in amount of irradiation of the spheres in order to just give breakdown of the gap on a definite impulse wave 50 per cent of the time. For each curve the shape of the voltage wave was kept constant and was an overshooting wave which for most of the curves, reached its peak in $^1/_2$ to 1 microsecond. Slight changes in wave form, however, prevent different curves of figure 1 from being exactly comparable. The intensity of radiation was varied by varying the distance of the lamp from the spheres. The lamp was permitted to illuminate both spheres with equal intensity and the line of radiation was perpendicular to the axis of the spheres. The axis of the spheres was horizontal and one sphere was grounded. The impulses were of such polarity that the ungrounded sphere was negative.

Figure 2 presents the curves of breakdown spacing versus relative intensity with different portions of the light radiation used to illuminate the spheres. In their numbered order, various light filters were used to transmit an increasing amount of ultraviolet light. The cut-off frequencies of these filters are shown in the caption of figure 2. These tests were conducted to obtain a fair idea of what wave lengths of light, within the range of the quartz-tube mercury-vapor lamp, had an appreciable effect on spark-over.

Other tests were made to determine whether ultraviolet light would affect spark-over using spheres of different metals. The metals used were chromium, copper, nickel, silver, and bronze. Each of the metals with the exception of bronze was plated on bronze spheres. It was found from the data taken, that ultraviolet light has practically the same effect on spark-over for all the metals used. Therefore, in all subsequent tests bronze spheres were used.

The erratic readings of the sphere gap without ultraviolet light seemed to indicate that breakdown was not occurring on the same part of the wave at all times. When ultraviolet light was illuminating the spheres, the readings became consistent and the spacings considerably larger for the same applied potential. It is true that the above tests were made under conditions which accentuate the time lag of the gap and the effect of the ultraviolet light in reducing this time lag. It was decided to determine on what part of the wave spark-over was occurring and if the sphere gap might possibly indicate more than the actual voltage. Curves of figures 1 and 2 indicate that the spacing at greater intensities is asymptotic to a constant value which it may be assumed represents the actual crest voltage of the impulse unaffected by time lag. To test this assumption it was decided to determine on what part of the wave spark-over occurs with and without irradiation.

Under the assumption that the then accepted calibration of the sphere gap could be relied upon for flat-topped, long-tailed waves, the oscillograph deflection was carefully calibrated and the actual crest voltage of the wave shown in figure 3 was determined by measurement from the oscillogram.

Tests With Reduced Spacings

The procedure in this test was to measure the voltage by the illuminated sphere gap, and then slightly reduce the spacing to obtain spark-over every time. Oscillograms taken of the breakdowns under these conditions are presented in figure 4. The spacing of the illuminated gap was then further reduced to provide breakdown on the front of the wave. Oscillograms of the breakdown on the front of the wave are shown in figure 5. Next, the voltage was measured by the sphere gap without using ultraviolet light. In order to take oscillograms of spark-over without light, it was necessary to reduce the spacing by

Fig. 3. Oscillogram of wave shape used in tests 1, 2, and 3

Test number	1	2	3
Crest voltage measured by oscillograph calibration, kv	13.05	11.28	11.28
Crest voltage measured by illuminated sphere gap*, kv	11.83	10.68	10.72
Crest voltage measured by non-illuminated sphere gap**, kv	6.79	7.54	6.79

* Gap spacing for test 1, 0.134 inches to give spark-over 50 per cent of the time.
** Gap spacing for test 1, 0.079 inches. Readings erratic and inconsistent for non-illuminated gap.

Fig. 4. Spark-over with ultraviolet light, showing test 1, only

Fig. 5. Spark-over on front of the wave with ultraviolet light, showing test 1, only

Fig. 6. Spark-over without ultraviolet light, showing test 2, only

Figs. 4, 5, and 6. Typical oscillograms showing spark-over of 6.25 centimeter spheres

	Fig. 4			Fig. 5			Fig. 6		
Test Number	1	2	3	1	2	3	1	2	3
Actual crest voltage of full wave by oscillograph calibration, kv	13.05	11.28	11.28				13.05	11.28	11.28
Above oscillograms taken with gap set for 0.133 inches,* kv	11.64	10.42	10.52						
Above oscillograms taken with gap set for 0.081 inches, kv				7.78	7.30	7.21			
Above oscillograms taken with gap set for 0.055 inches**, kv							5.25	5.62	5.11
Average value of voltage at break-down as measured from above oscillograms, kv	12.75	11.13	11.13	9.90	9.13	8.89			

* Gap setting slightly reduced to provide 100 per cent spark-over. Compare with voltage measurement setting (figure 3) for 50 per cent spark-over.

** It was necessary to reduce the spacing to this value before the gap would spark-over every time with even fair consistency.

about 35 per cent to make certain that spark-over would occur nearly every time. These oscillograms are presented in figure 6.

The above oscillographic tests were repeated 2 times in order to check results. For each of the 3 tests the results are given in the captions of figures

3, 4, 5, and 6. In each of these tests for each condition, 12 oscillograms were taken. For tests 1 and 2, the mercury vapor lamp was 7.5 inches from the center of the spheres, which is approximately 30 on the abscissa of figure 1. The last test was taken with the lamp 4 inches from the center of the spheres, which is a relative light intensity of approximately 100.

Figures 3, 4, 5, and 6 show convincingly the large time lag of small sphere gaps at small spacings for this type of wave and the effect of ultraviolet light in reducing this time lag.

In the tests using the calibrated oscillograph, the measurement of the crest voltage without light gave values of 52 per cent, 66 per cent, and 60 per cent of the actual crest voltage for tests 1, 2, and 3, respectively. The illuminated sphere gap gave values of 91 per cent, 95 per cent and 95 per cent of the actual crest voltage for tests 1, 2, and 3, respectively. Test 3, which was performed with the lamp 4 inches from the axis of the spheres, showed only slightly better accuracy.

From the above described tests it appears evident that the use of ultraviolet light has a decidedly beneficial effect in increasing the accuracy of measurement of the lower range of impulse voltages with small sphere gaps. For the illuminated gap, the oscillograms show that spark-over occurred very near the peak of each wave, while the oscillograms of spark-over of the nonilluminated sphere gap definitely show a decided time lag and therefore varying breakdown voltages. The type of wave used (see figure 3) accentuates the effect of the ultraviolet light since the voltage rises to crest rapidly and remains there only a short length of time. It had seemed desirable to determine the effect of ultraviolet light on this type of wave which occurs in measuring the impulse breakdown voltage of arrester gaps and flashovers of insulation or bushings which break down on the front of the wave.

Further tests were conducted to determine the desirability of using ultraviolet light when measuring the impulse voltages of proposed A.I.E.E. standard test waves. This was done by means of the calibrated oscillograph for the $1^1/_2 \times 40$, 1×10, 1×5, and $^1/_2 \times 5$ waves. Table I presents the data obtained from these tests and shows the accuracy of measurement in per cent of actual crest voltages. Three crest values of impulse voltages were used, ranging from approximately 10 kv to 80 kv. The lamp in these tests was 7.5 inches from the center of the spheres.

Table I—Accuracy of Voltage Measurement With and Without Ultraviolet Light

Wave	Actual Crest Voltage Kv	Crest Voltage Measured by 6.25 Cm Sphere Gap: With Light Kv	With Light Per Cent	Without Light Kv	Without Light Per Cent
$1^1/_2 \times 40$	78.4	78.5	100	78.4	100
$1^1/_2 \times 40$	38.8	38.4	99	38.4	99
$1^1/_2 \times 40$	9.73	9.64	99	8.95	92
1×10	76.9	76.9	100	76.9	100
1×10	39.1	38.2	98	36.5	93
1×10	9.28	9.19	99	6.86	74
1×5	66.7	66.2	99	66.2	99
1×5	34.8	33.4	96	33.3	95
1×5	8.37	7.57	91	4.33	52
$^1/_2 \times 5$	72.3	72.9	101	72.8	101
$^1/_2 \times 5$	37.7	37.0	98	36.2	96
$^1/_2 \times 5$	9.12	9.11	100	6.01	66

Summary

1. From the data of table I the conclusion may be readily drawn that the use of ultraviolet light is quite desirable for sphere gap measurement of low impulse voltages even for the $1^1/_2 \times 40$ wave, and the increase in accuracy of measurement due to the light is more pronounced with lower potentials and consequently smaller gaps.

2. The effect of ultraviolet light in reducing the time lag of sphere gaps is believed to be entirely due to photoelectric emission from the surface of the spheres. If any ionization of the air is taking place, the ionization would only be a very short distance from the quartz tube since it is probable that the ions would be readily deionized by the air around the tube. The results shown in figure 2 and the definition of surface photoelectric effect,[6] are evidence of the fact that the effect of ultraviolet light radiation on sphere gap breakdown is due to photoelectric emission from the surface of the spheres. In order to obtain maximum emission from the surface of the spheres, it is necessary that the surfaces be as clean and free as possible from any oil film left from cleaning the spheres. The electrons thus produced are available for acceleration and ionization when the proper gradient is reached.

3. Without ultraviolet light on the small gaps the relatively large and variable time lags seem to be the result of a variable and at times, insufficient number of free electrons to provide rapid ionization when the necessary gradient is reached. An insufficient supply of free electrons in the strongest part of the field may be the result of a naturally low density at the start of the rise in voltage; or, due to the short gap length, a large number of the available electrons may be drawn to the positive sphere before the ionizing gradient is reached. The fact that ultraviolet light provides an abundant and continually replenished supply of free electrons appears to reduce the effect of both of the above sources of time lag. The fact that the time lag of the sphere gap decreased with increased spacing is in line with the above theories. For greater spacing between the spheres the electrons would have to travel a greater distance to reach the positive sphere, thus, with the same rate of rise, the voltage would reach an ionizing gradient in time to make use of these electrons. Also, with a greater volume of air between the spheres the normal electron density would be more apt to prevail in the strongest part of the field.

4. Finally, it is believed that ultraviolet radiation on the small sphere gaps increases the accuracy of measurement by an amount sufficient to warrant its use for the measurement of impulse voltages.

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Magnetic Fields in Machinery Windings

In presenting the results of his studies of the magnetic field in and near the conductors of electrical machinery, the author seeks to fill the gap existing between the present accurate but difficult methods and the easier but less accurate methods of drawing and calculating these fields.

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THERE IS a wide gap in the methods of drawing and calculating the magnetic fields in the copper windings of machinery. Those that are most accurate are hard to understand and to use. The easier methods of calculation are less accurate, and the easier graphical methods are harder to analyze. This paper endeavors to fill this gap by showing how the method of superposition yields a rapid, accurate treatment, which is easily analyzed for the effect of the various modifying factors. It leads to methods of drawing the fields, and estimating their flux interlinkage. The investigation shows that:

1. Most of the fields in and near the copper conductors of machinery may be resolved into 3 simple components that are easy to draw and to use for computations.

2. Superposition of these components leads logically and simply to the resultant.

3. In certain cases this resultant field is a conic section; in others it contains a term of the type $e^{-kx} \cos ky$.

4. The fields laid out by this method are easily blended near pole tips and slot openings with the field more remote from the copper, found by other graphical methods.

The fields inside and outside of a current-carrying conductor are radically different in character, as indicated in figure 1. The heavy circle represents the surface of the wire, and the lighter circles lines of force spaced so that each tube of force contains the same flux. The law of flux density is shown at the right, and the discontinuity at the surface of the wire is apparent. The field outside the wire has a potential function and is termed "lamellar." Inside the wire there is no potential function, and the field is termed "vortical." In this region the "curl" of the field is said to be proportional to the current density. The center of the wire O is in this case the point at which the lines of force converge. Such a point is termed the "core" or "heart" of the field. The flux function at the point P is said to be -10, because there are 10 lines of force between it and the heart of the field, and minus because the flux is counterclockwise.

The radial lines in figure 1 designate equipotential surfaces outside the wire, but inside the wire there is no magnetic potential, so that in this region the radial lines are termed "level surfaces" or "lines of no work." The heavy radial line OA is an arbitrarily selected datum surface from which to reckon potential. It may be termed a "magnetic shell," or "cap surface." The magnetic potential on the right-hand side of this surface is the full ampere turns of the coil; on the left-hand side of this surface the potential is zero. The potential at any point such as P is proportional to the crosshatched area.

All resultant magnetic fields are "solenoidal"; that is, in any region there are as many tubes of induction entering as leaving its boundary surface. Stated in other words, the "divergence" is said to be zero. In insulation there can be no current except displacement current, and in a steady state the "curl" of the field in such a region must be zero. It is to be noted, however, that these restrictions apply only to the resultant field.

Component Solutions

The fields described in this paper can be built up out of 3 simple components by the method of superposition. These components are, respectively, the

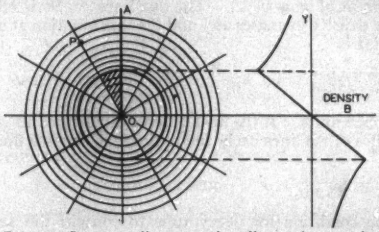

Fig. 1. Diagram illustrating lamellar and vortical fields

field inside the slot of a dynamo, the field between transformer coils, and the field which would be set up by an imaginary surface magnetized sinusoidally, with the same polarity on both sides. The restrictions as to divergence and curl do not apply to component fields, which are merely aspects of the total phenomenon. In this case all that is necessary is that the divergences of the component fields neutralize each other. It is also necessary in insulation that the values of curl for the component fields shall neutralize.

Components of the magnetic field are further classified as "main" and "compensating" components. By main component of a field is meant that simple field

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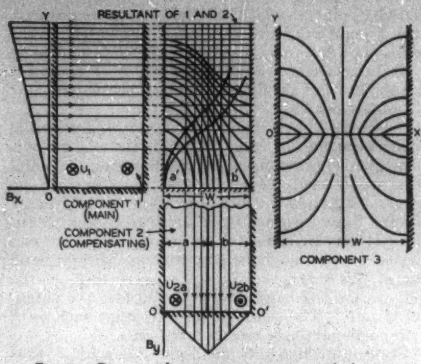


Fig. 2. Diagram showing superposition of elementary fields

which most closely approximates the actual field, and which leads to simple approximate formulas for the inductance and leakage flux. By compensating component is meant the remaining minor, and simple, component of the field which compensates the main field for any error in curl or divergence. For example, if the main field shows divergence, the compensating field should neutralize this divergence. Or again, if the main field shows curl in insulation, the compensating field neutralizes this curl.

These 3 component fields are further described in figure 2. At the left is shown a slot carrying a current of density U_1. The flux lines are horizontal, the density increases as y and the flux function at any point is

$$B_1 = 3.2\ U_1 y$$
$$\phi_1 = 1.6\ U_1 y^2 \tag{1}$$

in inch units. If the lines of force divide the flux into tubes of $\Delta\phi$ lines each, the ordinate of the nth line is

$$Y_n = \sqrt{\frac{n\,\Delta\phi}{3.2\ U_1}} \tag{2}$$

The condition for every tube to contain the same number of lines is essential if the fields are to be superimposed.

At the bottom of figure 2 are shown 2 coils carrying equal and opposite currents, much as in a transformer. The field is vertical, and the density is triangular and maximum between the coils. If U_2a and U_2b designate the current density at the left and the right, the flux functions are

$$B_{2a} = 3.2U_{2a}x;\quad \phi_{2a} = 1.6\ U_{2a}x^2 \tag{3}$$

$$B_{2b} = 3.2\ U_{2b}x';\quad \phi_{2b} = \phi_l - 1.6U_{2b}x'^2 \tag{4}$$

Where ϕ_l is the total flux represented by the area of the triangle of density B_x; x is the abscissa drawn from the center O; x' is the abscissa drawn from the center O'.

The lines are drawn so as to contain the same amount of flux ϕ as before.

1. For all numbered references see list at end of paper.

At the right of figure 2 is shown the third component field. This field is represented by the equation

$$\phi + jV = A\epsilon^{(\pi y + jx)\left(\frac{\pi}{W}\right)} \tag{5}$$

where V is the potential and y is, respectively, less and greater than zero. Upon expanding this exponential there is obtained

$$\phi + jV = A\epsilon^{\pi y\left(\frac{\pi y}{W}\right)}\left(\operatorname{Cos}\frac{\pi y}{W} + j\sin\frac{\pi x}{W}\right) \tag{6}$$

which is periodic in x. Thus the field need be drawn only between $x = O$ and $x = W$. On these 2 lines $V = 0$, and hence they may be iron surfaces, as represented in the figure. It is to be noted that there is a divergence of 20 tubes of force on this line $y = 0$.

Method of Superposition

The method of finding 2-dimensional vortical fields used by Hague,[1] Rogowski (see Stevenson[2]), and Park and Stevenson,[3] is by integration of the field created by each filament of current. Their methods are of great generality but of considerable difficulty.

The method of superposition is well illustrated in figure 2. The horizontal lines from the left-hand figure have been carried over to the right, and the lines from the lower figure are carried upward so that they intersect. A new system of lines has been drawn through the intersections of the 2 components in such a manner that the flux function ϕ on each of the lines is a constant, and the sum of the flux functions of the 2 component fields. The current densities also combined algebraically. Thus we have the equations 7 and 8 in regions a' and b', respectively.

$$U_a = U_1 + U_{2a};\quad \phi_a = \phi_1 + \phi_{2a} \tag{7}$$

$$U_b = U_1 - U_{2b};\quad \phi_b = \phi_1 + \phi_{2b} \tag{8}$$

The term superposition is peculiarly appropriate when, as in some of the more complicated cases, the figures are laid out by superposed sheets of tracing cloth. While it is believed that most books do not give enough attention to superposition, superposition methods have been used, but chiefly with lamellar and solenoidal fields. The author knows of one

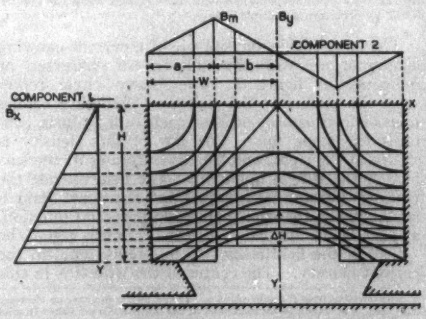


Fig. 3. Interpolar field in a shunt generator

example of superposition of a vortical with a lamellar field.[4] It is believed that one of the elements of novelty in this paper lies in the combination of vortical fields and the combination of 2 divergent fields.

Each of the 2 component fields has a density varying in a linear manner. Now, since energy storage varies as the density squared, and the volume of the 2 fields is the same, the ratio of the energy in the compensating field to that in the main field is as the square of the ratio of maximum densities, or if H is the depth of the slot,

$$\text{Energy ratio} = \left(\frac{U_{ba}}{U_1}\right)^2 \left(\frac{a}{H}\right)^2 \tag{8a}$$

Figure 2 was drawn for the following particular data:

Dimensions, $a = b = 1$ inch.
Current densities, $U_1 = 500$, $U_{ba} = U_{ab} = 1000$, $U_a = 1500$, $U_b = -500$.
Flux functions, $\phi_1 = 800\, y^2$, $\phi_{ba} = 1600\, x^2$, $\phi_{ab} = 3200 - 1600(x')^2$, $\phi = 400$ lines. The densities are in inch units.

Resolution of a Field Into Its Components

In the previous discussion of figure 2 we assumed that the component current densities were given. We will now investigate the conditions which must be satisfied by the component densities when the resultant densities are given. One component field must be similar to that in a slot, that is, the current is assumed to be uniformly spread out. The remainder is the compensating field. Thus,

$$U_1 W = U_1 = (a + b) = U_a a + U_b b \tag{9}$$

$$U_{ba} a = U_{ab} b = (U_a - U_b)\frac{ab}{W} \tag{10}$$

There is also a noteworthy difference in physical interpretation between the methods of the last 2 articles. When we have actual components vortical in character there must of necessity be copper wherever there is current. In resolving the field in insulation into components, current densities will be indicated equal and opposite and neutralizing. Thus the compensating field may be said to compensate for the error made by assuming the main field only to exist, with its curl in the insulation. The principal of superposition rests of the linear character of the differential equations of the field.

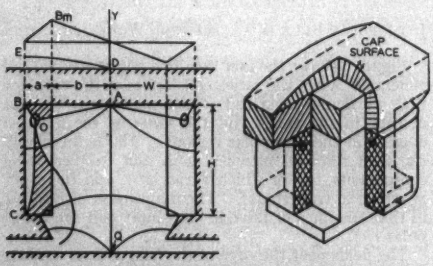


Fig. 4. Visualization of cap surface for a dynamo

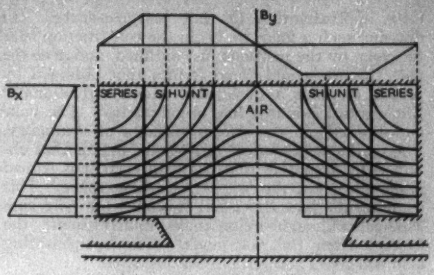


Fig. 5. Interpolar field in a compound generator

Shape of the Lines of Force and Level Surfaces

Again referring to figure 2 we note that the lines of force are ellipses and hyperbolas. This is easily established in the following manner: substitute equations 1 and 3 into 7 to obtain the new equation 11, and equations 1 and 4 into 8 to obtain the new equation 12, thus

$$\phi_a = 1.6\, U_1 y^2 + 1.6\, U_{ba} x^2 \tag{11}$$

$$\phi_b = \phi_1 + 1.6\, U_1 y^2 - 1.6\, U_{ab}(x')^2 \tag{12}$$

which are the equations of ellipses and hyperbolas. The ratios of axes of the conics $\frac{B}{A} = \sqrt{k}$, (or y intercept to x intercept), are

$$\left(\frac{B}{A}\right)_a = \sqrt{\frac{U_{ba}}{U_1}}\,;\left(\frac{B}{A}\right)_b = \sqrt{\frac{U_{ab}}{U_1}} \tag{13}$$

In certain cases the ellipses are circles, and the hyperbolas are rectangular, the latter being true in insulation, for example.

The level surfaces or lines of no work are those systems of lines which are orthogonal to the flux lines. If we denote the ratio $\frac{B}{A} = \sqrt{k}$, the level surfaces are parabolas of the kth degree, defined by the equation

$$x = Cy^k \tag{14}$$

One or 2 such lines are also shown in figure 2. We should also note that while the boundary of the field is shown as iron, any side may be a line of symmetry dividing the field as shown from its "image" field.

By way of summary for the preceding 3 sections, we may say that the fields are easily laid out on the drawing board, and the 2 component fields afford a convenient starting point in solving for inductance and leakage flux.

Interpolar Field of a Shunt Generator

In a multipolar machine the interpolar space is a close approximation to a rectangle, and the field is a

close approximation to that just considered. In drawing such a field, we begin the construction near the yoke by the methods just outlined, and near the pole tips we would blend it into that obtained by present methods, as outlined by Moore and Lehman.[5] The neutral axis is a line of symmetry. The yoke and the 2 pole cores form surfaces of symmetry. The main component of the leakage field is that obtained by assuming that the field current is spread uniformly over the whole interpolar space. This component gives the usual formulas for pole core leakage, although most books underestimate the leakage from the pole ends.[6] The compensating field will give a new term to be considered.

In figure 3 are shown the 2 component and the resultant fields in a shunt generator when the shunt coils occupy 50 per cent of the interpolar space. The horizontal field is the main and the vertical field is the compensating component. The resultant field is circular in the shunt coils, and equilateral hyperbolas in the insulation. The area of the triangle of flux density on the yoke surface indicates the "yoke" leakage flux, a component which apparently has hitherto been neglected. Yet it should not be neglected, as the saturation of the magnetic circuit will cause a small error in leakage flux to make a larger error in ampere turns. Since the flux is distributed along the yoke we may imagine it as concentrated at a point half way between the pole edge and the neutral axis.[7] Moreover, the vertical component of the field determines the shape of the lines near the pole tip. Thus, referring to figure 3, note the dimensions, a, b, W, H, ΔH, the ampere turns of the coil M, the maximum yoke density B_m, the yoke leakage flux ϕ_y, the pole tip leakage flux caused by the compensating component of the field ϕ_p, and ΔP_p, its permeance.

$$B_m = 3.2\,\frac{Mb}{HW}\,;\ \phi_y = 0.5\,B_m W = 1.6\,M\,\frac{b}{H} \tag{15}$$

$$B_p = 3.2\,\frac{M}{W}\,;\ \Delta H = \frac{\phi_y}{B_p} = \frac{Wb}{2H} \tag{16}$$

$$\Delta P_p = 1.6\,\frac{H}{W} = 0.8\,\frac{b}{H} \tag{17}$$

It is believed that the effect of both the yoke leakage ϕ_y and the extra pole tip leakage ΔP_p is sufficient to warrant consideration for accurate results.

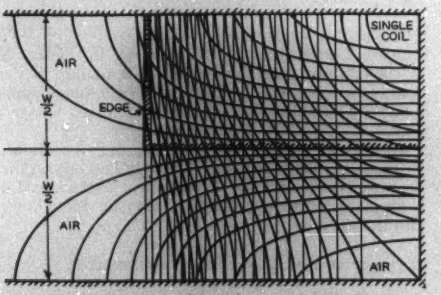


Fig. 6. Field in a shunt machine, showing edge effect

Surface of Zero Magnetic Potential in a Generator

The author has been unable to find any absolute value of magnetic potential assigned to the parts of the field of a dynamo. Since potential is a multivalued function, the magnetic circuit must be capped with a diaphragm which may serve as a datum from which to reckon magnetomotive force. In general this surface is arbitrary, but here considerations of symmetry almost require that the neutral axis be taken as one part of the surface of zero potential. In Figure 4 an attempt is made to visualize this cap surface. In this figure O is the heart of the field, the line DAQ is the neutral axis, and the line $OADE$ the trace of the cap surface. It is the line required in that it is a level line inside the coil, an equipotential outside the coil, and touches the neutral axis. On its inside surface and outside the coil the potential is the full amount of the field coils. On its outside surface the potential is zero. As it is believed this is the first attempt to depict this surface for a dynamo, the isometric projection is included in the figure showing the cap surface.

In figure 4 the effect of saturation in the core and yoke is shown by the core of the field being moved in from the corner where the iron core joins the yoke. The sectorial areas AOB and BOC represent the ampere turns lost respectively in the pole yoke and core.[4]

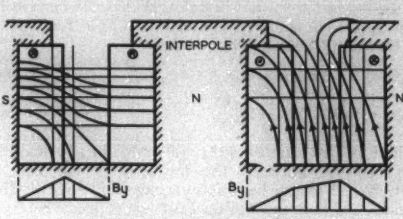


Fig. 7. Field at interpole

Interpolar Flux in a Compound Wound Machine

Figure 5 shows the flux lines in a compound wound generator, when the series coils are next the core, for that particular overload which makes the current density in the shunt coil the same as the average density in the interpolar regions. The figure shows the field resolved into its main and compensating components, one of which varies as y, and the other of which is trapezoidal. The diagram is of interest in that the lines of force in the shunt coil are parabolas.

The fields near the edge of the field coils of a shunt machine are distorted by the pole tips, the armature iron, and by a coil edge effect. It is believed that

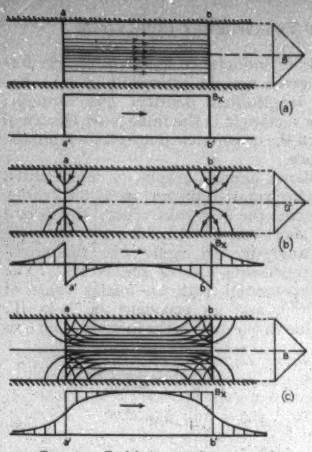


Fig. 8. Field in transformer coils

a. Main component
b. Compensating component
c. Total field

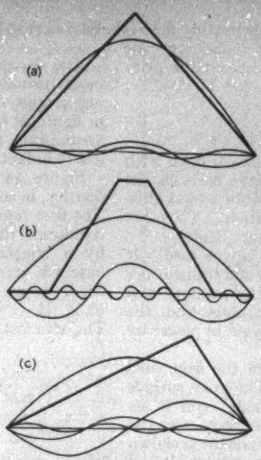


Fig. 9. Waves of flux density

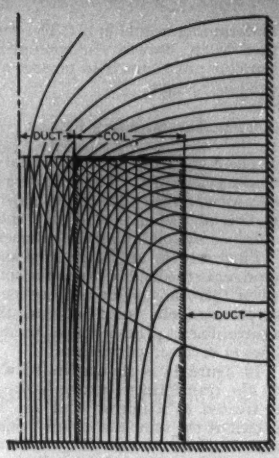


Fig. 10. Field in a transformer with ducts

the more usual graphical methods give the best guide in allowing for all these effects. Nevertheless figure 6 is included for theoretical interest. It represents the field between 2 short field coils but which have long pole cores. It is obtained by the superposition of a "slot" field and a field of a short transformer pair, as in figure 13.

Figure 7 shows the field in an interpolar machine for about half load, when the strength of the interpolar coils is about half that of the coils on the main poles. It is included to show how the method of superposition applies to this case also.

Main and Compensating Fields in Transformer Leakage

In figure 8 are shown the main, compensating and resultant leakage field in a transformer for the case when there are no oil ducts, but there are spaces between the coil ends and the yoke iron. One panel of the field only of a shell type transformer is shown.

Figure 8*a* shows the main component of the field. This field has a triangular density in y and a rectangular density in x. The lines of force come to a sudden end on the lines aa' and bb'. This component is that usually assumed in computing inductance, and meets the curl conditions exactly. It is, however, only a component, as it shows divergence along the lines aa' and bb' and must therefore be completed by another component which will neutralize the divergence on these lines.

Figure 8*b* shows the compensating component of the field. It not only neutralizes the divergence, but must meet the condition of curl = 0 at all points. It is to be noted that the longitudinal density caused by this field component operates to decrease the flux linkages.

Figure 8*c* shows the 2 component fields put together. It is to be noted first that 50 per cent of the flux comes out through the sides of the coil, decreasing the inductance. It is also to be noted that the curve of longitudinal density B_x is a smooth curve.

Building Up Compensating Fields

The iron surfaces in figure 8 are surfaces of symmetry, so that the field is periodic. It may be represented by a Fourier series of the type

$$\phi = \Sigma A_n e^{-(\pi n x/W)} \cos(\pi n y/W) \tag{18}$$

which gives the longitudinal density at the point x, y

$$B_x = \frac{d\phi}{dy} = -\Sigma A_n \frac{\pi n}{W} e^{-(\pi n x/W)} \sin(\pi n y/W) \tag{19}$$

On the line ($x = 0$) the exponential is unity. The problem in any particular case is therefore to choose the constant A_n so that the required wave of density is obtained. In particular, for a triangular wave, calling $B_m = 100$ per cent,

$$B_n = \frac{81}{n^2}; A_n = \frac{(WB_n 81)}{(\pi)(n)^2}$$

Figure 9 shows several such waves of flux density, representing (*a*) 2 equal coils in contact, (*b*) 2 equal coils with spaces between them, and (*c*) unequal sized coils in contact. In graphing a field such as shown in considerable tabular work must be done. The steps are essentially as follows: Values of $\pi y/w$ are taken every 10 degrees, as are a series of values of x/W. Values of ϕ are then calculated for the double series. The value of ϕ is then plotted against x, and values of x are taken off the curve for

uniform increments in ϕ. The compensating field is then easily drawn. In computing inductance the simplest procedure is to neglect all except the principal harmonics.

Special Transformer Fields

There are many possible special cases of fields with transformer coils. The following have been chosen because of novelty or because they afford a good illustration of the method of superposition. They are obtained by combining more elementary fields.

Figure 10 is an interesting and novel case. It represents the field between the coils of a transformer when there are oil ducts between the primary and secondary coils and between the coils and the neutral lines. The field is characterized in places by lines of reversed curvature.

In figure 11 is shown the effect of the iron yoke on the transformer leakage field. The yoke surface is treated as a mirror, and an "image" coil is assumed at the same distance h behind the yoke as the actual coil is in front. The real component is shown by solid and the imaginary component by dotted lines. The components are combined in the usual way. The effect is to increase the inductance.

Figure 12 shows the effect of 2 equal opposing pairs of coils edge to edge. It differs from figure 8 in that 100 per cent instead of 50 per cent of the flux comes out through the side. The inductance is considerably reduced, in fact the decrease of inductance is twice that in figure 8. In a similar manner the effect of short coils may be shown. Figure 13 shows the field of a transformer pair which is very short. It shows clearly the decrease in flux interlinkage which this causes. It is built up of components as shown in figure 8.

Estimation of Transformer Inductance

The decrease in inductance from the simple formulas usually given may be estimated by considering graphs of longitudinal density. For example, in figure 8c the rectangle is the linkage on the usual assumption, and the crosshatched area represents the loss in inductance.

Figure 14 shows similar graphs of longitudinal density, in comparison with the rectangle, for 2 cases. The first represents the iron yoke effect; the second represents the short coil effect. They are obtained by a simple analysis. In figure 14a the crosshatched area represents loss of inductance. The curve is an exponential with an initial value of (0.5) $(1-\epsilon^{-2\pi h/W})$, and an exponent of $-\pi x/W$. The area lost (due to one end) is the integral from 0 to D.

$$\frac{\Delta L}{L} = 100\,\frac{W}{2\pi D}\,(1-\epsilon^{-2\pi h/W})\int_0^D \epsilon^{-\pi x/W}\,d\pi x/W$$

$$= 100\,\frac{W}{2\pi D}\,(1-\epsilon^{-2\pi h/W})\,(1-\epsilon^{-\pi D/W}) \qquad (20)$$

This includes both the short coil and yoke iron effect. In this calculation all but the first term of the Fourier series were neglected. In certain more complicated cases they also would have to be considered. Figure 14b shows the short coil effect. The correction factor in equation 18 is given as a percentage of the inductance as calculated by the methods to be found in nearly every book. It is a modification and expansion of Rogowski's correction factor.

Main and Compensating Field in Slots

The main and compensating field in the case of armature slots is much like that in the interpolar

Fig. 11. Effect of iron yoke on transformer leakage field

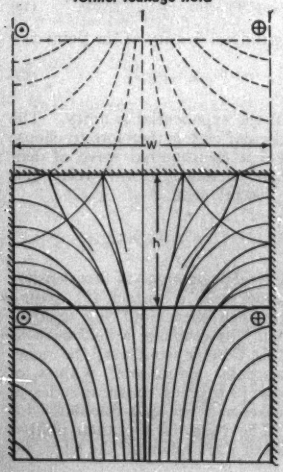


Fig. 12. Field with opposing transformer coils

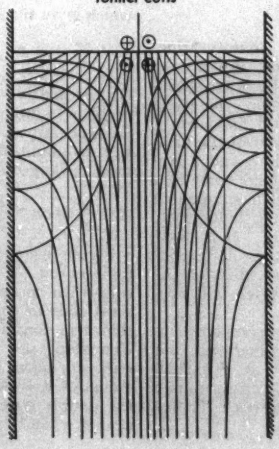
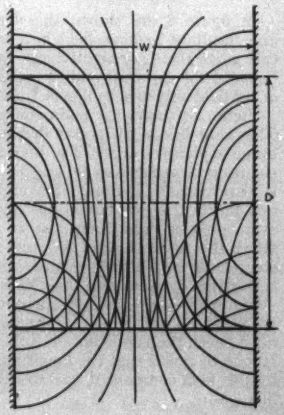


Fig. 13. Field of a transformer with short coils



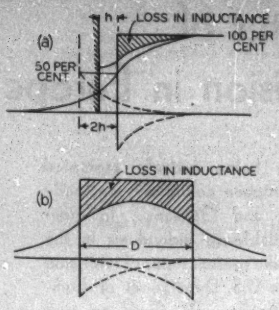


Fig. 14. Effect on transformer inductance of yoke iron (a) and of short coils (b)

regions of a dynamo in its shape. The simplest example is shown in figure 15, in which there is insulation on the sides of the conductor, but not on the bottom. Although not a practical case it will introduce us to the subject. The horizontal component is that of the main field, and the vertical component of triangular density is the compensating field. This is chosen so as to neutralize the curl in the insulation. The usual formulas for inductance regard the main component of the field only.[5]

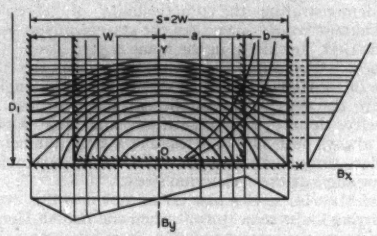


Fig. 15. Field in armature slot with side insulation only

The value of tooth tip and slot opening leakage appears to be somewhat too small in many of the formulas. The author considers his 1915 formula for slot opening leakage the closest, and finds that recent work confirms this.[6] Stevenson and Park have delineated the flux inside a slot but the writer does not consider the results susceptible to easy calculation of inductance. Novelty is claimed here only for method, and some special cases.

In figure 15 let us assume that we have an open slot of depth D_1 below the wedge and depth D_2 from surface to top conductor. The usual formula for inductance is, per inch of slot,

$$L' = 3.2(2\pi^2)\left[\frac{D_2}{W} + \frac{D_1}{3W}\right] \tag{21}$$

It is not particularly easy to compute the interlinkages of the compensating field directly, so resource will be had to theorems in stored magnetic

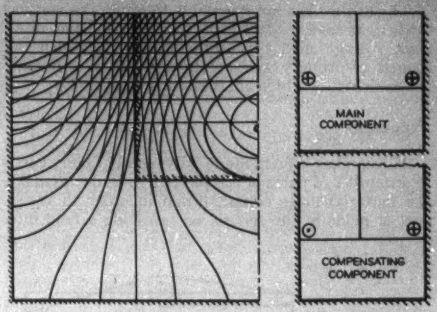


Fig. 16. Field in armature slot with full insulation

energy. We will use the following propositions:

1. For a given current inductance is proportional to stored energy.
2. In any elementary volume the energy stored is proportional to B^2, the square of the induction.
3. At any point $B^2 = B_x^2 + B_y^2$, so that the total energy may be found considering component fields separately.
4. Energy in a field in which the density varies as a straight line has $^1/_3$ the value it would have if the maximum density were to prevail throughout. (This is because the integral of x^2 is $x^3/3$.)

We have therefore the following proposition: The energy in the compensating field is to that in the main field as the square of the ratio of the maximum densities. If b is the thickness of insulation and $\Delta L/L$ the per cent error in the inductance,

$$\frac{\Delta L}{L} = 100\left(\frac{b}{D_1}\right)^2 \text{ per cent} \tag{22}$$

It is to be noted that the error is not considerable except in heavily insulated and shallow slots. With insulation on the bottom of the slot the above figure would be decreased slightly.

Special Armature Leakage Fields

Figure 16 shows a slot in which the conductor is half of the width of the slot and insulated equally on the bottom and the sides. The main component of the field is the usual slot flux; the compensating field is similar to figure 11; in fact, it is identical. The resultant field is the same as given in the paper by Stevenson and Park. The effect of the insulation on the bottom of the slot is to move the core of the field a little and to decrease the inductance a trifle.

Figure 17 shows a slot occupied by 4 conductors which is part of a short pitch winding. The 2 conductors on the right carry +200 amperes each. The upper left-hand conductor carries no current, the lower left-hand carries a current of −200 amperes. The main field is vertical and reverses at the level H. The compensating field is horizontal and is that of a short transformer coil as in figure 12. The example is included for illustration of the degree of complexity of the field which is solvable by the method proposed.

The author has not been able to apply the method with assurance to core type transformer coils, or to high voltage shell type transformers, in which the length of primary and secondary coils is different. These are cases which are treated by Rogowski.

Appendix

Allusion has been made to "divergence" and "curl" in a number of parts of the paper. In order to make the material more complete and in order to verify curl of fields in the section on resolving a field into

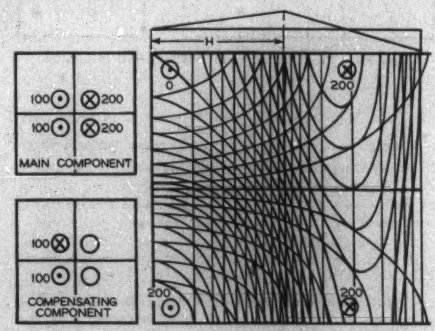


Fig. 17. Field in slot with short pitch winding

its components, the following general differential equations are given. Let V be the potential where there is any and let ϕ, B_x, x, y, and U have meanings before given, then

$$B_x = \frac{d\phi}{dy};\ B_y = -\frac{d\phi}{dx};\ \frac{dB_x}{dx} + \frac{dB_y}{dy} = \text{Divergence } B = 0$$

$$B_x = -\frac{dV}{dx};\ B_y = -\frac{dV}{dy};\ \frac{dB_x}{dy} - \frac{dB_y}{dx} = 3.2U = \text{Curl } B.$$

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The Status of Television in Europe

Television is being actively promoted in several European countries, principally Great Britain and Germany. In order to make available to individuals in the United States the present status of television in Europe, the U.S. Department of Commerce sent Andrew W. Cruse on a 2 months' study of television developments in England, Germany, and France. The article which follows is based upon an address delivered by Mr. Cruse upon his return.

It was early in 1925 that Baird in England and Jenkins in the United States succeeded in demonstrating the practicability of television and almost hourly since then the statement has been made that "television in the home is just around the corner!" For some unaccountable reason this mirage of visual transmissions which has been dangled before the eyes of the public has failed to lose its novelty despite this repetition—and any writer has always been sure of attracting a large number of readers through the simple expedient of developing a new angle on the "television story."

On May 14, 1934 a new note crept into this ever-recurring "television story," when the British House of Commons announced the appointment of a committee:

> To consider the development of television and to advise the Postmaster General on the relative merits of the several systems and on the conditions under which any public service of television should be provided.

This theme was built up to a terrific crescendo when, on January 14, 1935 the British television committee rendered its report. The corner had been turned, the public cheered, television stocks boomed—in short, a scientific sensation was created.

But in the background of the cheers in the United States could be heard the voices of those incredulous persons who were—and for that matter still are—demanding the answers to their questions: "What are *we* going to do about it? When are *we* going to have television in *our* homes? What is to be *our* answer to this challenge of our recognized leadership in the field of science?"

Based upon an address delivered by Andrew W. Cruse, chief, electrical equipment division, Bureau of Foreign and Domestic Commerce, U.S. Department of Commerce before the thirteenth annual convention of the National Association of Broadcasters, Colorado Springs, Colo., July 8, 1935. Manuscript received July 8, 1935; released for publication July 24, 1935.

That, in brief, was the situation when early in May 1935 the United States Department of Commerce decided to make a study of the television situation in Europe—because by this time Germany and France were also in the television picture—and advise the electrical and radio industries in this country on the exact state of affairs in a fair, unvarnished, uncolored, unbiased fashion.

The facilities of the Bureau of Foreign and Domestic Commerce available abroad have made this study possible in so short a period of time. The bureau maintains commercial attaches in the principal countries of the world, and these offices together with the consular offices of the Department of State are of inestimable value to American business in general. After having studied all the available material on television abroad and having secured letters of introduction to the leaders in that field from the industry in this country, the commercial attaches in England, Germany, and France were advised and they proceeded to lay out a schedule of appointments for the author which utilized every minute of the time available.

Before discussing the development of European television in detail, first consider what is meant by development. This can be given by answering the questions:

1. How many hours of television programs are now being given daily?

2. How many people are looking at those programs and how popular are those programs?

3. What are the prospects for increasing the scope of this television service in the immediate future?

Developments in Great Britain

In England, the British Broadcasting Corporation is now offering low definition television programs lasting from $^1/_2$ to $^3/_4$ of an hour twice each week. These programs are transmitted on a wave length of 261 meters with the accompanying sound on 398 meters, using 2 broadcast transmitters, 1 for the picture and the other for the accompanying sound. The Baird system employing mechanical scanning giving a 30 line picture 12 frames per second is used for this purpose. The B.B.C. appears to be doing an excellent job on these programs and the author was pleasantly surprised to discover that despite the low definition and objectionable flicker these programs do have an entertainment value for short periods—perhaps of the order of $^1/_2$ hour. Live talent is used exclusively on these programs and everything from a condensed version of "Carmen" to vaudeville acts is offered.

In answer to a query regarding the number of television receiving sets in service in the British Isles estimates were received which ranged from zero to 10,000. The British Post Office, however, which is in the best position to make an estimate, gave the figure of less than 100. Please bear in mind that these B.B.C. low-definition programs which are offered twice weekly and received by a maximum of 100 receiving sets comprise the only public television service now being offered in Great Britain. Both the Baird Company and Electrical and Musical Industries (E.M.I.) are transmitting experimental high definition television but inasmuch as no high definition receiving sets can now be purchased, these transmissions can in no way be considered as a public service.

Now, as to the prospects for increasing the scope of British television in the near future. On June 7, 1935 the Postmaster General announced that he had received "a communication from the television advisory committee regarding the choice of a site for the projected London television station and other matters relative to the proposed experimental television service." It may be noted that the Postmaster General refers to this as the "proposed *experimental* television service." The announcement goes on to state that the Alexandra Palace has been selected as the location and that Baird and E.M.I. have been called upon to submit bids for the transmitters to be used at that location. There is no reason to doubt that these bids will be accepted and the chances are that late this winter or early next spring high definition television service will be inaugurated by B.B.C. using alternately the E.M.I. 405-line 50-frame interlaced and the Baird 240-line 25-frame sequential transmitters. It is now proposed to operate 1 hour each morning and 2 hours each evening using 6.6 meters for vision and 7.2 meters for the associated sound signals. High definition television receiving sets capable of receiving programs sent by either transmitter, i. e., Baird 240 line or E.M.I. 405 line, are expected to make an appearance about the time the bids for the transmitters are actually accepted—which will probably be some time this fall. It is anticipated that their minimum price will be the equivalent of $250.

Other British Developments

Experimental work is being carried on in the field of coaxial cables for the land line relay of television programs from one city to another and there is one unconfirmed report that the British Post Office hope to have a coaxial cable link between London and Birmingham before the New York-Philadelphia coaxial cable is placed in service. In view of the fact that they speak of their cable as being capable of handling a frequency band of but 1.5 megacycles, it may seriously be doubted if they can, or will, plan to use it for television relay work.

Their ultimate plans call for the erection of 12 transmitters to cover the principal population centers of Great Britain and it is confidently predicted that 4 or 5 of these will be in service by the end of 1937. The confidence of the prospective manufacturers of television receivers is reflected in their prediction that 50,000 of those sets will be in service by the end of 1936 and from 5 to 10 times that many more by the end of 1937.

In considering television the question logically arises: "Who is going to pay the bills?" It should be remembered that approximately 7 million listeners are now paying license fees of $2.50 per year of which the B.B.C. receives $1.12 and the balance goes to the treasury. It is now proposed to increase the

B.B.C. share of the license fee to $2.25, thus giving them approximately $15,750,000 annually on which to operate both sound and visual services. It is most interesting to note that this new proposal has caused practically no adverse criticism from license holders in areas not to be served by the television programs.

The British Broadcasting Corporation's charter expires December 31, 1936 and it is going to be most interesting to observe what effect this venture into this new field will have upon its future!

Developments in Germany

In Germany, 180-line 25-frame sequentially scanned transmissions are being given at the present time from a 7 meter transmitter in Berlin. The Broadcasting Company of the Ministry of Propaganda provides a 2 hour program 3 nights a week and the Post Office supplies programs in the mornings and afternoons and on alternate evenings. Several places are provided in Berlin where the public may view these programs and they are proving most popular. Inasmuch as practically all the program material is provided by films, repetition is not infrequent and occasionally an old film leaves much to be desired. Generally speaking, however, the quality of these transmissions is excellent and impresses one with the high entertainment value which can be secured with a 180 line picture.

While the German engineers expect to carry on their experiments using 180 lines, they plan to eventually go to 270 line pictures. This latter figure has been arrived at as the most economically satisfactory standard, taking into consideration transmission costs and land line relays using coaxial cable. They are confident of their ability to manufacture long haul cables of this character capable of handling a band of 3 megacycles. The maximum frequency band which they have been able to handle by cable so far is 5 megacycles and that, they quite frankly admit, could only be accomplished over a distance of approximately 100 meters. The Post Office is considering the laying of a 3 megacycle cable between Berlin and Frankfort and expects to use this cable for the relay of television programs.

The German Ministry of Propaganda is most interested in securing broadcast coverage in those areas which are now in "dead spots." In view of the fact that practically all of the frequency bands available to that country are now in use, they expect to cover those "dead spot" areas with ultra-short wave, probably using 7 meters, and equipping each new location with both sound and television transmitters at the same time. In order to secure television coverage of the principal population centers of the entire country it is estimated that 25 20-kw ultra-short wave transmitters will be required. A survey of the locations of these transmitters has already been started using a full power (20 kw) "transportable" transmitter for both sound and television. This "transportable" transmitter was built by Telefunken and is mounted on several large trucks—one truck carrying a Diesel driven power plant. It is anticipated that these field strength surveys will require approximately 2 weeks for each locality and as soon as a locality has been approved, work on the permanent transmitter will be started.

Future of Television Sales in Germany

At the present time no high definition television receivers are being sold, but all of the principal manufacturers are planning to show models and offer them for sale during the summer of 1935. The manufacturers would really prefer to have the transmission standards raised to 270 lines before offering their sets for sale because they feel that the 180 line work is not sufficiently good to stimulate sales. As a matter of fact, they are only estimating their 1935 sales to be 1,000 receivers in the Berlin area where the present television programs are covering an area occupied by a population of 7 million. A patent pool is being formed and negotiations in this direction are proceeding very smoothly indeed. While natural competition exists between the various German radio manufacturers, they seem to be able to get together in the solution of their mutual problems in a very commendable fashion. It is anticipated that television receivers which will be adaptable to the 270 line standard will sell for from $240 to $500. In order to get these prices reduced as quickly as possible, the Loewe Company has already laid out an assembly line and are ready to go into quantity production in a very short time.

The Broadcasting Company has a very interesting piece of equipment which it calls its television truck and which is used to cover news events. This truck, which was first used at the May Day ceremony at the Templehof Aerodrome at which Chancellor Hitler spoke, consists of a low-powered ultra-short wave transmitter for both sound and television using the intermediate film method. The program is relayed by the high powered Berlin transmitter and the transmission was declared most satisfactory by people who saw it. The interval of delay between the taking of the picture by the camera mounted on top of the truck and the time when that picture has been televised is approximately 90 seconds. The Broadcasting Company engineers feel that the high speed with which it is necessary to develop and fix the film does not give a satisfactory sound track and are consequently preparing to record the sound by the steel tape method developed recently by the Lorenz Company.

Television is moving ahead in Germany on what certainly appears to be a most thorough basis and the cost is being carried by the license fees plus an additional governmental appropriation.

Developments in Other Countries

In France, the Ministry of Posts and Telegraphs is extremely interested in having that country match the television developments in England and Germany and is doing everything in its power to speed up this work realizing that France is behind those 2 countries in this respect. It has started experimental 60-line 25-frame transmissions on 175 meters but no regular schedule is maintained. The French

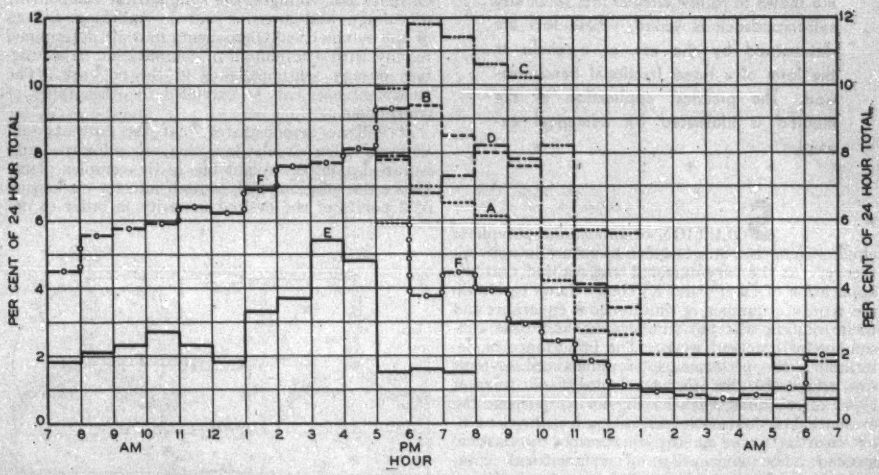
hope to be able to go to 90 lines and then to 180 lines as quickly as practicable but it may be seriously doubted whether much progress in this direction will be made before 1936.

Some work is being carried on in other European countries, notably Russia and Italy. So far these developments do not appear to have progressed very far—but, an entirely different picture should present itself in the next 2 years, particularly in England and Germany.

Regarding the future of television in the United States, we should not only continue along our present line, but in addition should observe the European picture closely. The technical development of television is still in a state of flux and much work in the laboratory still remains to be done. Also, the broadcasting industry must develop studio technique before it can hope to enter this field satisfactorily.

In Europe, the governments are directly or indirectly supporting and operating broadcasting and television; in the United States it is the author's belief that the interests of both broadcasting and television can best be served without government assistance. With business recovery and the development of the technical features, it will undoubtedly be possible to add television to the present broadcasting service and present television programs in the same thorough fashion in which broadcasts are now being presented.

The Important Rôle Played by Street Lighting in Automobile Fatalities



THE important rôle played by street lighting in automobile fatalities on city thoroughfares is depicted graphically in the accompanying chart, which has been prepared for the A.I.E.E. committee on production and application of light by R. E. Simpson (A'16) illuminating engineer, National Bureau of Casualty and Surety Underwriters, West Hartford, Conn. The percentage of day fatalities (line *E*) consistently is below the percentage of day traffic (line *F*), the ratio averaging 1 to 3, while during the hours of darkness this ratio is reversed as indicated by line *D*. During part of the year the hours from 5 to 8 p.m. and from 5 to 7 a.m. are daylight hours, and during the rest of the year they are dusk or darkness hours. Lines *D* and *E* overlap during these hours so that to obtain the total percentage of fatalaties for the year during these hours the percentages for the 2 lines must be added; for example, the percentage of fatalities from 6 to 7 p.m. when this is a daylight hour, is 1.6, and 6.8 when it is a dark hour, or a total of 8.4 during the entire year. The grades of lighting *A*, *B*, and *C* (lines *A*, *B*, and *C*, respectively) correspond to the minimum requirements of the street lighting code of the Illuminating Engineering Society for heavy, medium, and light traffic thoroughfares, respectively. It is noteworthy that as the level of street illumination decreases the percentage of fatalities increases. The night fatalities for all cities (line *D*) between the hours of 1 and 5 a.m. are grouped.

Current and Voltage Loci in 3-Phase Y-Y Circuits

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Engineers often find it convenient to be able to determine the various currents and voltages in an electrical system not merely for one fixed condition, but for any value of any impedance element from zero to infinity. In an effort to facilitate such computations, the method presented in this paper has been developed. Although the method as presented is applied specifically to the star-star (Y-Y) circuit, the treatment is said to be applicable also to other circuits. All voltages and currents in this circuit are shown to follow circular loci when any self-impedance is varied; these loci are determined by the use of a circle in the form of a linear fractional transformation. The practical application of the method is illustrated by numerical examples.

SOLUTION of unbalanced polyphase circuits comprises an extensive literature in network theory. At the very outset it was realized that the application of Ohm's and Kirchoff's Laws to obtain the requisite number of simultaneous equations and their solution was too cumbersome and time consuming for practical work. The importance of determining the performance of unbalanced systems was responsible for the development of different types of solutions, each having for its purpose the evaluation of the various currents and voltages without resorting to the lengthy equations of the classical method. The conception of symmetrical components by Fortescue[1] supplied a convenient and powerful tool for handling unbalanced conditions, capable of very general application. Various special methods have been described which are applicable to particular kinds of circuits—for example, the superposition of a reversed neutral voltage in a star circuit by Karapetoff.[2]

Frequently the solution of an unbalanced polyphase circuit is facilitated by the presence of a short circuit or an open circuit in one or more phases, which simplifies the network. However, where severely unbalanced conditions exist (for instance, a heavy single phase load such as an arc furnace), there is no network simplification and the system must be solved by the most appropriate method available, depending upon the type of connection. The numerical solution is valid for one particular condition of the load; and if it were desired to determine the performance of a network as the load or some other impedance varied, the problem would have to be solved point by point.

It is the object of this paper to show that in any star-star circuit, with or without neutral connection, with any values of linear and bilateral self- and mutual impedances in the phases of source and load and in the interconnecting lines, with internal voltages in the source and load phases of any value, all currents and voltages, the symmetrical components of voltages and currents, and the unbalance factors of the symmetrical components may be determined readily with a minimum of computation as a function of any self-impedance in the network. The treatment also can be extended to other types of connections.

It will be demonstrated that the currents and voltages follow circular loci when any self-impedance is varied along a straight line in the complex plane. Hence the solution resolves itself into the evaluation of 3 points of the desired quantity in order to determine the circle. For this purpose, it is convenient to consider the circle as a linear fractional transformation, as originally applied to alternating current problems by Schenkel.[3] The Schenkel form is

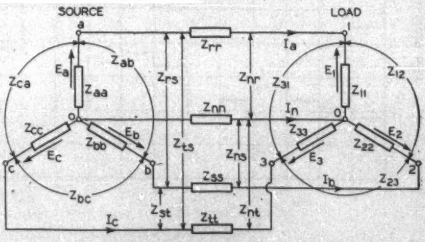

Fig. 1. Schematic diagram of general star-star circuit

$$S = \frac{\alpha + \beta\rho}{\gamma + \delta\rho} \tag{1}$$

in which S is a vector describing a circle as the scalar variable, ρ ranges from minus to plus infinity, and α, β, γ, and δ are complex constants. The radius

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1. For all numbered references see list at end of paper.

and the center vector may be evaluated in terms of these constants, using expressions developed by Schumann.[4] Generally, however, it will be found more expedient to determine the invariant points of the circle, namely, when $\rho = 0$ and when $\rho = \infty$, and use for the third point any convenient value of ρ. These 3 points suffice not only to locate the circle, but also to fix the linear scale line that connects points on the circle with corresponding values of the variable ρ. With the scale line drawn, the value of S may be read off the plot in magnitude and phase angle for any value, positive or negative, of the variable scalar. The construction of the circle and the scale line has been described in a previous paper.[5]

The fundamental current equations in the form of linear fractional transformations are given in detail for the star-star circuit, with and without mutual impedances. The corresponding current equations for a star connected load with constant applied voltages at the sending end may be obtained directly by dropping the terms involving the internal impedances of the source and considering the internal voltages of the source phases to be the applied voltages.

General Solution, Without Mutual Impedances

The circuit that will be studied is a star-star connection tied through line and neutral impedances as shown in figure 1. At first no mutual impedances will be considered between any of the circuit elements. The self impedances are subject to no restriction, with the exception that they be linear and bilateral. The frequency will be maintained constant, and for greatest generality internal voltages of any magnitude and phase will be assumed to exist in both the source and load phases.

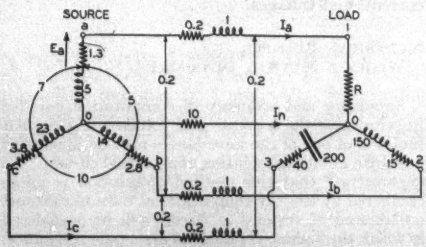

Fig. 2. Specific star-star circuit for which current and voltage loci are shown in succeeding figures

All circuit constants are in ohms

Writing the electromotive force equations for the various meshes and eliminating the neutral current,

$$I_a(Z_{aa} + Z_{rr} + Z_{11} + Z_{nn}) + I_bZ_{nn} + I_cZ_{nn} = E_a - E_1 \quad (2)$$

$$I_aZ_{nn} + I_b(Z_{bb} + Z_{ss} + Z_{22} + Z_{nn}) + I_cZ_{nn} = E_b - E_2 \quad (3)$$

$$I_aZ_{nn} + I_bZ_{nn} + I_c(Z_{cc} + Z_{ll} + Z_{33} + Z_{nn}) = E_c - E_3 \quad (4)$$

Solutions for the 3 line currents may be written in the form

$$I_a = \frac{\Delta I_a}{\Delta_s} \qquad I_b = \frac{\Delta I_b}{\Delta_s} \qquad I_c = \frac{\Delta I_c}{\Delta_s} \quad (5)$$

The numerators are:

$$\Delta I_a = (E_a - E_1)(Z_{bb} + Z_{ss} + Z_{22})(Z_{cc} + Z_{ll} + Z_{33}) + Z_{nn}[(E_a - E_1 - E_c + E_3)(Z_{bb} + Z_{ss} + Z_{22}) - (E_b - E_2 - E_a + E_1)(Z_{cc} + Z_{ll} + Z_{33})] \quad (6)$$

$$\Delta I_b = (E_b - E_2)(Z_{cc} + Z_{ll} + Z_{33})(Z_{aa} + Z_{rr} + Z_{11}) + Z_{nn}[(E_b - E_2 - E_a + E_1)(Z_{cc} + Z_{ll} + Z_{33}) - (E_c - E_3 - E_b + E_2)(Z_{aa} + Z_{rr} + Z_{11})] \quad (7)$$

$$\Delta I_c = (E_c - E_3)(Z_{aa} + Z_{rr} + Z_{11})(Z_{bb} + Z_{ss} + Z_{22}) + Z_{nn}[(E_c - E_3 - E_b + E_2)(Z_{aa} + Z_{rr} + Z_{11}) - (E_a - E_1 - E_c + E_3)(Z_{bb} + Z_{ss} + Z_{22})] \quad (8)$$

The common denominator of the expression for line currents is:

$$\Delta_s = (Z_{aa} + Z_{rr} + Z_{11})(Z_{bb} + Z_{ss} + Z_{22})(Z_{cc} + Z_{ll} + Z_{33}) + Z_{nn}[(Z_{aa} + Z_{rr} + Z_{11})(Z_{bb} + Z_{ss} + Z_{22}) + (Z_{bb} + Z_{ss} + Z_{22})(Z_{cc} + Z_{ll} + Z_{33}) + (Z_{cc} + Z_{ll} + Z_{33}) \times (Z_{aa} + Z_{rr} + Z_{11})] \quad (9)$$

The impedance elements will be considered as varying: (1) along the resistance component, (2) along the quadrature component, and (3) in magnitude at constant phase angle. Inspection of the equations for line currents discloses all the numerators and the common denominator to be linear with respect to any one impedance element. Therefore with any one of the impedances considered variable, the remaining impedances being considered constant, each numerator and the denominator may be written as a constant term plus a variable term. Hence, whichever impedance be chosen as the variable, the 3 expressions for line currents readily may be rewritten in the canonical form of a circle. Moreover, the neutral current, being a summation of the 3 line currents, likewise follows a circular locus because the numerators may be added directly, the denominator remaining unchanged. Thus

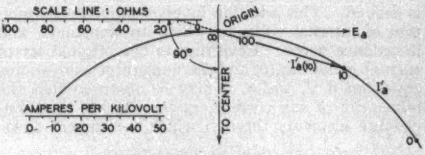

Fig. 3. Locus of line current I_a' of circuit of figure 2 without mutual impedances

$$I_n = -(I_a + I_b + I_c) \quad (10)$$

Writing the neutral current as $I_n = (\Delta I_n)/\Delta_s$ and substituting the line current expressions into equation 10,

$$\Delta I_n = (E_a - E_1)(Z_{bb} + Z_{ss} + Z_{22})(Z_{cc} + Z_{ll} + Z_{33}) + (E_b - E_2)(Z_{cc} + Z_{ll} + Z_{33})(Z_{aa} + Z_{rr} + Z_{11}) + (E_c - E_3)(Z_{aa} + Z_{rr} + Z_{11})(Z_{bb} + Z_{ss} + Z_{22}) \quad (11)$$

When there is no neutral connection, making Z_{nn} infinite in equations 5,

$$I_a = \frac{(E_a - E_1 - E_c + E_2)(Z_{bb} + Z_{ss} + Z_{22}) - (E_b - E_2 - E_a + E_1)(Z_{cc} + Z_{11} + Z_{12})}{(Z_{aa} + Z_{rr} + Z_{11})(Z_{bb} + Z_{ss} + Z_{22}) + (Z_{bb} + Z_{ss} + Z_{22})(Z_{cc} + Z_{11} + Z_{12}) + (Z_{cc} + Z_{11} + Z_{12})(Z_{aa} + Z_{rr} + Z_{11})} \tag{12}$$

$$I_b = \frac{(E_b - E_2 - E_a + E_1)(Z_{cc} + Z_{11} + Z_{12}) - (E_c - E_1 - E_b + E_2)(Z_{aa} + Z_{rr} + Z_{11})}{(Z_{aa} + Z_{rr} + Z_{11})(Z_{bb} + Z_{ss} + Z_{22}) + (Z_{bb} + Z_{ss} + Z_{22})(Z_{cc} + Z_{11} + Z_{12}) + (Z_{cc} + Z_{11} + Z_{12})(Z_{aa} + Z_{rr} + Z_{11})} \tag{13}$$

$$I_c = \frac{(E_c - E_1 - E_b + E_2)(Z_{aa} + Z_{rr} + Z_{11}) - (E_a - E_1 - E_c + E_2)(Z_{bb} + Z_{ss} + Z_{22})}{(Z_{aa} + Z_{rr} + Z_{11})(Z_{bb} + Z_{ss} + Z_{22}) + (Z_{bb} + Z_{ss} + Z_{22})(Z_{cc} + Z_{11} + Z_{12}) + (Z_{cc} + Z_{11} + Z_{12})(Z_{aa} + Z_{rr} + Z_{11})} \tag{14}$$

Thus the loci of the line currents remain circular.

When the neutral impedance is zero, the following equations are obtained from equations 5

$$I_a = \frac{E_a - E_1}{Z_{aa} + Z_{rr} + Z_{11}} \tag{15}$$

$$I_b = \frac{E_b - E_2}{Z_{bb} + Z_{ss} + Z_{22}} \tag{16}$$

$$I_c = \frac{E_c - E_3}{Z_{cc} + Z_{11} + Z_{12}} \tag{17}$$

Under this condition, 2 of the circular loci degenerate into points, that is, constants, or circles of zero radius. For instance if Z_{11} were taken as the variable impedance, I_a would be a circle and I_b and I_c would be constants.

Voltages. The process of evaluating voltages is simply that of adding potential differences between those points in the system across which the voltage is desired. This addition involves only the summation of internal voltages, which are constants, and impedance drops. Reverting to the original set of current equations (5) and the numerator expressions, equations 6, 7, and 8, it may be observed that the numerator of any current equation is free of all impedance elements through which the current flows.

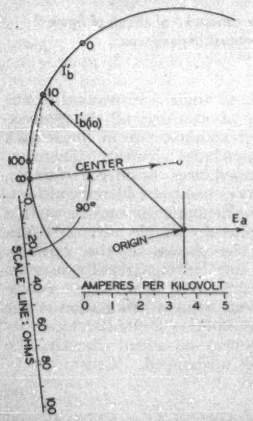

Fig. 4. Locus of line current I_b' of circuit of figure 2 without mutual impedances

Therefore, the multiplication of any current expression by any impedance to give an actual impedance drop existing in the system does not disturb the linearity of any numerator with respect to any impedance. The denominator being common, any summation of existing impedance drops is obtained by direct addition of the numerators of the currents multiplied by the impedances through which they flow. Thus it immediately follows that the loci of all phase and line voltages, voltage between neutral points, and line voltage drops are circular when any one impedance is varied. For example, the voltage across phase 1 of the load is I_aZ_{11}. Let the variable impedance be Z_{11}. The expression for I_a does not contain Z_{11} in the numerator and thus I_aZ_{11} remains a linear fractional transformation.

The expressions for the line currents are the 3 fundamental equations for this type of solution. Once these expressions are evaluated, since the denominators are alike, the calculation of any voltage in the circuit is effected by multiplication of the numerators of the currents by the proper impedances. It is not necessary to substitute into detailed expressions for voltages since that work has already been done in obtaining the expressions for currents.

Symmetrical Components. Bearing in mind that symmetrical components of currents and voltages are summations of actual currents and voltages multiplied by the sequence operators, it is evident that all symmetrical components of the circuit likewise follow circular loci. The same holds true for the unbalance factors, that is, the ratios of negative and zero sequence to positive sequence amplitudes of currents and voltages.

Numerical Example, Without Mutual Impedances

Simplicity and economy of computation entailed in computing the currents and voltages as a circular function of one of the impedances may be illustrated best by a numerical solution of an actual circuit. To demonstrate that this method of solution is unencumbered by lengthy computations, even in the most unbalanced of systems, a circuit will be considered in which the 3 phases of the load are a pure resistance, an impure inductance, and an impure capacitance, respectively. The phases of the source will be considered to have unequal values of inductive impedance, and the neutral to possess an appreciable resistance. The impedances of the connecting lines will be considered to be inductive and equal; the internal voltages at the source will be considered to be balanced, and no internal voltages will be assumed to exist in the load phases.

The constants of the circuit will be as follows:

$Z_{aa} = 1.3 + j5.0$ ohms $\quad Z_{11} = R + j0$ ohms
$Z_{bb} = 2.8 + j14.0$ ohms $\quad Z_{22} = 15 + j150$ ohms
$Z_{cc} = 3.8 + j23.0$ ohms $\quad Z_{33} = 40 - j200$ ohms
$Z_{rr} = Z_{ss} = Z_{tt} = 0.2 + j1.0$ ohms
$Z_{nn} = 10 + j0$ ohms

This circuit is shown in figure 2; the mutual impedances indicated will be treated later and will not be considered to exist at present. The resistance arm of the load, Z_{11}, will be taken as the variable impedance, and the loci of currents and voltages will be determined for a variation of $R = Z_{11}$ between zero and infinity. Merely enough unequal elements have been introduced into this problem to indicate the generality of the method. Inspection of the preceding equations shows that if, in addition, the internal voltages at the source had been assumed to be unbalanced and internal voltages assumed to exist in the load, the result would have been merely a modification in the constants of the current equations. The same holds true for inequality of line impedances.

The internal voltage E_a will be considered as the reference vector and all quantities will be evaluated

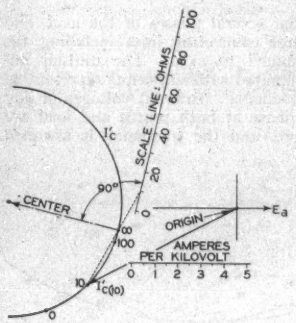

Fig. 5. Locus of line current I_c' of circuit of figure 2 without mutual impedances

in terms of amperes or volts per volt of internal voltage E_a. To prevent any confusion all unit quantities will be indicated by a prime (′). Substituting the constants of this problem into equations 5, the following expressions are obtained for the line currents:

$$I_a' = \frac{33{,}970\angle 7.0^\circ}{393{,}900\angle 35.7^\circ + R \times 30{,}710\angle 7.4^\circ} \text{ amperes per volt} \quad (18)$$

$$I_b' = \frac{2{,}927\angle 154.5^\circ + R \times 177.4\angle 169.4^\circ}{393{,}900\angle 35.7^\circ + R \times 30{,}710\angle 7.4^\circ} \text{ amperes per volt} \quad (19)$$

$$I_c' = \frac{3{,}688\angle -116.2^\circ + R \times 159.8\angle -161.9}{393{,}900\angle 35.7^\circ + R \times 30{,}710\angle 7.4^\circ} \text{ amperes per volt} \quad (20)$$

The 3 loci now are determined by evaluating equations 18, 19, and 20 for 3 points: $R = 0$, $R = \infty$, and R = some other value, for example, 10 ohms. The corresponding values of line currents (in amperes per kilovolt) are found to be as follows:

	$R = 0$	$R = 10$	$R = \infty$
I_a'	$86.24\ \angle -28.6^\circ$	$49.94\angle -16.3^\circ$	0
I_b'	$7.431\angle 118.8^\circ$	$6.856\angle 136.8^\circ$	$5.778\angle 162.0^\circ$
I_c'	$9.362\angle -151.8^\circ$	$7.258\angle -152.9^\circ$	$5.203\angle -169.4^\circ$

These points are also sufficient to determine the scale lines of the circles. The resultant loci are drawn in figures 3, 4, and 5. The construction of the scale lines is indicated as well as the location of 4 points on each circle corresponding to 0, 10, 100, and ∞ ohms for R. Dotted lines are shown connecting the scale lines with the point on each circle corre-

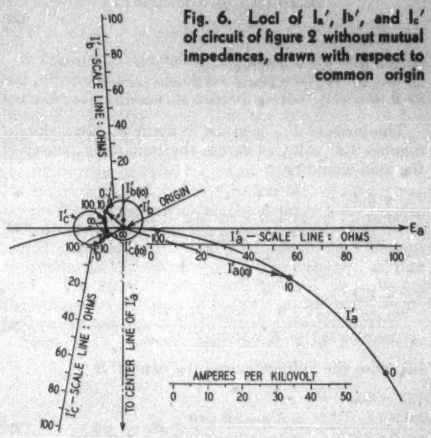

Fig. 6. Loci of I_a', I_b', and I_c' of circuit of figure 2 without mutual impedances, drawn with respect to common origin

sponding to 10 ohms. The corresponding current vector drawn from the origin, as shown, then represents the value of current in magnitude and phase for 10 ohms. The 3 current loci are drawn with respect to a common origin in figure 6 to give a better picture of the relationship of the currents. This figure, as a consequence of the considerable reduction in size for reproduction and the small scales of I_b' and I_c' as compared with that of I_a', is not as suitable for quantitative work as the preceding figures, but it does give a more comprehensive representation of the simultaneous variation of the currents in the various phases.

By substituting the current expressions in equations 18, 19, and 20 into equation 10 the neutral current assumes the following form:

$$I_n' = \frac{29{,}520\angle -177.0^\circ + R \times 326.8\angle 3.0^\circ}{393{,}900\angle 35.7^\circ + R \times 30{,}710\angle 7.4^\circ} \text{ amperes per volt} \quad (21)$$

The 3 points necessary to determine the neutral current locus, for the same values of resistance as before, are

for $R = 0$ $\quad I_n' = 74.95\angle 147.3^\circ$ amperes per kilovolt
for $R = 10$ $\quad I_n' = 38.60\angle 160.9^\circ$ amperes per kilovolt
for $R = \infty$ $\quad I_n' = 10.64\angle -4.5^\circ$ amperes per kilovolt

The locus of neutral current is plotted in figure 7 with the same details shown as for the line currents. It is not necessary to use the expression for neutral current directly as given in equation 10 to evaluate the 3 points of the circle if instead the specific values of line currents obtained for different values of R are added.

With all the current loci determined, any voltage circle now may be located by taking the proper impedance drops. For example, the voltage across phase 1 of the load is

$$V_{01}' = RI_a' = \frac{R \times 33{,}970 \angle 7.0^\circ}{393{,}900 \angle 35.7^\circ + R \times 30{,}710 \angle 7.4^\circ} \text{ volts per volt} \tag{22}$$

which gives

for $R = 0$ $\quad V_{01}' = 0$ volts per volt
for $R = 10$ $\quad V_{01}' = 0.4994 \angle -16.3^\circ$ volts per volt
for $R = \infty$ $\quad V_{01}' = 1.106 \angle -0.4^\circ$ volts per volt

The locus of V_{01}' is given in figure 8. In a similar manner the voltages across the remaining phases of the load would be

$$V_{02}' = Z_{22}I_b' = \frac{441{,}200 \angle -121.2^\circ + R \times 26{,}750 \angle -106.3^\circ}{393{,}900 \angle 35.7^\circ + R \times 30{,}710 \angle 7.4^\circ} \text{ volts per volt} \tag{23}$$

and

$$V_{03}' = Z_{33}I_c' = \frac{752{,}100 \angle 165.1^\circ + R \times 32{,}590 \angle 119.4^\circ}{393{,}900 \angle 35.7^\circ + R \times 30{,}710 \angle 7.4^\circ} \text{ volts per volt} \tag{24}$$

Likewise the voltage across the neutral is

$$V_{00}' = Z_{nn}I_n' = \frac{295{,}200 \angle -177.0^\circ + R \times 3{,}268 \angle 3.0^\circ}{393{,}900 \angle 35.7^\circ + R \times 30{,}710 \angle 7.4^\circ} \text{ volts per volt} \tag{25}$$

The symmetrical components of the line currents are determined by the following relationships:

$$I^0 = \frac{1}{3}(I_a + I_b + I_c) \tag{26}$$

$$I^+ = \frac{1}{3}(I_a + \sigma I_b + \sigma^2 I_c) \tag{27}$$

$$I^- = \frac{1}{3}(I_a + \sigma^2 I_b + \sigma I_c) \tag{28}$$

in which the sequence operators are $\sigma = 1\angle 120^\circ$ and $\sigma^2 = 1\angle 240^\circ$. To obtain these loci it is necessary only to go back to the specific values of line currents evaluated at the beginning of the solution and operate on the points with 1, σ, and σ^2. Combining terms in this manner, the values of the symmetrical components of currents (in amperes per kilovolt) for 0, 10, and ∞ ohms in Z_{11} become:

	$R = 0$	$R = 10$	$R = \infty$
$I^{0\prime}$	$24.98 \angle -31.6^\circ$	$12.87 \angle -19.1^\circ$	$3.547 \angle 175.5^\circ$
$I^{+\prime}$	$27.37 \angle -28.0^\circ$	$16.21 \angle -16.1^\circ$	$1.006 \angle -14.3^\circ$
$I^{-\prime}$	$33.93 \angle -27.0^\circ$	$20.89 \angle -14.8^\circ$	$2.561 \angle -0.6^\circ$

The loci of $I^{0\prime}$, $I^{+\prime}$, and $I^{-\prime}$ are drawn in figure 9 with construction details as before. Dividing $I^{0\prime}$ and $I^{-\prime}$, respectively, by $I^{+\prime}$ at $R = 0$, 10, and ∞ would determine the circular loci of the 2 current unbalance factors. The symmetrical components of the voltages are handled similarly.

General Solution, With Mutual Impedances

When a star-star circuit contains mutual impedances, the same analysis may be followed as outlined for the circuit with self-impedances only. As in the star-star circuit with self-impedances only the most general form of circuit involving mutual impedances will be treated. As shown in figure 1, mutual impedances among the several phases of the

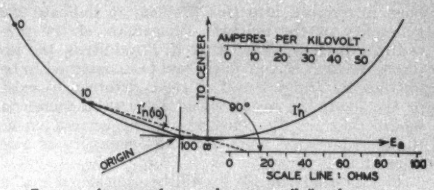

Fig. 7. Locus of neutral current (I_n') of circuit of figure 2 without mutual impedances

source, among the several phases of the load, and among the several connecting lines including the neutral, are assumed to exist. The mutual impedances are designated with subscripts representing the interacting elements. Internal voltages of any magnitude and phase at both source and load are assumed as before, and the frequency is assumed

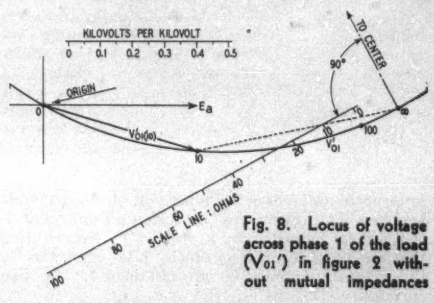

Fig. 8. Locus of voltage across phase 1 of the load (V_{01}') in figure 2 without mutual impedances

to be constant. Both self- and mutual impedances are considered to be linear and bilateral.

Writing the electromotive force equations for this circuit corresponding to the group of equations 2, 3, and 4, and eliminating the neutral current,

$$I_aA_1 + I_bB_1 + I_cC_1 = E_a - E_1 = K_1$$
$$I_aA_2 + I_bB_2 + I_cC_2 = E_b - E_2 = K_2$$
$$I_aA_3 + I_bB_3 + I_cC_3 = E_c - E_3 = K_3$$

The A's, B's, and C's represent linear summations of self- and mutual impedances. If these equations be written out term by term it may be observed that

$$B_1 = A_2 \qquad C_1 = A_3 \qquad C_2 = B_3$$

Making the substitutions indicated, the electromotive force equations may be rewritten in the form

$$I_aA_1 + I_bA_2 + I_cA_3 = K_1 \tag{29}$$
$$I_aA_2 + I_bB_2 + I_cB_3 = K_2 \tag{30}$$
$$I_aA_3 + I_bB_3 + I_cC_3 = K_3 \tag{31}$$

The various coefficients of the currents in equations 29, 30, and 31 are:

$$A_1 = Z_{aa} + Z_{rr} + Z_{11} + Z_{nn} - 2Z_{nr} \quad (32)$$
$$B_1 = Z_{bb} + Z_{ss} + Z_{22} + Z_{nn} - 2Z_{ns} \quad (33)$$
$$C_1 = Z_{cc} + Z_{tt} + Z_{33} + Z_{nn} - 2Z_{nt} \quad (34)$$

$$A_2 = Z_{ab} + Z_{rs} + Z_{12} + Z_{nn} - Z_{nr} - Z_{ns} \quad (35)$$
$$B_2 = Z_{bc} + Z_{st} + Z_{23} + Z_{nn} - Z_{ns} - Z_{nt} \quad (36)$$
$$A_3 = Z_{ca} + Z_{tr} + Z_{31} + Z_{nn} - Z_{nt} - Z_{nr} \quad (37)$$

For convenience the solutions of the currents may be expressed as

$$I_a = \frac{\Delta I_a}{\Delta_m} \qquad I_b = \frac{\Delta I_b}{\Delta_m} \qquad I_c = \frac{\Delta I_c}{\Delta_m} \quad (38)$$

The numerators of these expressions are as follows:

$$\Delta I_a = K_1(B_2C_3 - B_3^2) + K_2(A_3B_3 - A_2C_3) + K_3(A_2B_3 - A_3B_2) \quad (39)$$
$$\Delta I_b = K_1(A_3B_3 - A_2C_3) + K_2(A_1C_3 - A_3^2) + K_3(A_2A_3 - A_1B_3) \quad (40)$$
$$\Delta I_c = K_1(A_2B_3 - B_2A_3) + K_2(A_2A_3 - A_1B_3) + K_3(A_1B_2 - A_2^2) \quad (41)$$

and the common denominator is

$$\Delta_m = A_1B_2C_3 - A_1B_3^2 - B_2A_3^2 - C_3A_2^2 + 2A_2A_3B_3 \quad (42)$$

If the numerators and the denominator be examined term by term after substituting the values of the coefficients as given in equations 32 to 37 it may be found that:

1. The denominator is linear with respect to all self- and mutual impedances.
2. The numerator of any current equation is linear with respect to all self-impedances.
3. No numerator of any current equation contains any self-impedances through which the current flows, or any mutual impedances connecting any element through which the current flows.
4. The numerator of any current equation contains squares of all mutual impedances in the circuit except those connecting any element through which the current flows.

These observations indicate that with fixed mutual impedances any current in the system may be written as a linear fractional transformation with any one self-impedance considered as a variable. Any current thus is seen to be a circular function of any self-impedance in the circuit.

The voltage across any part of the system consists of the summation of internal voltages and impedance drops between the 2 points under consideration. For example, the voltage across phase 1 of the load is V_{01} which is

$$V_{01} = E_1 + I_aZ_{11} + I_bZ_{12} + I_cZ_{31} \quad (43)$$

If the mutual impedances remain fixed and one of the self-impedances such as Z_{11} be considered as the variable, I_a, I_b, and I_c all will follow circular loci. Since Z_{11} does not enter into the numerator of the expression for I_a, I_aZ_{11} remains a linear fractional transformation. Likewise, Z_{12} and Z_{31} being constants, the linearity of I_bZ_{12} and I_cZ_{31} with respect to Z_{11} is not disturbed. The denominator of all current expressions being common, the summation of I_aZ_{11}, I_bZ_{12}, and I_cZ_{31} is merely another linear fractional transformation which when added to the constant E_1 produces the voltage V_{01} across phase 1 of the load. Therefore, with fixed mutual impedances the voltage in any part of the system follows a circular locus when any one self-impedance is varied.

Since both currents and voltages in a star-star circuit with mutual impedances may be represented by a linear fractional transformation when any self-impedance varies, and the denominator of all current and voltage expressions is common, it follows that the symmetrical components and their unbalance factors likewise follow circular loci.

Thus, the circuit with mutual impedances succumbs to precisely the same treatment as applied to circuits containing self-impedances only. The presence of mutual impedances, however, does impose a restriction: The currents and voltages follow circular loci when any self-impedance is considered as the variable, but not when a mutual impedance is varied. Since squares of mutual impedance terms appear in the numerators of the current expressions, a variation of a mutual impedance would engender

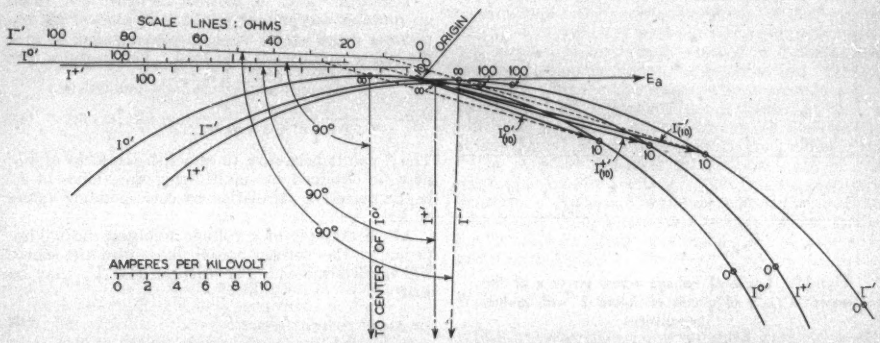

Fig. 9. Loci of the symmetrical components of current in circuit of figure 2 without mutual impedances

loci of higher order which will not be treated in the present paper.

Numerical Solution, With Mutual Impedances

To illustrate the application of the 3 point method to the evaluation of circular loci when mutual impedances are present, the same circuit will be em-

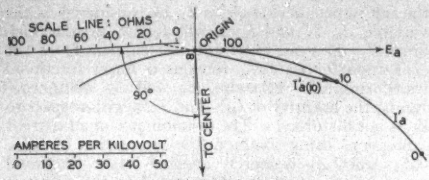

Fig. 10. Locus of line current I_a' of circuit of figure 2 with mutual impedances

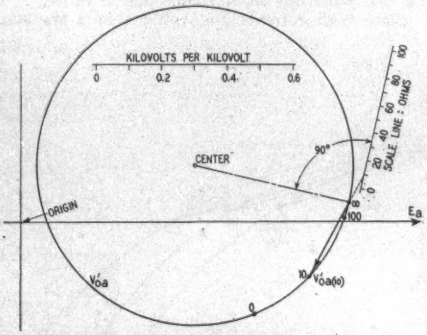

Fig. 11. Locus of voltage across phase a of the source (V_{oa}') of circuit of figure 2 with mutual impedances

ployed as in the preceding example with the addition of the following mutual coefficients in the source phases and in the connecting lines:

$Z_{ab} = j5$ ohms
$Z_{bc} = j10$ ohms
$Z_{ca} = j7$ ohms
$Z_{rs} = Z_{st} = Z_{tr} = j0.2$ ohms

These mutual impedances are shown in the diagram in figure 2.

No mutual impedances will be considered to exist among the load phases because of the nature of the load impedances assumed in this problem. However, if these mutual impedances were present they merely would be added in to form the general constants of the current equations as indicated by equations 32 to 37. The same applies to mutual impedances involving the neutral.

The resistance arm Z_{11} of the load will be considered as the variable self-impedance and the various currents and voltages will be evaluated as a function of R, that is, Z_{11} in terms of unit internal voltage in phase a of the source, which will be considered as the reference vector.

Substituting the circuit constants into the expressions for the general coefficients, equations 32 to 37, and then substituting these coefficients into equations 38 to 42 the following linear fractional transformations are obtained for the current equations:

$$I_a' = \frac{34{,}200\angle 9.9^\circ}{397{,}900\angle 34.6^\circ + R \times 30{,}790\angle 7.0^\circ} \text{ amperes per volt} \quad (44)$$

$$I_b' = \frac{3{,}983\angle 162.5^\circ + R \times 169.8\angle 167.2^\circ}{397{,}900\angle 34.6^\circ + R \times 30{,}790\angle 7.0^\circ} \text{ amperes per volt} \quad (45)$$

$$I_c' = \frac{3{,}328\angle -97.3^\circ + R \times 166.8\angle -164.5^\circ}{397{,}900\angle 34.6^\circ + R \times 30{,}790\angle 7.0^\circ} \text{ amperes per volt} \quad (46)$$

Evaluating the currents (in amperes per kilovolt) for $R = 0$, 10, and ∞,

	$R = 0$	$R = 10$	$R = \infty$
I_a'	$85.96\angle -24.7^\circ$	$49.87\angle -12.7^\circ$	0
I_b'	$10.01\angle 127.9^\circ$	$8.278\angle 141.3^\circ$	$5.516\angle 160.1^\circ$
I_c'	$8.364\angle -131.9^\circ$	$6.212\angle -141.1^\circ$	$5.417\angle -171.6^\circ$

The locus of I_a' is plotted in figure 10. Since no mutuals are present in the load phases, self-impedance drops across the load phases suffice to give the phase voltages at the load. For instance, the voltage V_{01} across phase 1 is I_aZ_{11} or

$$V_{01}' = \frac{R \times 34{,}200\angle 9.9^\circ}{397{,}900\angle 34.6^\circ + R \times 30{,}790\angle 7.0^\circ} \text{ volts per volt} \quad (47)$$

The 3 points necessary to establish the locus of V_{01}' may be obtained by multiplying the values of I_a' in the preceding tabulation by corresponding values of R.

As an example of a voltage involving mutual impedances, the voltage across phase a of the source will be determined. For this purpose V_{oa} may be written

$$V_{oa} = E_1 - I_aZ_{aa} - I_bZ_{ba} - I_cZ_{ca} \quad (48)$$

Substituting the specific values of currents obtained for $R = 0$, 10, and ∞ ohms, the phase voltage becomes

when $R = 0$ $V_{oa}' = 0.7655\angle -21.0^\circ$ volts per volt
when $R = 10$ $V_{oa}' = 0.8953\angle -10.5^\circ$ volts per volt
when $R = \infty$ $V_{oa}' = 1.006\angle 3.6^\circ$ volts per volt

The locus of V_{oa}' is drawn in figure 11.

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Analysis of Rectifier Filter Circuits

The analysis of wave forms in circuits containing rectifiers is in reality a study of transient conditions which repeat cyclically. This paper presents a method of solution for such circuits by means of Fourier series, assuming initially a perfect rectifier with sinusoidal applied voltage. It shows, for cases in which the rectifier conducts current continuously, that the curve of voltage output from rectifier to d-c load consists of sinusoidal segments, and that the series for this voltage can be used, term by term, to find the current series. In some circuits the rectifier conducts current for only a portion of the cycle; in such cases the voltage curve consists of sinusoidal parts joined by sections of other forms. Wave forms are found by computation for several typical circuits, and verified by oscillograms.

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RECTIFIERS of various kinds are finding continually wider application in all branches of electrical work, not only as sources of direct current, but also for other purposes, such as measurement of alternating current by d-c meters, oscillographic recording of mechanical measurements, etc. In many cases it is important to make an analytical study of current and voltage conditions in the circuit, either for the determination of meter readings, or for an analysis of wave forms. The wave forms are determined by the load circuit in some cases, in other cases a filter is interposed between rectifier and load. Analysis of rectifier circuits presents difficulties not encountered in ordinary a-c circuits, due to the changing conduction of the rectifier with reversal of current flow. The wave forms, in general, are composed of sinusoidal parts and transient terms which recur cyclically.

The problem of wave form can be solved, in theory at least, by writing the differential equations of the circuit, solving for the roots, and evaluating the constants to conform with the boundary conditions. The solution for the roots and for the constants becomes exceedingly difficult if the circuit is at all involved. In addition, the results are obtained in a form which is difficult to interpret for many purposes.

The object of this paper is to present a method of analysis using Fourier series to represent currents and voltages. The use of series is not new, as applications have been made in many cases in the expression of rectifier voltage forms, and to some extent in the solution for currents.[1,2] There does not seem to be, however, a clear understanding of the limitations of the simple voltage series made up of sections of sine loops. On the other hand, the full possibilities have not been realized in the development of a general method. It is felt that the extension of the series method here presented will make the entire idea more useful and broader in application.

Circuit Conditions and Assumptions

In this paper rectifiers will be treated purely as switching devices, or "valves." This point of view applies to power circuits, in contrast with the detectors employed in communication circuits. It will be assumed that departures of the rectifier from pure valve action either are unimportant, or else can be treated with sufficient accuracy by an approximation. The method is accordingly studied in 2 parts, first the assumption is made of a hypothetical "perfect rectifier," then rectifier imperfections are taken into account. The perfect rectifier is defined as one in which the impedance is zero to current flow in one direction, and infinite to flow in the inverse direction.

The rectifiers discussed in this paper are of the single phase, full wave type. This is not a necessary limitation. Extension of the method can be made to other types. The alternating voltage applied to the rectifier and its circuit is assumed to be of pure sinusoidal form.

Wave Forms in Simple Circuits

Full wave rectification is obtained from either circuit of figure 1, where the arrow symbol is used to denote a circuit element having unilateral conducting properties. In (*a*) 2 rectifying elements are used, so that current flows from the transformer center tap to the load, and returns through the 2 rectifiers alternately to the transformer terminal which is negative at the instant. In the bridge, or Graetz, circuit of figure 1(*b*), 4 rectifying elements are used, 2 of which are conducting current and 2 blocking for any half cycle. The 2 circuits give essentially the same load effect, assuming zero transformer impedance. No further distinction will be made between them.

Circuits of various characteristics will be connected in the position marked "load" in figure 1, beginning with the simple cases of pure resistance, resistance and inductance in series, and resistance and capacitance in parallel. Development will then be

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1. For all numbered references, see list at end of paper.

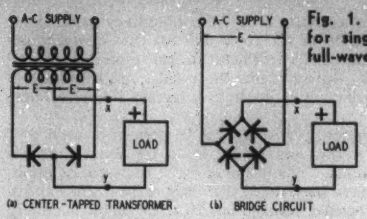


Fig. 1. Circuits for single-phase full-wave rectification

made to care for more complicated circuits. The term "input voltage" used throughout this paper should be understood to mean the voltage measured at the input to the load circuit, that is, between terminals x and y of figures 1.

1. Resistive Load

The supply voltage is assumed to be sinusoidal in form so that the rectified voltage is represented by $e = E_{max} \sin \omega t$ from 0 to π, and by $e = -E_{max} \sin \omega t$ from π to 2π. This voltage may be expressed by the series,[1]

$$e = E_{max} \frac{2}{\pi} \times \left[1 - \frac{2}{3} \cos 2\omega t - \frac{2}{15} \cos 4\omega t - \ldots - \frac{2}{n^2 - 1} \cos n\omega t \ldots \right] \quad (1)$$

The equation for the current i is identical with this in form, with E_{max} replaced by I_{max}. Furthermore, $I_{max} = E_{max} \div R$.

The oscillograms of current and voltage wave forms of figure 2 show agreement with the theoretical shapes. This oscillogram, and others shown later, were taken with the circuit of figure 1(a), using a 60-cycle electromotive force of 230 volts for each half of the transformer secondary. A type 83 tube was employed as the rectifier.

Voltage curves consisting of sinusoidal loops all on the same side of the axis are encountered in many circuits other than the foregoing resistive case. This type of variation will be termed, for convenience, the "sine-loop" voltage.

2. Resistance and Inductance in Series

In case the circuit contains inductance, the current does not drop to zero at the end of the half cycle, but has a value at this instant denoted by i_0. The current for the succeeding half cycle must start from this value, as the current cannot be discontinuous in an inductive circuit. If the circuit has been closed long enough so that starting effects are negligible, all half cycles must be identical, so that i_0 is the starting value and the ending value for each half cycle. The form of the current curve may be obtained by using the differential equation for the interval 0 to π, and applying the boundary conditions $i = i_0$ at $\omega t = 0$ and at $\omega t = \pi$. The coefficients of the Fourier series to represent the current may be found by the usual methods of analysis.[3] The resulting series is most easily interpreted if the sine and cosine terms of each harmonic are combined in a single term to give amplitude and phase angle. The series then becomes

$$i = E_{max} \frac{2}{\pi} \left[\frac{1}{R} - \frac{2}{3} \frac{1}{R^2 + (2\omega L)^2} \cos \left(2\omega t - \tan^{-1} \frac{2\omega L}{R}\right) - \ldots\ldots - \frac{2}{n^2 - 1} \frac{1}{R^2 + (n\omega L)^2} \cos \left(n\omega t - \tan^{-1} \frac{n\omega L}{R}\right) \ldots \right] \quad (2)$$

Comparison of the current series of equation 2 with the voltage series of equation 1 shows that any term of the current series could have been obtained, in magnitude and in phase, from the corresponding term of the voltage series by dividing the voltage by the impedance of the circuit for that particular frequency. It will be seen later that this convenient method for obtaining the equation of the current can be used in a large class of circuit problems. The oscillogram of figure 3 shows the current form for a series combination of $L = 5$ henrys and $R = 2{,}000$ ohms, at 60 cycles.

3. Resistance and Capacitance in Parallel

The parallel combination of resistance and capacitance is of particular interest in illustrating a type of behavior frequently encountered in rectifier circuits. If, initially, the combination of figure 4(a) is connected to an a-c supply, without a rectifier, the branch currents i_C and i_R have the phase relationship to the voltage shown in figure 4(b). The total current passes through zero at θ_2 where i_C and i_R are equal and opposite. Beyond θ_2 the total current is negative. If the parallel R and C combination is connected as a load to either rectifier circuit of figure 1, the behavior is the same up to the angle θ_2,

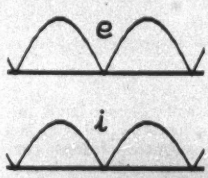


Fig. 2 (left). Oscillogram of voltage and current wave forms with resistive load

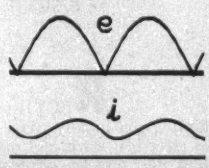


Fig. 3 (right). Oscillogram of voltage and current wave forms with inductive load

R = 2,000 ohms, L = 5 henrys, f = 60 cycles

but beyond θ_2 the reversal of the total load current is prevented by the rectifier. The effect, with a perfect rectifier, is as though the switch S were opened at θ_2, disconnecting the circuit from the supply. After θ_2 the condenser discharges through the resistance, giving a simple exponential decay of voltage, represented by the equation

$$e = E_{max} \sin \theta_2 e^{-\frac{1}{CR} t} = E_{max} \sin \theta_2 e^{-\frac{1}{\omega CR} \omega t}$$

where the t and ωt in the exponents are measured from the θ_2 point.

The exponential section continues until a point $\pi + \theta_1$ is reached where the increasing sinusoidal voltage of the next half cycle becomes as great as the voltage across C and R. Conduction is now resumed, following immediately the sinusoidal pattern if the applied a-c voltage retains the pure sine form (negligible voltage drops in the supply system). The combination of sinusoidal and exponential sections is shown in the e and i_R curves of figure 4(c). The condenser current follows a segment of a cosine curve from θ_1 to θ_2, and then is equal and opposite to i_R from θ_2 to $\pi + \theta_1$. The sudden changes of i_C and i_{total} imply, of course, negligible resistance and inductance in the supply system.

The angle θ_2, which marks the transition of the rectifier from the conducting to the nonconducting period, will be referred to as the "cut-out point." It can be found by equating $i_C = \omega C\, E_{max} \cos \omega t$ to the negative of $i_R = (E_{max} \sin \omega t) \div R$, for $\pi t = \theta_2$, giving the result,

$$\theta_2 = \tan^{-1}(-\omega CR) \tag{3}$$

The angle θ_1, or $\pi + \theta_1$, where conduction begins, will be called the "cut-in point." It is determined by the condition that the exponential voltage after a decay period of $\theta_1 + \pi - \theta_2$ is equaled by the rising sinusoidal voltage. This may be expressed by the equation,

$$E_{max} \sin \theta_2 e^{-\frac{\theta_1 + \pi - \theta_2}{\omega CR}} = E_{max} \sin \theta_1 \tag{4}$$

where θ_2 can be regarded as known. Solution for θ_1 is made difficult by its presence in sine and exponential functions. In a numerical case, however, the value of θ_1 can be found either by trial or by graphical means.

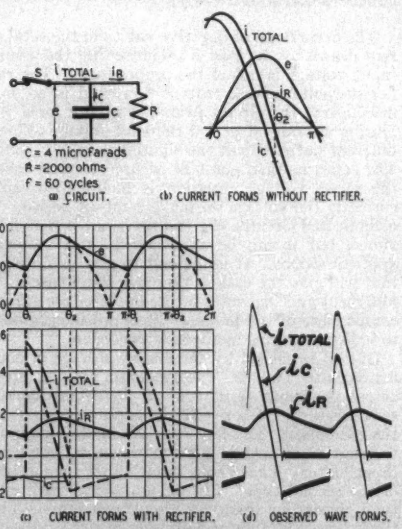
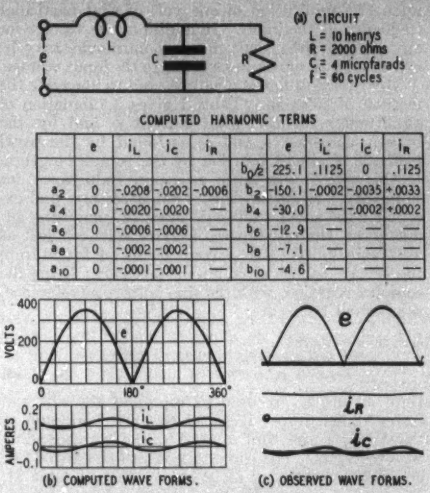


Fig. 4. Voltage and current wave forms, R and C in parallel full-wave rectifier



COMPUTED HARMONIC TERMS

	e	i_L	i_C	i_R		e	i_L	i_C	i_R
					$b_0/2$	225.1	.1125	0	.1125
a_2	0	-.0208	-.0202	-.0006	b_2	-150.1	-.0002	-.0035	+.0033
a_4	0	-.0020	-.0020	—	b_4	-30.0	—	-.0002	+.0002
a_6	0	-.0006	-.0006	—	b_6	-12.9	—	—	—
a_8	0	-.0002	-.0002	—	b_8	-7.1	—	—	—
a_{10}	0	-.0001	-.0001	—	b_{10}	-4.6	—	—	—

Fig. 5. Wave forms and harmonic terms for a continuous conduction case

It would not be expected that the sine-loop voltage of equation 1 would yield the correct current series in this case, as the actual input voltage follows a different variation, shown by the e curve of figure 4(c). A modified series can be found for this combination of sine and exponential sections by the usual Fourier methods. (Or, see appendixes I and II.) The angles θ_1 and θ_2 and the series coefficients are functions of ωCR, and may be shown by a plot with ωCR as abscissa. Such a graph is not included here, however, due to lack of space.

The experimental curves, shown in the figure 4(d), follow the theoretical forms except for the sudden rise at the cut-in point. The experimental curves at this point necessarily show a finite slope, due to resistance and inductance in the supply lines, and also to the inertia of the oscillograph element. The curve of the voltage e was not included in the oscillogram, as it must of necessity be of the same shape as the current through the resistance.

General Circuit Solution

The first step in the solution of a circuit is the computation of the circuit constants for the frequencies of the harmonics found in the rectified wave, which, for a single-phase full-wave rectifier, are the even multiples of the power line frequency. The circuit constants for each frequency are best expressed as admittances based upon the voltage at the input terminals of the circuit, or, in other words, as the currents which flow in various parts of the circuit

upon the application of one volt of that particular frequency at the input. In addition, the voltage for any part of the circuit, for any harmonic, may be expressed by a multiplier applied to the input voltage.

The circuit of figure 5 will be used to illustrate the method of solution. Table I gives a tabulation of admittances for the total current i_L and for the branch currents i_R and i_C as found by the usual methods of circuit solution by the complex algebra. In this case L was taken as a pure inductance, for simplicity. However, this is not necessary, and except for the small additional labor in computing admittances, the resistances of choke coils can just as well be included. The current terms are found from the voltage by the usual circuit methods. Using the complex notation, with the sine voltage as reference, the current terms are

$$\begin{aligned} i_n = e_n Y_n &= (a_n + jb_n)(G_n + jB_n) \\ &= (a_n G_n - b_n B_n) + j(b_n G_n + a_n B_n) \\ &= a_n' + jb_n' \end{aligned} \tag{5}$$

Here a_n and b_n are used to represent the sine and cosine terms, respectively, of the nth harmonic of the voltage series, and a_n' and b_n' the corresponding current terms. The computation can be carried out in a tabular form, as for example, that of table II. The applied voltage has the form of equation 1, with an effective value of 250 volts and a frequency of 60 cycles per second.

The current wave can be plotted by computing ordinates at intervals for the series whose coefficients are given in table II. A form for this purpose is shown in table III, in which ordinates are found at 10 degree intervals. The figures in the "multiplier" column are the appropriate sine and cosine functions of the multiple angles, and are parts of the form sheet to be used in all such computations. It is possible that a more compact arrangement could be devised, but this has at least the merit of showing clearly the processes involved. The computation is less extensive than would appear at first glance, as each a or b term is multiplied by only 4 factors. Symmetry of some form exists about 0 degrees (or 180 degrees) and 90 degrees for all harmonics, so that, for any a or b, the entries in the table are found to be the same, except for sign, at 10, 80, 100 and 170 degrees, and similarly for other angles.

The solution obtained in the foregoing manner is the correct solution, provided that, as in this case, the total current does not show a negative value at any point. The currents and voltages can be computed for any desired part of the circuit from the input voltage and the circuit constants as in table II. The current wave forms are shown in figure 5 for i_L and i_C. The plot of i_R is not given, as it would be nearly a straight line. The harmonic content of i_R, however, is shown in the tabulation beside the curves, and indicates a very rapid decrease in the magnitude of the higher frequency terms.

Occurrence of negative values in the total current is evidence that the rectifier is actually not passing current continuously, that is, cut-off is taking place. In this event the circuit must be given further study, and the proper modification made in the input voltage.

Table I—Admittances for the Circuit of Figure 5

Harmonic	f	Y_L		Y_R		Y_C	
		G_L	B_L	G_R	B_R	G_C	B_C
		$\times 10^{-6}$		$\times 10^{-6}$		$\times 10^{-6}$	
0 (DC)	0	500	−	500	−	−	−
2	120	+1.027	−138.55	−22.33	− 3.87	+23.36	−134.68
4	240	+0.062	− 67.05	− 5.52	− 0.46	+ 5.58	− 66.58
6	360	+0.012	− 44.43	− 2.45	− 0.14	+ 2.46	− 44.29
8	480	+0.003	− 33.25	− 1.38	− 0.06	+ 1.38	− 33.19
10	600	+0.002	− 26.57	− 0.88	− 0.03	+ 0.88	− 26.54

Table II—Computation of Current Series for i_L, Figure 5

Term	Input Voltage	Y_L			i_L amperes
		G $\times 10^{-6}$	bG	aB	$\times 10^{-6}$
$b_0/2$	225.08	+ 5.00	+112540	—	+112540
b_2	−150.05	+ 1.03	− 155	0	− 155
b_4	− 30.01	+ .06	− 2	0	− 2
b_6	− 12.86	0	0	0	0
b_8	− 7.15	0	0	0	0
b_{10}	− 4.55	0	0	0	0
		B	aG	−bB	
a_2	0	138.55	0	−20789	−20789
a_4	0	− 67.05	0	− 2012	− 2012
a_6	0	− 44.43	0	− 571	− 571
a_8	0	− 33.25	0	− 238	− 238
a_{10}	0	− 26.57	0	− 121	− 121

Circuits Causing Cut-Off

The occurrence of negative values in the total current drawn by the load is evidence that the assumed input voltage is not of the proper form. The rectifier prevents reverse current flow, and in so doing, disconnects the circuit from the supply for a time. During the cut-off period the load voltage follows a different pattern than the sinusoidal supply voltage. The series method can still be used in such cases if the input voltage equation is modified to express correctly the voltage during the cut-off period. For complicated circuits, the voltage is not known in advance, but it can be approached by a system of approximations. It is difficult to give definite rules that will give the easiest approach in all cases. The judgment and ingenuity of the operator are valuable components of the process. It is possible, however, to indicate general methods of procedure.

Cut-off is caused by the energy storage of a condenser in the circuit. The condenser may be directly across the input terminals, or there may be some series impedance between the input terminals and the condenser. The first type of circuit corresponds to what is termed in filter parlance a "condenser-input" filter. The "choke input" filter is an example of the second type. Cut-off may occur with either type, depending upon the circuit constants. The 2 types represent a natural division in circuit study, as different methods apply in the 2 cases. Examples

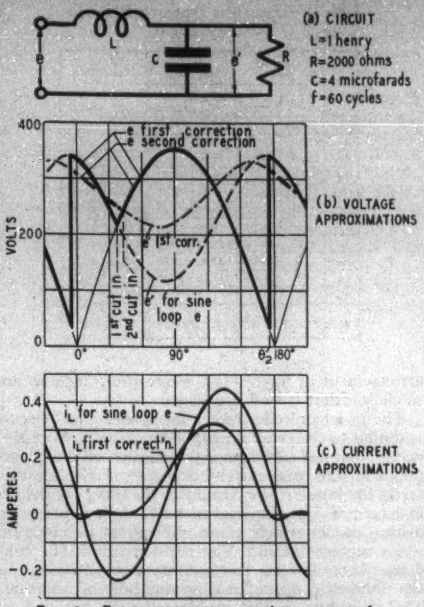


Fig. 6. First approximation and corrections for a cut-off case, series impedance input

will be given to illustrate the procedure with the 2 types.

A—Series Impedance Input

The input voltage is sinusoidal during the conducting period. While the input current is zero, there is, of course, no voltage drop across the impedance at the input, and consequently the voltage measured at the input is the same as the voltage across the condenser nearest the input. The general plan of procedure is to find the cut-out and cut-in points, and to make up the input voltage of a sinusoidal section during conduction and a section equal to the condenser voltage during cut-off. The desired quantities may be found by successive approximations, approaching as closely as desired to the true values.

The circuit arrangement of figure 5 will be used, with the exception that L is reduced to one henry, in order to produce cut-off. A trial value of current, found from the sine loop voltage by the methods described previously, shows that cut-off does occur, as the total current is negative from 5 to 75 degrees, as shown in the plot of figure 6. The voltage e' (See figure 6*a*) computed on the assumption of sine loop input voltage, is plotted in the same figure. The intersection of e' with the sine voltage at 38 degrees gives a first approximation to the cut-in angle θ_1, as the intersection has the same general significance as in the R-C circuit of figure 4. The cut-out angle θ_2 is not determined definitely, but can be judged to be somewhat earlier than the 185 degree (or 5 degree) point where i_L goes negative, due to the fact that i_L in the new trial is to become positive at 38 degrees, instead of the 75 degrees referred to above. Accordingly, a value of 175 degrees is used as a first approximation.

A first correction to the voltage e at the input terminals can be obtained by following the curve of e' (for sine loop input) during the cut-off period, that is, from approximately 175 to 38 degrees (or 180 + 38 degrees), and by following the sine curve during the conduction portion of the cycle. This variation shown by the heavy solid line of figure 6(*b*), can be represented by a series. The coefficients needed for the sinusoidal section are obtained from the formulas of appendix II. The coefficients required to make the new series follow the old e' during the cut-out period may be found from appendix IV. Addition of the coefficients of corresponding terms for the 2 sections gives the new voltage equation. This voltage cannot be strictly correct, as the e' used in finding it was only approximate, but it is at least much closer to the true value than was the original sine loop voltage.

The curve of i_L from the revised voltage series, plotted in figure 6(*c*), shows values which are fairly close to zero during the cut-off period. If greater accuracy is desired, the correction process can be carried out again, using the e' from the first correction voltage as the e during cut-out for the second correction. A new value of θ_1 is taken from the intersection of the revised e' curve with the sine curve at approximately 43 degrees. A new value of the cut-out point, at $\theta_2 = 174$ degrees is taken to eliminate the small negative value of current found in the first correction. The results of the sine loop approximation and the first and second corrections of i_L and e' are shown in table IV. The difference between the first and second corrections are sufficiently small to indicate that additional corrections would make only

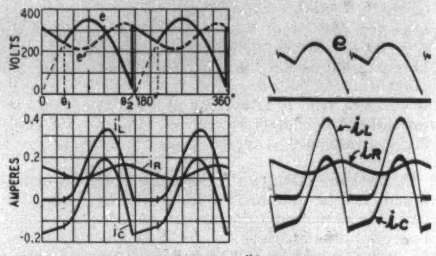
Table III—Ordinates for i_L Curve, Figure 5

	0°		10°		20°		30°		40°		50°		60°		70°		80°		90°		100°		110°		120°		130°		140°		150°		160°		170°	
	Mult	Prod.	Mult.	Prod.	Mult	Prod.	Mult.	Prod.	Mult	Prod.	Mult	Prod.	Mult.	Prod.	Mult.	Prod.	Mult.	Prod.	Mult.	Prod.	Mult	Prod.	Mult	Prod.	Mult	Prod.	Mult	Prod.	Mult	Prod.	Mult	Prod.	Mult	Prod.	Mult	Prod.
e_2	−2079	00	0	3420	−711	6428	−1336	8660	−1800	9848	−2047	9848	−2047	8660	−1800	6428	−1336	3420	−711	00	0	−3420	+711	−6428	+1336	−8660	+1800	−9848	+2047	−9848	+2047	−8660	+1800	−6428	+1336	−3420	+711
b_2	−16	1.00	−16	9397	−15	7660	−12	5000	−8	1736	−3	−1736	+3	−5000	+8	−7660	+12	−9397	+15	−1.00	+16	−9397	+15	7660	+12	−5000	+8	−1736	+3	1736	−3	5000	−8	7660	−12	9397	−15
e_4	−201	00	0	6428	−129	9848	−198	8660	−174	3420	−89	−3420	+89	−8660	+174	−9848	+198	−6428	+129	00	0	6428	−129	9848	−198	8660	−174	3420	−89	−3420	+89	−8660	+174	−9848	+198	−6428	+129
b_4	0	1.00	—	7660	—	1736	—	−500	—	−9397	—	−9397	—	−5000	—	1736	—	7660	—	1.00	—	7660	—	1736	—	−5000	—	−9397	—	−9397	—	−5000	—	1736	—	7660	—
e_6	−57	00	0	8660	−49	8660	−49	00	0	−8660	+49	−8660	+49	00	0	8660	−49	8660	−49	00	0	−8660	+49	8660	+49	00	0	8660	−49	8660	−49	00	0	−8660	+49	−8660	+49
b_6	0	1.00	—	5000	—	−5000	—	−1.00	—	−5000	—	5000	—	1.00	—	5000	—	−5000	—	−1.00	—	−5000	—	5000	—	1.00	—	5000	—	−5000	—	−1.00	—	5000	—	−5000	—
e_8	−24	00	0	9848	−24	3420	−8	8660	+21	6428	+15	6428	−15	8660	−21	−3420	+8	−9848	+24	00	0	9848	−24	3420	−8	8660	+21	−6428	+15	6428	−15	8660	−21	−3420	+8	−9848	+24
b_8	0	1.00	—	1736	—	−9397	—	−5000	—	7660	—	7660	—	−5000	—	−9397	—	1736	—	1.00	—	1736	—	−9397	—	−5000	—	7660	—	7660	—	−5000	—	−9397	—	1736	—
e_{10}	−12	00	0	9848	−12	−3420	+4	8660	+10	6428	−8	6428	+8	8660	+10	−3420	+4	9848	−12	00	0	9848	+12	3420	−4	8660	−10	−6428	+8	6428	−8	8660	+10	−3420	+4	−9848	+12
b_{10}	0	1.00	—	−1736	—	−9397	—	5000	—	7660	—	−7660	—	5000	—	9397	—	−1736	—	−1.00	—	−1736	—	−9397	—	5000	—	−7660	—	7660	—	−5000	—	9397	—	1736	—
Amperes $\times 10^{-6}$			11236		10364		9655		9303		919		9305		9625		10091		10650		11270	b_{12}	11918		12446		12999		13289		13311		13189		12809		12184

Multiplier = 10^{-5} Constant term = $b_0/2$, = 11254 Add to all columns.

COMPUTED HARMONIC TERMS.

	e	i_L	i_C	i_R		e	i_L	i_C	i_R
					$b_0/2$	+270.3	+.1351	0	+.1351
a_2	+29.0	-.1557	-.1376	-.0181	b_2	-71.8	-.0866	-.1094	+.0228
a_4	+40.3	+.0162	+.0186	-.0023	b_4	+21.4	-.0300	-.0283	-.0015
a_6	+32.3	+.0072	+.0080	-.0008	b_6	+15.5	-.0150	-.0145	-.0004
a_8	+17.6	+.0040	+.0043	-.0002	b_8	+11.8	-.0060	-.0058	-.0002
a_{10}	+8.1	+.0038	+.0039	-.0001	b_{10}	+14.2	-.0022	-.0021	-.0001



(a) COMPUTED WAVE FORMS. (b) OBSERVED WAVE FORMS.

Fig. 7. Wave forms and harmonic terms for a cut-off case, series impedance input. Circuit of figure 6

minor changes. Figure 7 gives the complete wave form and harmonic terms for the corrected input voltage. It is interesting to note the form of the voltage, with its change from the sine to the e' curve when conduction ceases. Also, the e', i_R and i_C curves are seen to have exponential sections during the cut-off period. The oscillogram of figure 7(*b*) was taken for a circuit having quite closely the constants of the computed case.

Advantage could have been taken in this problem of the fact that the voltage e' is exponential during the cut-off period. With θ_1 and θ_2 determined approximately, a combined sinusoidal and exponential series could have been obtained by appendixes I and II. The computation would have been somewhat simpler than for the method above. The general method was illustrated, however, as it can be used with complicated circuits where nothing is known in advance of the form of the curve during cut-off. Multisection filters, for example, fall in this class.

B—Condenser Input

A condenser input circuit does not produce cut-off in all cases. However, for the values of resistance, inductance, and capacitance used in practical filter circuits, cut-off does occur. It can be stated, moreover, that a condenser across the input is of no value in smoothing the output current unless it is of sufficient capacity to cause cut-off, since continuous conduction means that the input voltage is of the sine loop form, of definite harmonic content (see equation 1). The input voltage is made smoother than this by the effect of cut-off, as shown for a simple case by the e' curve of figure 4(*c*). The effects in a circuit more representative of filter design are shown by the

Table IV—Successive Approximations, Circuit of Figure 6

Term	Sine Loop Voltage		First Correction		Second Correction	
	e volts	i_L amperes	e volts	i_L amperes	e volts	i_L amperes
$b_0/2$	225.08	.1125	270.71	.1354	270.28	.1351
b_2	-150.05	-0.0425	-69.00	-.0838	-71.77	-.0866
b_4	-30.01	-0.002	+26.84	-.0315	+21.38	-0.299
b_6	-12.86	-	+19.62	-.0183	+15.46	-0150
b_8	-7.15	-	+11.31	-.0090	+11.78	-.0060
b_{10}	-4.55	-	+10.86	-.0037	+14.17	-.0022
a_2	0	-.3427	+28.16	-.1496	+29.00	-.1557
a_4	0	-.0223	+42.59	+0203	+40.32	+.0162
a_6	0	-.0060	+39.48	+0092	+32.30	+.0072
a_8	0	-.0024	+26.26	+.0039	+17.63	+.0040
a_{10}	0	-.0012	+13.73	+.0029	+8.11	+.0038
θ_1			38°		43°	
θ_2			175°		174°	

arrangement of figure 8(*a*), where the constants are so chosen that cut-off does occur.

The intial procedure for a condenser input circuit is similar to the general method described previously, except that the admittance constants should be computed for the total current exclusive of the condenser at the input. The current to the input condenser is determined in a special manner, since it possesses discontinuities which cause difficulties in accurate series representation. The peculiarities of the condenser behavior are, however, used to advantage in the following approximation method of solution. The procedure in this problem can be outlined as follows:

1. Find i_L due to an approximately correct input voltage. The sine loop voltage of equation 1 could be used as a first approximation to the input voltage. However, considerable labor can be saved and the approximation process shortened, if an initial voltage series is devised which is closer to the true form. It is known that energy storage in the input condenser has the effect of bridging over the "valleys" between loops of the sine voltage. Accordingly, a voltage series selected from suitable values of an *R-C* circuit, which has the same general smoothing effect (see figure 4), is a better first guess than the sine loop voltage.

2. Estimate the cut-out angle θ_2. This can be done by finding the point where i_C has a negative value, on the cosine curve, equal and opposite to i_L.

3. Estimate the cut-in angle θ_1. During cut-off period, i_L is drawn entirely from condenser C_1, and hence is a measure of the decrease of the voltage across it. Beginning at θ_2, find the discharge of C_1 up to 2 points such as, in this case, 25 degrees and 35 degrees. It is then possible to interpolate between the points and find the angle at which the decreasing condenser voltage is equaled by the increasing sinusoidal voltage.

4. Find the series for the current i_{C_1}. It would be undesirable to find i_{C_1} from the approximate input voltage, as any discrepancies in the voltage form would be magnified in the condenser current. A more accurate method is to find i_{C_1} by sections, since it is known to follow a cosine curve during the conduction period, and to be equal and opposite to i_L during the cut-off period. The formulas of appendix III serve for the coefficients of the cosine section, and those of appendix IV for the cut-off section. Addition of coefficients, term by term, for the 2 sections gives the complete i_C series.

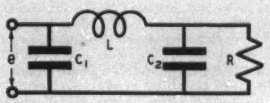
5. Obtain a corrected input voltage series. The series for i_{C_1} is correct for the conduction period, and approximately correct for the cut-off period. Multiplication of each term of the series for i_{C_1} by the impedance of C_1 for the corresponding frequency yields a new voltage series which is more accurate than the original approximation. The currents for various branches of the circuit can now be computed, and new values found for θ_1 and θ_2. In case it seems desirable, the correc-

tion process can be carried through a second time. The table of computed terms of figure 8 shows the results of the first correction, which seemed sufficiently accurate, as the changes from the original trial values were relatively small.

It is interesting to compare filtering effects in figure 5 and figure 8, as the circuits are the same except for the addition of the condenser at the input. The input condenser is seen to cause a reduction of harmonic content in all parts of the circuit, and an increase in the d-c component. Both of these effects would be anticipated from the changed form of the input voltage. There is another difference, however, in that the total current drawn through the rectifier is fairly uniform in the choke input case, but is intermittent and has high peaks with the condenser input. The method presented above is useful in the analysis of other filter arrangements, but space does not permit fuller discussion.

A-C Line Current

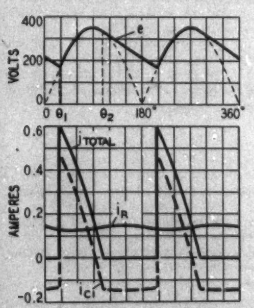
The harmonics of the current in the a-c line wires leading to the rectifier can be found from the harmonics in the rectified current. The line current for the perfect rectifier is similar to the total rectified current, except that the direction is reversed in alternate half cycles. The formulas for finding a-c line harmonics from the rectified current harmonics are easily derived. For the single phase full wave rectifier the a-c line current contains odd harmonics, only.



(a) CIRCUIT
L=10 henrys
R= 2000 ohms
C_1, C_2= 4 microfarads
f = 60 cycles

COMPUTED HARMONIC TERMS

	e	i_L	i_{C1}	i_R		e	i_L	i_{C1}	i_R
					$b_0/2$	+276.2	+.1381	—	+.1381
a_2	-24.8	-.0102	+.2226	+.0003	b_2	-73.8	+.0034	-.0749	+.0017
a_4	-17.7	+.0006	-.0500	+.0001	b_4	+8.3	+.0012	-.1070	—
a_6	-1.5	+.0003	-.0547	—	b_6	+6.1	—	-.0131	—
a_8	+3.2	—	-.0370	—	b_8	+3.1	—	+.0381	—
a_{10}	+2.3	—	+.0118	—	b_{10}	-0.8	—	+.0342	—



(b) COMPUTED WAVE FORMS.

Fig. 8. Wave forms and harmonic terms for a cut-off case, condenser input

Half-Wave Rectifiers

Half-wave rectifier circuits can be solved by the series method, but the difficulty is somewhat increased, due to the fact that cut-off occurs, in effect, with all types of load. A series can be written[1] for a voltage which follows the sine form from 0 to π, and which is zero from π to 2π, but this is the correct input voltage only in the very special case of a purely resistive load. For all other cases the input voltage must be modified to suit the circuit. This point is worthy of note, as cases are found in the literature of the application of this so-called half-wave voltage equation to circuits to which it does not properly apply.

Rectifier Imperfections

For some purposes, and in some circuits, the solution on the basis of the hypothetical perfect rectifier is sufficiently accurate. In other cases it is desirable to make at least an approximate correction for the departures of the rectifier from perfect action. The method to be employed in the correction depends upon the type of rectifier used. In the case of a vacuum tube rectifier, if the load voltage is large compared with the tube drop, it may be possible to ignore curvature of the tube characteristic and replace the tube by a constant resistance for the conducting direction. The inverse resistance would still be considered infinite.

For a gaseous conduction rectifier, such as a mercury vapor tube, a good approximation is made by the assumption of a constant tube drop for the conducting direction. This is easily taken into account by the series method, by subtracting the tube drop from the constant term of the voltage series.

The inverse conduction cannot be neglected in the case of contact rectifiers, such as the copper oxide, when high accuracy is desired. Huss has shown[5] that for ordinary power frequencies the copper oxide rectifier can be replaced by 2 resistances, a low resistance D for the conducting direction, and a higher value S for the inverse direction. Under these conditions, for continuous conduction in a full-wave

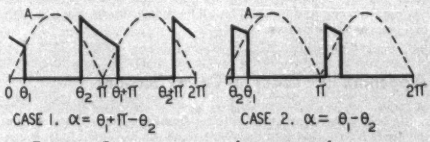


Fig. 9. Curve consisting of exponential sections

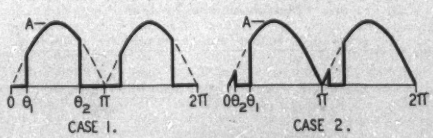


Fig. 10. Curve consisting of sine sections

bridge circuit, the rectified current can be found in terms of the perfect rectifier if a resistance $DS \div (D + S)$ be placed in series with the load, and if the applied voltage be reduced by the factor $(S - D) \div (D + S)$.

Appendix I—Series for Exponential Sections

The series coefficients needed to represent the exponential curve within the limits θ_2 to $\theta_1 + \pi$, and zero elsewhere, as shown in figure 9, are given by the following expressions. The exponential curve is of the form $y = \text{constant} \cdot e^{-k\theta}$. Cases 1 and 2 differ only in the expression for α.

Even values, only, for m
Multiply all terms by A/π

$$a_m = \frac{2 \sin \theta_1}{k^2 + m^2} \left\{ e^{k\alpha}(k \sin m\theta_2 + m \cos m\theta_2) - (k \sin m\theta_1 + m \cos m\theta_1) \right\}$$

$$b_m = \frac{2 \sin \theta_1}{k^2 + m^2} \left\{ e^{k\alpha}(k \cos m\theta_2 - m \sin m\theta_2) - (k \cos m\theta_1 - m \sin m\theta_1) \right\}$$

$$\frac{b_0}{2} = \frac{\sin \theta_1}{k} (e^{k\alpha} - 1)$$

The multiplying constant is given in terms of the magnitude of the sine curve which intersects the exponential curve at θ_1, to conform with the general usage in this paper. However, other applications can be made by noting that the factor $A \sin \theta_1$ is the ordinate at θ_1.

Appendix II—Series for Sections of a Sine Curve

The series coefficients needed to represent the sine curve between the limits θ_1 and θ_2, and zero elsewhere, as shown by figure 10, are given by the following expressions.

Case 1. Omit terms in brackets
Case 2. Use the complete expression
Even values, only, for m
Multiply all terms by A/π

$$a_m = \frac{\sin(m-1)\theta_2 - \sin(m-1)\theta_1}{m-1} - \frac{\sin(m+1)\theta_2 - \sin(m+1)\theta_1}{m+1}$$

$$b_m = \frac{\cos(m-1)\theta_2 - \cos(m-1)\theta_1}{m-1} - \frac{\cos(m+1)\theta_2 - \cos(m+1)\theta_1}{m+1} - \left[\frac{4}{m^2-1}\right]$$

$$\frac{b_0}{2} = \cos \theta_1 - \cos \theta_2 + [2]$$

Note that all terms contain sine and cosine functions of the general form $(\sin k\theta_2 - \sin k\theta_1)/k$, k being odd. This makes possible the computation of a and b values for all harmonics up to, say, the 10th in a compact tabular form.

Appendix III—Series for Cosine Sections

The series coefficients needed to represent the cosine curve within the limits θ_1 to θ_2, and zero elsewhere, as shown in figure 11, are given by the following expressions.

Even values, only, for m
Multiply all terms by A/π

$$a_m = -\frac{\cos(m-1)\theta_2 - \cos(m-1)\theta_1}{m-1} - \frac{\cos(m+1)\theta_2 - \cos(m+1)\theta_1}{m+1}$$

$$b_m = \frac{\sin(m-1)\theta_2 - \sin(m-1)\theta_1}{m-1} + \frac{\sin(m+1)\theta_2 - \sin(m+1)\theta_1}{m+1}$$

$$\frac{b_0}{2} = \sin \theta_2 - \sin \theta_1$$

Fig. 11. Curve consisting of cosine sections

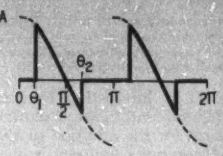
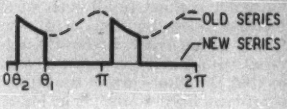


Fig. 12. New series derived from old series



Appendix IV—Series for Sections of Another Series Curve

A series can be found whose curve follows an old series between the limits θ_2 and θ_1, but is zero elsewhere, by means of the following expressions. Small letters are used to represent coefficients of the old series, and capital letters the new series.

Even values, only, for n and m

$$A_m = -2\frac{b_0}{2}\frac{\cos m\theta_1 - \cos m\theta_2}{\pi m} + a_m\left[\frac{\theta_1-\theta_2}{\pi} - \frac{\sin 2m\theta_1 - \sin 2m\theta_2}{\pi 2m}\right] - b_m\frac{\cos 2m\theta_1 - \cos 2m\theta_2}{\pi 2m} + \sum_{n \neq m} a_n\left[\frac{\sin(m-n)\theta_1 - \sin(m-n)\theta_2}{\pi(m-n)} - \frac{\sin(m+n)\theta_1 - \sin(m+n)\theta_2}{\pi(m+n)}\right] + \sum_{n \neq m} b_n\left[-\frac{\cos(m-n)\theta_1 - \cos(m-n)\theta_2}{\pi(m-n)} - \frac{\cos(m+n)\theta_1 - \cos(m+n)\theta_2}{\pi(m+n)}\right]$$

$$B_m = 2\frac{b_0}{2}\frac{\sin m\theta_1 - \sin m\theta_2}{\pi m} + b_m\left[\frac{\theta_1-\theta_2}{\pi} + \frac{\sin 2m\theta_1 - \sin 2m\theta_2}{\pi 2m}\right] - a_m\frac{\cos 2m\theta_1 - \cos 2m\theta_2}{\pi 2m} + \sum_{n \neq m} b_n\left[\frac{\sin(m-n)\theta_1 - \sin(m-n)\theta_2}{\pi(m-n)} + \frac{\sin(m+n)\theta_1 - \sin(m+n)\theta_2}{\pi(m+n)}\right] + \sum_{n \neq m} a_n\left[\frac{\cos(m-n)\theta_1 - \cos(m-n)\theta_2}{\pi(m-n)} - \frac{\cos(m+n)\theta_1 - \cos(m+n)\theta_2}{\pi(m+n)}\right]$$

$$\frac{B_0}{2} = \frac{b_0}{2}\frac{\theta_1 - \theta_2}{\pi} + \sum_{n=2,4,\ldots} b_n \frac{\sin n\theta_1 - \sin n\theta_2}{\pi n} - \sum_{n=2,4,\ldots} a_n \frac{\cos n\theta_1 - \cos n\theta_2}{\pi n}$$

It will be noted that all terms consist of sine or cosine differences of the general form $(\sin k\theta_1 - \sin k\theta_2)/\pi k$, where k is an even integer. These factors can be computed easily in a tabular form. If sine and cosine factors are tabulated for k up to twice the highest harmonic being used in the circuit computations, all factors entering into the computations will be at hand. The grouping of the factors for the finding of the various A_m and B_m terms can be facilitated greatly by the use of a form sheet, or a stencil system.

References

1. Alternating Current Rectification, L. B. W. Jolley. 3rd ed., chap. I, John Wiley and Sons.

2. Mathematical Treatment of Rectification Phenomena, D. C. Prince, I.R.E. *Proc.*, Oct. 1922, v. 10, p. 393–8.

3. Fourier Series and Spherical Harmonics, W. E. Byerly. Chap. II, Ginn and Company.

4. Reference 1, chap. III.

5. Circuit Analysis of the Copper Oxide Rectifier, P. O. Huss. Doctoral thesis, Univ. of Mich., August 1934.

Discussions

Of A.I.E.E. Papers—as Recommended for Publication by Technical Committees

ON this and the following 19 pages appear discussions of papers presented at the distribution & transmission and insulation & protection sessions of the South West District meeting, Oklahoma City, Okla., April 24–26, 1935, and at the instruments and measurements, power generation, and selected subjects sessions of the 1935 A.I.E.E. summer convention, Ithaca, N. Y., June 24–28. Authors' closures, where they have been submitted, will be found at the end of the discussion on their respective papers.

Members anywhere are encouraged to submit written discussion of any paper published in ELECTRICAL ENGINEERING, which discussion will be reviewed by the proper technical committee and considered for possible publication in a subsequent issue. Discussions of papers scheduled for presentation at an A.I.E.E. meeting or convention will be closed 2 weeks after presentation. Discussions should be (1) concise; (2) restricted to the subject of the paper or papers under consideration; and (3) typewritten and submitted in triplicate to C. S. Rich, secretary, technical program committee, A.I.E.E. headquarters, 33 West 39th Street, New York, N. Y.

Recommended Transformer Standards

Authors' closing discussion of a paper published in the December 1934 issue, pages 1594–7, and presented for oral discussion at the insulation and protection session of the South West District meeting, Oklahoma City, Okla., April 24, 1935. This paper was also presented at the winter convention, New York, N. Y., January 22, 1935, and other discussion was published in the July 1935 issue, pages 770–1, and in the August 1935 issue, pages 887–8.

J. E. Clem: I. W. Gross, in his discussion, raises some very interesting points. Whether or not the transformer design levels proposed by the transformer subcommittee (and at present in use) correspond to those which may result from the recommendations of the joint N.E.M.A.-E.E.I. co-ordination committee is not so important as it might at first seem. The levels given in the paper have developed from experience and have been in use for some time. It should be recognized as necessary that standards be available for use until the joint co-ordination committee completes its labors. If the proposals of that committee require different design levels than at present in use and the proposals are accepted, it should be an easy matter to make whatever changes are required.

It is a reasonable point to raise that the transformer might not be the logical starting point to set up a co-ordination scheme. However, the transformer subcommittee saw the need for some action in regard to transformers some time ago and began the study of the problem as it affected transformers. In reality the proper point for the start of the co-ordination scheme is the protection level. If a protection level were to be set up the design level of equipment could readily be agreed upon.

The 2 years of experience which has been had with the impulse test code have shown that factory impulse tests are practical. Two years is probably too short a time to demonstrate whether or not the right magnitude of impulse test has been selected.

Another point raised by Gross is in reference to the polarity of the test wave. The gap spacings were selected to give insulation strengths about the same as experience had indicated to be generally satisfactory. The selection of gap spacings was made on the basis of the positive wave because flashover data for this wave were much more complete than for the negative wave. If the negative had been used, it is very likely that shorter gap spacings would have resulted. If the negative wave should be used now either shorter gap spacings or more insulation (with increased costs) would be required. It seems that the test using the positive wave should be satisfactory because considerable data is now available for correlating tests made with the positive wave with tests made with the negative wave.

A co-ordination gap, as listed in table I of the paper, may be considered as the gap which establishes the required insulation level for any particular rated circuit voltage. The work of the joint N.E.M.A.-E.E.I. co-ordination committee should yield results which will replace the insulation levels indicated by these gap spacings.

The gap was used to establish insulation levels because of the apparent discrepancy in the impulse flashover data emanating from the various laboratories. It was felt that if the impulse strengths were stated in terms of a gap spacing and tested with a specified wave by gap flashover, the test would be the same regardless of what kilovolt value might be reported. Unfortunately the use of co-ordination gaps was considered by some as affording protection and this has led to considerable confusion. It is hoped that kilovolt values will ultimately be used.

Gross seems to have misinterpreted the information given in table III. Inasmuch as the impulse test is made by flashing over the bushing, it seems obvious that the transformer winding should be stronger than the bushing for the test conditions.

Minimum flashover voltages for transformer bushings were set up by the transformer subcommittee sometime ago as 15 per cent above the flashover of the co-ordination gap. This automatically places the required bushing flashover 5 per cent above the test gap. This standard flashover level is substantially the same as it has been in the past for the circuit voltages at the upper end of the range but becomes increasingly lower as the other end of the range is approached. It is expected that distribution transformer bushings will conform to this standard flashover level, but that power transformers will retain their present bushings, which have a flashover in excess of this level.

Some of C. M. Foust's difficulties, especially those covered by his paragraphs numbers 1 and 3, arise from the fact that the present paper did not copy completely the original impulse test code. Reference to the original test code would clear up all the questions outlined by him. ("Progress Report on Impulse Testing of Commercial Transformers," Montsinger and Vogel. A.I.E.E. TRANS., volume 52, 1933, pages 409–10.)

The question as to whether or not one terminal of the transformer should be grounded during test has not been covered in the test code, but it seems desirable that this be done. This question will be taken up by the transformer subcommittee.

H. V. Putman: For a period of years an effort has been made to establish more rational insulation tests for distribution transformers—tests that would not handicap the design or increase the cost, but that would be of some value as a check in determining the quality of the insulation. Perhaps it is unfortunate that these new proposals of the transformer subcommittee for higher dielectric tests make their appearance at a time when operating engineers are trying as never before to find ways and means of reducing the cost of electric service in order that it may be extended into rural districts heretofore considered uneconomical. The new test voltages have been questioned on the ground that they might lead to increased costs, or that they might preclude the possibility of certain cost reductions which otherwise could be made. I am, therefore, glad to see the data presented by J. K. Hodnette to show that from a practical manufacturing standpoint only an insignificant saving could be made in transformer costs by designing to lower test voltages. The savings possible certainly would not compensate for the reduction in quality which would result.

I wish to commend I. W. Gross on his excellent discussion. The questions he

raises in connection with insulation levels and impulse testing are of interest to all operating engineers. All of these questions have been raised before, but his discussion is evidence that they have not been settled.

The transformer subcommittee has not set up new insulation levels (except in the distribution transformer voltage classes); rather the committee has made use of the existing insulation levels which have been established by the 60 cycle insulation tests which have been in the A.I.E.E. standards for many years. The committee has attempted to define these insulation levels in terms of impulse strength, and to establish an impulse testing procedure which would demonstrate the existence of that impulse strength, not only in the major insulation (which could equally well be demonstrated by the 60 cycle test) but between the turns and layers of the winding (which can be demonstrated only by impulse tests).

Speaking for my own company, we have made commercial impulse tests on customers orders on approximately 50 transformers. These have ranged in rating from 45,000 kva to 200 kva for power transformers, and down to 200 volt-amperes for potential transformers. They range in voltage from 287 kv to 5.5 kv.

There were 3 failures on test within the first 6 months, but none since then. In these cases the transformers passed the A.I.E.E. 60 cycle test successfully, and the impulse tests revealed obvious defects which otherwise would not have been found. There have been no failures from lightning in the field. The first transformers were installed in the fall of 1931, so that some of the units have already seen 3 lightning seasons.

Gross seems to feel that by selecting the $1^1/_2 \times 40$ wave shape and positive surges rather than negative we are not obtaining the required severity in our impulse tests. The question of severity is not one of wave shape or polarity, but rather the magnitude of the applied surge. Personally, I believe that some increase in severity of the test in the higher voltage classes should be made. See, for example, paper by F. J. Vogel in the *Electric Journal* for January 1935, entitled "Adequate Impulse Tests," also letter to the editor of *Electrical World* by F. J. Vogel, January 19, 1935. But in general it can be said that any appreciable increase in the severity of the impulse test will call for more insulation, correspondingly higher 60 cycle tests and correspondingly higher costs. I am sure the manufacturers would be quite willing to furnish transformers with more insulation at higher prices if they are desired.

The extent to which protection can be obtained with the co-ordinating gaps listed in table I of the paper has been indicated in several of the recent papers on insulation co-ordination; for example, "Factors Influencing the Insulation Co-ordination of Transformers—II," ELECTRICAL ENGINEERING, June 1934, pages 870–6. In general we can say that the co-ordinating gap cannot be depended on for protection against direct strokes, but it will give protection against all ordinary traveling waves. The protection obtained is a matter of steepness of the wave front of the incoming surge.

In making a plea for the use of some simple, definite method of stating impulse strength, Gross voices a common desire. However, the practical difficulty of using definite kilovolt values in expressing impulse strength, as he suggests, is simply that the impulse strength of insulation is not a definite value in kilovolts. Its impulse strength depends on the wave shape, so that in expressing the impulse strength of an insulation structure in kilovolts it is necessary to state the particular wave shape for which the kilovolt value is given. Obviously this is a complicated method of expressing the impulse strength and, furthermore, does not express it completely, because it gives impulse strength for only one wave shape. The use of the equivalent gap also has its limitations because the time lag characteristics of various insulation structures are not exactly alike.

The proposed impulse flashover voltages for transformer bushings were established as follows: The bushing level was made as low as possible in order to obtain the maximum margin of co-ordination relative to the impulse strength of the winding, but sufficiently high so that when used in practice with the co-ordinating gaps of table I the gap would always flash over rather than the bushing.

In connection with Robert Treat's comments on the proposed changes in the impulse test procedure, I would like to say that these changes are not fundamental at all, but involve only certain simplifications which will reduce the labor and cost of making such impulse tests, and in certain cases will increase the severity of the tests slightly in the higher voltage classes.

Treat states that the second proposed test which specifies "A wave sufficient to flash over the bushing, provided standard bushings are used, and having a crest voltage bearing a definite relation to the 60 cycle test voltage" would seem to be a little dangerous unless it is very certain that the 60 cycle test voltages are so wisely selected, that when multiplied by this definite relation they always produce the correct value of impulse test voltage. The 60 cycle test voltages, have, of course, been in the Institute standards for a great many years. They do bear a rational relation to the circuit voltages, and they have formed the basis for the design of the major insulation on transformers ever since they have been in existence, and still do. The trouble with the present 60 cycle tests is not that they demand too much or too little insulation in high voltage transformers, but rather that they do not provide a test for that insulation which simulates voltage stress conditions in service at the time of lightning surges. The new impulse tests are designed not to change the magnitude of the major insulation in high voltage transformers, which is established by the 60 cycle test voltages as in the past, but rather to give assurance that the same level of insulation strength is present within the winding (between turns and coils) under surge voltage conditions.

By establishing a maximum impulse test voltage which bears a definite relation to the 60 cycle test voltage, we are simply establishing an impulse test of the same relative severity as the 60 cycle test, so far as the major insulation is concerned, and then proving that that same insulation strength or level is present within the winding.

It is true, as Treat states, that if the bushing is to be flashed over the ratio of the maximum impulse test voltage required to the 60 cycle test voltage may in some cases be higher than the proposed ratio. This is actually the case with the proposed bushing standards. It will be found in the lower voltage classes that the power bushings have higher flashovers than the product of the 60 cycle test and the proposed ratio. For these classes (say up to 46 or 69 kv) the insulation is actually determined by the bushings for power transformers. This is not the case for the proposed distribution transformer bushings, where the proposed ratio multiplied by the 60 cycle test voltage will be practically sufficient to represent the bushing flashover.

If for some special reason transformer bushings having flashover voltages higher than the proposed standards are employed, it is of course obvious that correspondingly higher test voltages must be used if insulation co-ordination is to be maintained.

Portable Schering Bridge for Field Tests

Authors' closing discussion of a paper published in the January 1934 issue, pages 176–82, and presented for oral discussion at the insulation and protection session of the South West District meeting, Oklahoma City, Okla., April 24, 1935. This paper was also presented at the winter convention, New York, N. Y., January 25, 1934, and other discussion was published in the March 1934 issue, pages 478–81, April 1934 issue, pages 618–22, September 1934 issue, page 1311, and July 1935 issue, pages 888–90.

C. F. Hill, T. R. Watts, and G. A. Burr: Probably one of the chief benefits to the electrical industry accruing from the presentation of our paper has been the wealth of test data brought forth by the discussers, which otherwise might not have been published.

Referring to the discussion by I. W. Gross, we regret his charge that we made a misleading statement when we said that "a portable instrument for the measurement of dielectric loss was not available for purchase and use by the power companies until the Schering bridge here described was developed." Having acknowledged earlier power factor tests in the field, in our abstract at the beginning, we were merely saying that the Westinghouse inverted Schering bridge outfit was offered for outright sale, while to the best of our knowledge the wattmeter insulation testing set had then been offered only in connection with special engineering service or on a rental basis. We believe that the existence of the wattmeter method, and also the commercial situation, were so well known to every one concerned that our statement was not misleading. We thought we were the first to use the Schering bridge in the field for bushing tests, but the discussion brought out the fact that the Schering bridge (not inverted) had been previously used in England for such tests. (B. L. Goodlet's discussion, April 1934 issue).

In regard to the relative merits of the bridge method and wattmeter method, we

believe there is but little advantage of either over the other as to the data given directly by the instruments. We are all agreed that the power factor is not the whole story, but the rest of the story is easily available, with the aid of a slide rule, from either set of instruments. It is immaterial whether we think in terms of power factor and watts loss, or in terms of power factor and capacitance, except that the former is easier with the wattmeter method, and the latter with the bridge method.

Probably the chief advantage of the inverted Schering bridge method over other methods is its ability to test transformer bushings having "fished through" leads without requiring much preliminary preparation. This advantage is explained in our original paper (page 181, right hand column) but evidently we did not lay sufficient emphasis upon it, since G. W. Gerell's discussion shows that he completely overlooked it. Admitting that his experience has been limited in the main to the use of the wattmeter set, he deplores the 15 to 20 man hours required to prepare a transformer unit for test. The elimination of this difficult preparation is an outstanding advantage of the inverted Schering bridge circuit. The recent development of a current transformer attachment, by means of which it is hoped to duplicate this advantage with the wattmeter method, presents inherent difficulties which we believe will still leave the inverted Schering bridge circuit the preferable method for transformer bushing tests.

Concerning high power factor oil, this is usually the result of oxidation and for excessive oxidation may become quite high. It is for this reason and the accompanying sludging that we try to prevent oxidation. However, high power factor does not necessarily indicate low breakdown. As a matter of fact an oil with high power factor due to oxidation should have a higher dielectric strength than a new oil providing there is no moisture present. One of the dangers of the high acidity due to oxidation is moisture absorption which leads to lower strengths. The ordinary mechanical filtering removes solids, as suspended sludge, for example, and a dry filter process removes such moisture but will not remove the acids. These acids can be removed, but at an appreciable cost, and we are not convinced that such oils are worth reclaiming.

An Improved Electrothermic Instrument

Discussion and author's closure of a paper by P. M. Lincoln, published in the May 1935 issue, pages 474–81, and presented for oral discussion at the Instruments and measurements session at the summer convention, Ithaca, N. Y., June 25, 1935.

True McLean (Cornell Univ., Ithaca, N. Y.): In his paper on "Rates and Rate Making" written in 1915, Prof. P. M. Lincoln showed that the instrument shown schematically in improved form in figure 6 of the present article is a true wattmeter. In the present article he has described improvements in the thermal and mechanical systems so that errors due to thermal and mechanical causes can be reduced to very small percentages. In all previous instruments of this general type, the errors were relatively so large that a rather crude electrical system was so much better than the rest of the apparatus, that refinements of the electrical system were a total waste of effort.

The improvements described are of such a fundamental nature that they eliminate thermal errors at their basic cause, without resort to nonlinear calibration scales or compensation tricks of any kind that might introduce other uncertainties of their own. The Bourdon tube construction results in such very large torques compared to other instruments that the mechanical system presents no problems of friction or balance. The net result is that as far as the thermal and mechanical system is concerned, the limit of accuracy is determined in the end by the reading errors of a conventional pointer and scale.

These important refinements make worthwhile, in fact necessary, a careful scrutiny of the electrical system. The requirements are briefly, that there must be produced in the closed secondary potential circuit (figure 6) a current which is strictly proportional to the line voltage, and exactly in phase with it. The liquid reservoirs require a power in the neighborhood of $^3/_{16}$ of a watt from the potential circuit to maintain a satisfactory temperature rise above ambient under no load conditions. Doctor Lincoln has shown that the best range of temperatures for various loads at various power factors is obtained when the circulating current is somewhat larger than the load current. Taking an arbitrary figure of 6 amperes for example in a nominal 5 ampere instrument, the total resistance of the 2 heaters is about 0.02 ohm. The heaters are made of an alloy having an extremely small temperature coefficient of resistance, and to minimize the coefficient of the entire circuit, the total copper resistance is held to less than 5 per cent of the heater resistance. This includes the secondary winding of the potential transformer directly, and also the primary winding reduced to equivalent secondary value.

Assuming for the moment an ideal potential transformer, it is easily seen that in a circuit of only about 0.02 ohm impedance, the stray inductance must be held to a very small value to prevent the circulating current from lagging behind the line voltage by an intolerable amount. A phase angle of 10 minutes of arc will produce an error in the meter reading of 0.5 per cent at 0.50 power factor, assuming the calibration correct at unity power factor. At standard 60 cycle frequency the total permissible inductance in the closed loop is only about 0.12 microhenry, or 12 perms, using a unit more convenient in this case. Still assuming an ideal transformer, and placing it as close to the heaters as a convenient arrangement of parts will permit, the total length of lead wires can be reduced scarcely below about 6 inches.

If we assume simply for ease of calculation, a transmission line, 3 inches in length, composed of a pair of 16 gauge wires with $^1/_4$ inch spacing, the inductance is 7.78 perms, over half the tolerance, allowing nothing for the leakage reactance of a practical transformer. Accordingly, the permeance of the closed loop was reduced as far as conveniently practicable by making the conductors of copper tape $^3/_8$ inch wide, separating each lead from its return companion by a layer of thin insulation, and lacing the combination tightly together. Using 5 mil tape and 5 mil insulation, the inductance is about 0.042 perm per inch of line as against 2.6 perms for the round wire spaced $^1/_4$ inch. The reduction of inductance in a ratio of roughly 60 to 1 in lead wires solved that problem, but the design of a practical transformer of small dimensions, and very low leakage reactance presented a problem. Since the resistance of both windings must be kept low, and the secondary must be center tapped, a 2 turn secondary was used. By careful dimensioning of the windings it was found possible to keep

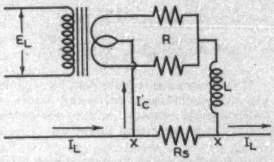


Fig. 1. Circuit for compensating phase angle errors

the leakage reactance safely within the limit and still have enough insulation to pass a 2,500 volt test.

In small transformers of only one watt output, the greatest difficulty encountered when striving for a small phase angle, is the angle between line voltage and induced electromotive force. The magnetizing current which is in lagging quadrature with the voltage produces a resistive drop in the primary winding. This effect is extremely small in power transformers, but becomes of major importance in very small designs. The effect is reduced in good instrument transformer designs by using windings all out of proportion to the wattage ratings. High permeability alloy cores do not offer a solution in this case because the principal reluctance in the magnetic circuit is due to the minimum air gap attainable with commercial punchings. There appeared to be only 2 ways out of the difficulty; either to use a ring core and toroidal winding, or considerably increase the bulk of the design. Neither of these ways is satisfactory from the standpoint of cost.

Prof. W. C. Ballard suggested that a way out was to shift the phase of the load circuit current by an amount just equal to the unavoidable shift in the potential circuit, and thereby attain perfect compensation at any load power factor.

The addition of a resistive shunt around the load circuit in combination with a small inductance connected between the shunt and the potential circuit accomplishes the double purpose of permitting perfect phase adjustment and also extending the range of the nominal 5 ampere instrument to any desired higher value.

The electrical circuit of the meter may be conveniently redrawn as in figure 1. The line current is designated as I_L; and the total current through the heaters due to the load, as I_C. R_S is the resistance of the non-

inductive shunt, R and L are the total values of resistance and inductance of the heater circuits measured between the junction points X-X and include heaters, transformer secondary, lead wires, and loading coil. The quantity of interest is the complex ratio of the currents I_L/I_C which expresses both the magnitude of the increase in line current due to the diversion of the shunt and the phase shift introduced. By straight forward circuit analysis the resulting expression is

$$\frac{I_L}{I_C} = Ae^{j\alpha}$$

where the modulus $A \geqq 1$ for all values of R_s from zero to infinitely large, and has the value

$$A = \sqrt{\left(\frac{R}{R_s} + 1\right)^2 + \frac{\omega^2 L^2}{R_s^2}}$$

and the argument α, has the value

$$\alpha = \text{arc tan } \frac{\omega L}{R + R_s}$$

It is interesting to note that for a given instrument, the values of R_s and L may be independently chosen, within reasonable limits. The theoretical limits are

$$R_s \xrightarrow{lim} \infty \; A = 1 \text{ and } R_s \xrightarrow{lim} 0 \; A \longrightarrow +\infty$$

$$\text{also } R_s \xrightarrow{lim} \infty \; \alpha = 0 \text{ and}$$

$$R_s \xrightarrow{lim} 0 \; \alpha = \text{arctan } \frac{\omega L}{R}$$

The practical limits on the shunt resistance are determined by simple considerations. The lower limit is reached when so large a fraction of the line current is diverted that the heater current becomes inconveniently small. The upper limit is determined by the size of inductance that can be built with reasonable bulk, remembering that the total resistance R includes the coil, and the portion of R external to the actual heaters is restricted to 5 per cent of the total. This is assuming that an adjustment is being made to a value of α predetermined by the characteristics of a practical potential transformer.

Since the phase shifts which are due to primary winding resistance and due to secondary circuit plus leakage inductance, are in opposite directions, they can be made to cancel if the design is carefully worked out; then no compensation is required. The circuit of figure 1 compensates for lagging current in the heater circuit. If the primary resistance effect predominates, the compensation is reversed in direction by connecting the inductance in series with the shunt R_s instead of in series with the heaters as shown.

With a method at hand to correct completely for any reasonable phase shift in the potential transformer, the temptation at once appears to select a transformer as small and cheap as possible, since its lag can theoretically be completely compensated, however bad it may be. In doing this, however, there is danger of a second order error becoming appreciable. The magnetizing current of the transformer which is responsible for most of the total lag is a nonlinear function of the line voltage, and consequently if a close compensation is depended on at rated voltage, there will be a power factor error in the instrument when the line voltage departs appreciably from the value for which the compensation was adjusted. The best course, therefore, appeared to design for the best transformer characteristics practicable at reasonable cost, considering the space restrictions of the instrument case. Compensation may be then applied by choosing a shunt resistance that gives a reasonable diversion of load current and an inductance of small bulk.

After choosing approximate values for the shunt and phase correcting inductance from the above considerations, a final adjustment of each can be made in each individual instrument after assembly. Filing the edges of the shunt of course brings the deflection to the proper point on the scale and is a sensitive means of final calibration. The final adjustment of phase correction may be accomplished to a high degree of precision by observing that the currents due to the load and due to the potential transformer are in opposition in one of the heaters. If the load is a pure resistance, the phases of the 2 currents are exactly opposite, except for the shift due to the potential transformer. At a critical value of load resistance, the current through the heater may be made to just pass through zero, provided that the phase correcting inductance has the right value. Accordingly, an a-c voltmeter is connected across the heater through a fairly high gain amplifier, which gives an ordinary rectifier type instrument sufficient sensitivity for the purpose. The inductance inserted is made lightly too large, and reduced to the exact value by deforming the coil. Since this is a null method, the amplifier need not be calibrated.

The electrothermic instrument appears now to have reached a stage of development where its performance compares favorably with high grade laboratory instruments.

P. A. Borden (The Bristol Co., Waterbury, Conn.): It is the practice of designers of pressure gauges and thermometers involving the opposed action of Bourdon springs or bimetallic elements to provide some form of differential device permitting each element to deflect freely without restraint. In the development of the several forms of thermal ammeters and wattmeters for which Prof. P. M. Lincoln has been responsible, this feature has doubtless received intensive study. Since Professor Lincoln has standardized on the form having the elements directly in opposition, it is to be assumed that he has found the restraint so imposed on the expanding elements to have no ill effects on the accuracy or permanency of the calibration. A summary of Professor Lincoln's experiences in this connection would be of interest.

Paul MacGahan (Westinghouse Elec. and Mfg. Co., Newark, N. J.): I think we will generally agree with Prof. P. M. Lincoln in the idea that the exponential or logarithmic meter is not only consistent with the standard definition established for demand, but that it also gives a reasonable approximation to representing the "fixed charge" factor of the service demanded. Thus it gives a basis for dividing such costs equitably between different consumers, according to the character of the load.

In order to be acceptable as a standard, a meter must be such as to facilitate calibration in terms of standard units. The important point is not whether we measure a commodity in pounds or in bushels, on a block interval basis or on a logarithmic demand basis, but whether the unit used is readily reproduced for calibration, and whether it is acceptable to both buyer and seller.

When Professor Lincoln developed the earliest type of thermal demand meter, I recollect that I was of some assistance in influencing his development away from the earliest form, which had liquid sylphon type of expanding units, and adopting the bimetallic strip element.

While that construction resulted in a practical instrument, problems of the errors due to heat dissipation control were still present, and the resulting difficulties in accurate calibration undoubtedly retarded the general application of thermal meters.

This thermal meter difficulty, as associated with the previous meters, must not be confused with the general subject of logarithmic or exponential principle of demand charging as it can only apply to such earlier demand meters as operate on the electrothermal principle. In such meters the electrical energy of the windings is first converted into heat and then the effect of the heat is measured through expansion of bodies which, in turn, move the pointer across a scale.

It does not apply to lagged demand meters, which operate electro-mechanically, such as the Hall meter (Patent No. 1,331,-059), the Boddie meter (Patent No. 1,408,-255), or the meter described in the paper "A New Demand Meter," B. H. Smith, Elec. Engg. (A.I.E.E. Trans.) v. 53, Jan. 1934, p. 94–6.

This latest instrument, as described by Prof. Lincoln, apparently eliminates the earlier difficulties which for many years seemed to be unalterably associated with thermal instruments.

It should revive general interest and confidence in the logarithmic method of measuring demand.

P. M. Lincoln: A gentleman has asked if dimensional analysis has been applied to the solution of the problems arising in connection with this improved meter. No attempt has been made to apply this method of analysis. I do not see at the moment that this method of analysis can have any application, but I wish to thank the gentleman for his suggestion.

A gentleman has asked what is the minimum amount of power that may be measured by this improved instrument, and has specifically asked if one watt could be measured. One watt can certainly be measured but the accuracy of measurement would depend upon unspecified conditions. If one watt were applied to a 1,000 watt wattmeter, the accuracy would certainly be low. If it were applied to a 10 watt wattmeter, a high degree of accuracy could be obtained.

A rather loose statement which is contained in the appendix of the paper should be pointed out. In the appendix the statement is made that $\frac{d\,V_l}{dK_l}$ becomes a constant when $\alpha + \beta + \gamma = c(\alpha' + \beta' + \gamma')$. To a mathematician it is obvious this is not true

unless and until $\alpha = c\alpha'$, $\beta = c\beta'$ and $\gamma = c\gamma'$, c having the same value in each case; that is, until the coefficients of each power of t bear a given ratio to each other. For all practical purposes, however, the statement is true as it stands; this is because in actual application, the effects of the β and γ coefficients are practically negligible.

P. A. Borden has pointed out that it is common practice when Bourdon tubes are used opposing each other to permit of free deflection by using some sort of differential device. May I say that this point has been thoroughly considered, and exhaustive tests have been made with the tubes disposed as Mr. Borden suggests, and also with the tubes directly opposing each other as I suggested in my paper. While it is undoubtedly true that the limitations of the Bourdon tubes when used as I propose are somewhat less than if used as Mr. Borden proposed, my tests have shown that there is not sufficient gain in the yield point of the tube material by such method of use as to justify the additional cost of the differential mechanism.

Direct Measurement of Surge Currents

Discussion and authors' closure of a paper by C. M. Foust and J. T. Henderson published in the April 1935 issue, pages 373–8, and presented for oral discussion at the instruments and measurements session of the summer convention, Ithaca, N. Y., June 25, 1935.

W. W. Lewis (General Elec. Co., Schenectady, N. Y.): It may be of interest to list some applications of surge crest ammeter magnets which have been made in the past 2 or 3 years. The towers of the following lines have been completely equipped, in some cases with 4 brackets and in the remainder of the cases with one bracket per tower: The Pennsylvania Power and Light Company's 220 kv, 65 mile Wallenpaupack-Siegfried line, the Appalachian Electric Power Company's 132 kv, 65 mile Glenlyn-Roanoke line, the Pennsylvania Water and Power Company's 220 Kv, 70 mile Safe Harbor-Westport line, and the Philadelphia Electric Company's 66 kv, 14 mile Philadelphia-Chester line.

The Pennsylvania Power and Light Company and the Appalachian Electric Power Company have equipped portions of their ground wire and counterpoise installations, also crossarms and vertical lightning rods at some towers have been equipped.

Distribution circuit lightning arrester down leads have been equipped at about 1,000 locations in Chicago, Detroit, Boston and Atlanta.

The principal broadcasting towers in eastern United States have been equipped with magnets. Miscellaneous applications have been made on station lightning arrester ground leads, lightning rod installations, etc., in various parts of the country.

All told, about 12,000 magnetic links have been installed in the past 3 years.

Currents up to 100,000 amperes per tower have been measured and up to 220,000 amperes total in all the towers affected by one stroke. In the distribution lightning arrester circuits, currents up to 10,000 amperes have been measured. Currents up to 50,000 amperes have been measured in broadcasting towers.

The majority of currents in all classes of installations have been of negative polarity. The larger currents, as a rule, are unidirectional with the smaller currents tending to be oscillatory.

It has been possible in the case of some of the more complete installations to tell whether the stroke hit the conductor, tower, or ground wire; and thereby to evaluate the efficiency of the ground wire arrangement.

K. B. McEachron (General Elec. Co., Pittsfield, Mass.): The authors have described a method of measurement of surge currents which is simple and reliable, and which will yield information not only of magnitude of current but direction and degree of oscillation, if present. A large number of these magnetic links are now in service and have already added considerably to our knowledge of the lightning discharge and its effects on lines and towers.

Between magnetic links there is some variation which results in some loss in accuracy, however, in those cases where more accurate readings are desired, the magnetization may be determined with the ballistic galvanometer, after which the magnetization curve may be taken giving a close calibration of the link. This method has the advantage that it is only necessary to examine more accurately those which have interesting records, thus making it unnecessary to make such determinations on the majority of the links in service.

It seems to me that considerable care should be exercised with reference to the interpretation to be placed on records which show the presence of reversed current. It is probably true that in most cases the links as used will not be materially influenced by the presence of power follow current. However, it is a factor which should be considered when reviewing data from locations where power follow might occur.

It does not seem to me that the data thus far accumulated will justify the conclusion that lightning oscillates, although the presence of reverse current has been found in a considerable proportion of the records. Voltage reflections in towers may occur, but these do not give rise to reversed currents. It may be that the measurement of reversed current is the result of the combination of the induced and direct stroke effects. It is well known that the induced potential will be of opposite polarity from the direct stroke, and thus a measured reversal could be accounted for which is not in the direct stroke itself.

If the reversal is the result of a combination of induced and direct effects, certain evidence should be found to substantiate this idea. In most cases, at least where the overhead ground wire was struck, reversal might be expected, but if the stroke occurred in the vicinity, but not to the ground wire, then induced effects alone would give rise to current, but without reversal. It seems to me likely that data from measuring instruments, located at the upper end of conducting structures, would give the most certain information concerning the current in the direct stroke itself. I feel that more data under less complicated conditions will have to be obtained before we can make a definite statement concerning oscillation in the stroke itself.

Another factor in interpreting the record from the magnetic link that must not be lost sight of is the inability of the link to indicate whether or not the reversal occurred within one stroke or whether it is associated with separate but multiple strokes, or whether the reversal resulted from independent effects which may have had considerable separation in time. All of this indicates the necessity of not drawing conclusions too hastily from insufficient evidence.

C. L. G. Fortescue (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): I consider this paper by C. M. Foust and J. T. Henderson to be a most lucid statement of the theory of the surge crest ammeter. The method of measuring the degree of magnetism retained is most ingenious. I am convinced that with this instrument reliable measurements of unidirectional surges can be obtained. I am not convinced of the reliability of the device for obtaining data on oscillatory surges, nor of the interpretation of some of the readings in terms of oscillatory surges. In short, I do not believe that there are oscillatory discharges in a lightning stroke and that if any are indicated they are probably, as K. B. McEachron has pointed out, due to positive unidirectional surges arising from induction from a lightning stroke external to the line, superimposed on the negative unidirectional surge due to a direct stroke.

This suggests the need of great caution in the interpretation of values of surge potential indicated by these little devices, for if, let us say, one of them has been subjected to a negative potential of 100 per cent during a thunderstorm, and during that same storm to a number of positive induced surges varying from 1 per cent to 10 per cent, would not the demagnetizing effect of the positive induced surges be cumulative in reducing the retained magnetism caused by the first surge? In this respect the method developed by the Detroit Edison Company based on the calibration of a hole burned in a piece of paper between flat copper plates has points of merit, because if a heavy negative surge has burned a hole in the paper any number of positive surges following certainly cannot unburn the hole already found so that this method within its range of reliability will give a measure of the maximum surge to which the device has been subjected. The possible demagnetizing effect of succeeding surges of opposite polarity to that due to the lightning stroke surge appears to me to be the weak point in an otherwise admirable and intriguing device.

For this reason I agree with P. L. Bellaschi that data from all sources and means of measuring lightning currents should be weighed and given fair consideration in determining the yearly distribution of current magnitude in lightning strokes that terminate on a transmission line. Some of the records obtained in the past by the surge recorder showed values as high as 800,000 amperes for the total current in a lightning stroke. When checked against values obtained by computation from data reported by other methods, such as the total quan-

tity of electricity found by ballistic methods, it was decided that these values were so large that there must be some mistake in calibration and later on this was found to be the case. More recent measurements with the surge recorder shows maximum values of the order of 190,000 amperes which appears to be about right. When the first results from the surge crest ammeter were published the maximum recorded value was 70,000 amperes as I recall, making a possible value for the lightning stroke of the order of 100,000 amperes. There had been too many records to ascribe the low value to the absence of strokes of maximum severity, so I am compelled to assume that all factors such as the amount of current flowing in alternative paths (for example displacement currents and those in adjacent towers) had not been fully accounted for. It is interesting to note that values derived from crest ammeter readings are on the upgrade again and maximum values of 200,000 amperes total surge current, including reflection, have been recorded.

P. L. Bellaschi (Westinghouse Elec. and Mfg. Co., Sharon, Pa.): The recent work by C. M. Foust, W. W. Lewis, Philip Sporn, and Edgar Bell in this country and the similar investigations by Grunewald in Germany confirm the suitability of magnetic links for recording lightning currents. Another device, employed by Collins to measure lightning currents in the ground leads of arresters, comprises 2 metal disks separated with thin paper insulation. Still a third method consists in comparing directly the effects associated with natural lightning to similar results obtained with lightning stroke current generators in the laboratory. This third method has been used at the Sharon laboratory for the past 2 years. The more common field experiences on lightning stroke currents investigated in the laboratory have been associated largely with the following physical effects:

1. Fusion of conductors.
2. Crushing of conductors and tubes.
3. Surface burning of conductors.
4. Explosive and shattering effects.
5. Magnetic and magnetizing effects.
6. Characteristics of lightning arc.
7. Other effects.

The extensive data on the fusion and crushing of conductors establish that lightning stroke currents infrequently exceed crest values considerably greater than 100,000 amperes. Multiple strokes apparently account for the severe crushing of conductors and the fusion of heavy conductors. *This third method has also yielded valuable data on the physical characteristics of the lightning channel.* It is found that the lightning current arc when restricted or confined develops pressures in the order of 10,000 to 20,000 pounds per square inch. It is also established that the core of the lightning stroke channel has a diameter of one to 2 centimeters.

Lightning current distribution curves established from field records obtained by the different methods of measurement indicate a substantially similar trend. The current amplitudes range from about 10,000 amperes to a maximum in the order of 150,000 amperes.

With the modern facilities and refinements for calibrating magnetic links, more and more dependable data from this method of measurement should be forthcoming in the future. It will however be through a correlation of all the data available that comprehensive information of the magnitude, wave form and duration of the lightning stroke currents can be fully established.

S. K. Waldorf (Pa. Water and Pwr. Co., Baltimore, Md.): The work on the calibration of surge crest ammeter links by Messrs. C. M. Foust and J. T. Henderson is of great interest and importance to everyone dealing with lightning phenomena, particularly to those employing the links for the measurement of lightning currents in transmission towers. At the beginning of the summer of 1934, the Pennsylvania Water and Power Company equipped one leg of each of the 477 towers of the Safe Harbor-Westport 230 kv line with a bracket holding 2 surge crest ammeter links. This season the study has been extended to a 69 kv line and a 132 kv line. The former has 227 towers and the latter 179 towers, making a grand total of 883 towers equipped with these links, of which 85 towers have a bracket and 2 links on each of the 4 legs.

The additional data presented in this paper appreciably affects our interpretation of the lightning current records obtained with surge crest ammeter links. The link calibrations originally provided with the surge crest ammeters were for unidirectional currents only, and in using them for links magnetized by actual lightning currents in transmission towers, discrepancies at once became apparent. The nature of these discrepancies is indicated in the accompanying table I of some sample records obtained in 1934 on the Safe Harbor-Westport line. The examples cited are not isolated inconsistencies, but in each case are representative of a number of records of the given type.

Consideration of the simple electromagnetic principles involved leads one to expect the magnetization of the links to be inversely proportional to their respective distances from the current center of the tower leg to which they are connected. All of the records given in table I were obtained on towers having 5 inch by 5 inch legs on which the "distance ratio" of the links is $^9/_3 = 3$. For non-oscillatory currents, the deflections caused by the inner and outer links theoretically should bear this same ratio. Examination of table I shows deflection ratios ranging from zero to infinity. In most cases, the deflection ratio was found to be between about 1.5 and 2.5 in the records obtained last summer, indicating that the great majority of tower currents were not unidirectional.

The new oscillatory calibrations now provided by the authors theoretically will care for those cases where the ratios of deflections range from zero to the value of the corresponding distance ratios. In table I, the third, fourth, and fifth items are in this classification and the readings can be interpreted satisfactorily, and in the sixth item where the inner link showed no magnetization and the outer link showed some, an approximate method of evaluation has been provided. In the first 2 items of table I, where the deflection ratios are greater than the corresponding distance ratios, no evaluation is yet possible except by assuming a unidirectional surge. If a unidirectional surge caused the records of the first item, the outer link would be expected to show an appreciable deflection of at least 3 or 4 divisions on the surge crest ammeter. It is possible that an oscillation occurred which was of sufficient magnitude to reverse completely the magnetization of the inner link and demagnetize the outer link. We wish to inquire if this explanation seems reasonable to the authors or if they have found some other cause of the observed phenomenon.

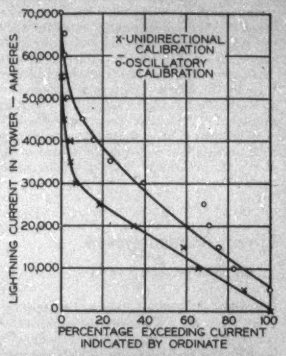


Fig. 1. Currents indicated by magnetic links on towers on Safe Harbor-Westport line believed struck by lightning in 1934

Table I—Sample 1934 Tower Lightning Current Records

230 Kv Safe Harbor-Westport Line of the Pennsylvania Water and Power Co.

	Surge Crest Ammeter Readings			Tower Currents in Amperes			
				Unidirectional Calibration			
Tower Number	Inner (1 inch) Link	Outer (7 inch) Link	Ratio	Inner Link	Outer Link	Average	Oscillatory Calibration
67	−15	0	Inf.	10,400	0	10,400*	10,400
28T	−14	− 2	7	9,600	4,000	6,800	10,000
337	−44	−18	2.4	30,000	37,400	33,700	42,800
169	−26	−16	1.6	18,000	32,800	25,400	42,000
168	−11	−12	0.9	7,500	4,000	5,700	32,400
115	0	−11	0	0	22,400	22,400*	48,000

* Zero records were considered as being inaccurate and therefore were not included in average.

Table II—Comparison of Unidirectional and Oscillatory Calibrations of Magnetic Links on Typical Towers Believed Struck by Lightning

1934 Records From 230 Kv Safe Harbor-Westport Line of Pennsylvania Water and Power Company

	SCA Deflection		Tower Amperes		Tower Potential in Kv		Ratio of
Tower Number	Inner Link	Outer Link	Unidirectional Calibration	Oscillatory Calibration	Unidirectional Calibration	Oscillatory Calibration	Oscillatory to Unidirectional
62T	+60	+20	44,000	44,000	308.0	308.0	1.00
330	−45	−16	32,000	37,000	32.0	37.0	1.16
121T	−52	−27	55,000	70,000	660.0	840.0	1.27
303	+51	−22	40,500	53,000	324.0	424.0	1.31
120	−28	−15	30,000	43,500	720.0	1045.0	1.45
323	−26	−13	22,000	33,600	440.0	672.0	1.53
169	−26	−16	25,400	42,000	1220.0	2020.0	1.66
315	−10	−10	14,000	28,000	294.0	588.0	2.00
172	0	−12	24,800	48,000	1040.0	2020.0	1.94
60	0	−10	20,800	48,000	810.0	1870.0	2.31

Much of the difficulty in evaluating the surge crest ammeter deflections occurs for those cases where the deflections are small, that is, where the deflection of one of a pair of links is less than 10 divisions on the surge crest ammeter and the accuracy of the meter readings is low. The first two and the last items of table I fall under this classification.

Aside from the importance of being able to determine correctly the current flowing in the angle iron of towers on which the links have been mounted, it is of importance that the true significance of the indicated oscillations be known. This is brought out by consideration of the accompanying curve and the data of table II in which tower potential is the product of tower current and tower footing resistance. There has been considerable evidence accumulated indicating that flashover of transmission towers due to lightning does not occur if the product of tower footing resistance and tower crest surge current does not exceed the flashover value of the insulator string. [See "Lightning Investigation on Transmission Lines," W. W. Lewis and C. M. Foust, Elec. Engg. (A.I.E.E. Trans.), v. 53, Aug. 1934, p. 1180–6.] These data for the most part have been based on the unidirectional calibration of the surge crest ammeters. As can be seen from the graph and table II, the oscillatory calibrations indicate larger crest currents, and consequently higher tower potentials, than the older calibration and all of the accumulated data may no longer support this theory if interpreted in the light of this new work. Table II shows that tower potentials indicated by the unidirectional calibration were all appreciably below the flashover value for the given line, but as now interpreted, the highest were apparently dangerously close to the maximum permissible value of about 2500 kv for the tower top, but still conformed to the theory. Also, the maximum tower current which we have recorded is raised from about 55,000 amperes to 70,000 amperes.

The apparent oscillations may be an indication that cross and diagonal members of transmission towers have a greater effect on surge crest ammeter readings than at present allowed for. It is possible that the closed loops formed by the tower members are subjected to local oscillations of radio frequency, affecting the link readings, and that the recorded currents are local and not indicative of the current in the tower as a whole. Another possible effect is that the diagonal members carry appreciable current to ground in addition to that conducted by the four tower legs and for which no allowance is made at present. It will be interesting if the authors will tell us whether the calibrations of the links have been checked under field conditions by sending surges of known characteristics through actual tower structures.

L. A. Eggleston (Natl. Aniline and Chem. Co., Buffalo, N. Y.): I raise the question as to how to reconcile the various sets of lightning data, some of which are based on surge crest measurement and instrument values, as against other sets of data based upon burning effect or pressures, which must involve an effective value with a variable time axis due to different surge frequencies.

C. M. Foust and J. T. Henderson: Discussion on this paper was confined almost entirely to the interpretation of field records, and dealt particularly with those records wherein some degree of current oscillation was indicated. The material included in the paper presented was selected in an effort to give a clear description of a new surge current measurement technique. The few field records included in the paper served only to complete the description of this new method. A very great number of field records have been obtained and these will be analyzed at a later date.

The use of the surge crest ammeter for lightning currents proved conclusively for the first time by direct measurement the negative and unidirectional polarity characteristics of these currents in transmission line structures. In general, for lightning stroke currents of the higher order of magnitudes the 2 link measurement stations show quite conclusively a single direction of current flow. For the lightning currents of lower order of magnitude some degree of oscillation is sometimes indicated.

As pointed out by K. B. McEachron, these records should not be hastily interpreted as proving that lightning currents sometimes oscillate, although it is clear that they do show the presence of some degree of current reversal in the line structure. Mr. McEachron suggests that this current reversal may be due to a combination of induced and direct effects. Such records would be obtained only when the direct stroke currents and the induced currents were not simultaneous. Detailed study of records now being obtained in various parts of the line structure will quite likely give more information on this point.

C. L. Fortescue called attention to the possible cumulative effect of reversed currents in reducing the retained magnetism caused by the first surge. Such a demagnetizing effect is, of course, a possibility but our records indicate it to be a very uncertain one. That such a reduction takes place does not appear reasonable in view of the many records already obtained, especially at high currents where inner link-outer link ratios indicate the presence of unidirectional currents. Such records could be obtained only in the absence of such a cumulative reduction in retained magnetism.

S. K. Waldorf called attention to a case where an inner link showed some magnetization and the outer link practically none, and suggested an oscillation of sufficient magnitude to reverse completely the magnetization of the inner link and demagnetize the outer link. While it is true that some possible combination of successive surge currents might produce such an effect, we do not consider such an interpretation to be justified in view of our available calibration data. In our laboratory calibrations we used surges of constant decrement up to 50 per cent oscillation over a wide range of amplitudes, and in all cases obtained inner link-outer link ratios less than the distance ratio. It appears more reasonable to attribute such records to the circumstance that Mr. Waldorf refers to immediately following and which pertains to difficulties in interpretation where surge crest ammeter deflections are small. We believe it good practice to follow the rule of omitting oscillatory interpretations unless both links give surge crest ammeter readings between 10 and 100.

Mr. Waldorf also calls attention to the correlation between insulator assembly flashover records and corresponding tower potentials obtained from surge crest ammeter currents and tower footing resistances. In general, this correlation seems to be better for the currents obtained from the oscillatory calibrations than from those obtained from the older unidirectional calibrations. This kind of analysis can be properly evaluated of course only after the accumulation of a great number of records. Uncertainties such as the real value of the footing resistance under surge current conditions and the wave shape of the tower potential also now prevent final conclusions on this point.

In answer to Mr. Waldorf's inquiry concerning laboratory calibrations we did not use a complete tower structure and as yet have not studied the possible effect of currents in the diagonal members. In the laboratory, surge currents were passed through angle iron sections similar in size to tower legs. A surge generator of considerable size would be required for actual field calibrations on full size towers at current values of 50 to 100,000 amperes.

L. A. Eggleston raised the question of accuracy of crest current values as obtained by the direct magnetic method and by burning effect or pressures. Undoubtedly, the

size of a hole burned in a piece of paper depends upon current and time, and the results obtained are dependent upon the use of laboratory surges for calibration having the same time elements as the surges to be measured. The authors feel very decidedly that the magnetic method, especially when 2 links are used, is productive of values of greater accuracy.

Lubrication Increases Life of Meter Bearings

Discussion and author's closure of a paper by T. A. Abbott and J. H. Goss, published in the April 1935 issue, pages 428–31, and presented for oral discussion at the instruments and measurements session of the summer convention, Ithaca, N. Y., June 25, 1935.

L. D. Price (Public Service Elec. and Gas Co., Paterson, N. J.): As the authors have pointed out, developments in watthour meter design over the period of the past several years have left the lower bearing as probably the one remaining weak spot in the meter. Realizing this and attempting to gather further knowledge of meter bearings, the Public Service Elec. and Gas Company is conducting a laboratory test on 306 watthour meters at Paterson, N. J. The purposes of the test are to study the effect of varied degrees of lubrication on sustained meter accuracies, to ascertain the causes of jewel failure, and, if possible, to determine the maximum length of test schedule economically possible under present operating conditions. The meters are representative single element meters of American manufacture; both natural and synthetic jewels are being used and the tests are conducted under classification 2 of the suggested means of obtaining test data at normal speeds under various loading conditions designed to approximate actual service conditions. We felt that this method of test was preferable to the accelerated test because of the time factor involved in the possible breaking down of the lubricant.

Although the test has not progressed to a point where many definite deductions can be drawn, there is sufficient evidence to support the authors of this paper on one contention; namely, that in a bearing of the pivot type, liberal lubrication is essential to sustained meter accuracy.

Our test has raised a number of questions, however, that we should like to pass on to the manufacturers for their consideration. The new jewel mounting described in this paper answers the very important question of lubrication, and we hope that this is the beginning of a development comparable to the very fine progress made in the past several years in improving load and temperature characteristics, and in the standardization of physical dimensions.

Furthermore, we should like to emphasize the importance of cleanliness as a factor in proper lubrication. We have found that dirt or foreign material present in the jewel cup absorbs a considerable portion of the oil and after a short time forms a gummy substance that increases the frictional torque of the meter appreciably. This condition also interferes with lubrication and tends to increase corrosion of the pivot. We suggest that replacement jewel screws and pivots be sealed in individual moisture proof and dust proof containers, such as capsules or cellophane envelopes.

In attempting to ascertain the cause of jewel failure we have formed several theories based upon our observations. Under the general heading of insufficient lubrication we have the formation of rust, which is undoubtedly a ferrous oxide with traces of carbon and other elements. This rust may act in one of 2 ways, or both; namely, (1) some of the rust particles may be of the same relative degree of scratch hardness as the sapphire jewel and form a grinding compound, or (2) the corrosion roughens the surface of the pivot so that under the tremendous pressure microscopic projections on the pivot dislodge microscopic fragments from the jewel surface and these eventually form a grinding compound. In other words, a polishing process starts and gradually advances to the grinding stage. This latter theory is substantiated by several observations that have shown worn and polished spots prior to jewel breakdown.

Well lubricated jewel bearings with no trace of corrosion on the pivot often show scratches and are badly ground up within a few million revolutions. Here again we have 2 possible answers. In the process of mounting the jewels by crimping and/or spinning, strains are set up in the jewel. These strains sometimes result in transverse cracks, but more often cause small fractures to appear at the rim of the jewel. Small particles of sapphire, loosened by the fracture, fall into the cup and form a grinding mixture. The second cause of this same condition is to be found in the handling of meters, the impact of pivot against jewel apparently being sufficient to scratch or chip the sapphire. Examination of jewels removed from new meters shows a surprising number of damaged jewels, and this is probably the cause of the failure of so many bearings after short service. Great care is exercised by the manufacturers to protect the meter case and glass cover from injury during shipment but only on polyphase meters are the shafts blocked so that the pivot is off the jewel. To guard against these controllable factors involving jewel life, we recommend, therefore, first the development of a more satisfactory method of jewel mounting and secondly the application of removable blocks under the disks of all meters, when packed for shipment.

Since the manufacturers are so much better equipped for research than the operating companies, we should like to suggest 2 major subjects for their consideration. First, the use of a noncorrosive, possibly nonmetallic pivot. It seems probable that a composition pivot with reasonable elastic constants might be developed. Second, the use of lubricants of heavier body than oil. A lubricant of the consistency of vaseline at normal temperatures, that would withstand zero temperature without hardening would be very desirable in keeping foreign materials from being precipitated to the jewel surface.

In conclusion, we hope that the development of the perfect bearing will progress and that we shall eventually be able to standardize on one bearing for all makes of meters, with the resulting economies and conveniences inherent to standardization. We realize that the problem of the superiority of the pivot type bearing over the ball type or *vice versa* will never be settled. We do not know that either type is now perfect. Utility companies are "jewel bearing conscious" and we should certainly appreciate the co-operation of the manufacturers in the solution of this problem. Between us, we should get the answer.

M. W. Pullen (Johns Hopkins Univ., Baltimore, Md.): T. A. Abbott in his presentation emphasizes the enormous bearing pressures in meter pivots; and, further, that pivot wear reducing this pressure to approximately 2,000 pounds per square inch affected the meter calibration but slightly. The authors state it is apparent that it is impossible by any reasonable manufacturing process to shape the pivot to give this initial pressure, however deviable it may be. It seems to me that the manufacturing process will be developed if the demand is great enough. The advantages are certainly obvious. The authors have not stated what kind or character of oil they use, and whether it is put in the bearing before the meter is shipped or when it is installed? If the former, what keeps it from leaking out during shipment so rendering the condition of the meter bearing to be no better than without any lubrication?

J. H. Goss: L. D. Price pointed out that cleanliness is an important factor in bearing life. This is certainly true in that a hard gritty material in the bearing probably would accelerate wear and the presence of an organic material could possibly contaminate the lubricant.

The suggestion that heavy lubricants approaching the consistency of petroleum jelly be used to give better protection for the bearings is subject to the limitations of the available lubricants. For a limited temperature range petroleum jelly will give good performance, but at low temperatures the material becomes thick and viscous. For this reason it is necessary to use lighter oils that have a low temperature coefficient of viscosity. The problem of a heavy lubricant with a flat temperature-viscosity characteristic must rest with the oil chemist for solution.

The use of new bearing materials as suggested has been the subject of particular interest to meter manufacturers during the past few years. It is quite possible that some improvement will be made in the bearing by the use of a nonferrous material for the pivot.

It is gratifying to note that Mr. Price's data substantiates our own for certainly the utility companies are in a best position to obtain data on bearing performance as their entire system can be turned into a testing laboratory if desired.

M. W. Pullen pointed out the necessity for a stable bearing lubricant.

The lubricants for bearings that are available are in the majority of cases the product of years of development and research and embody the latest improvements in the field of lubrication. The lubricant used in obtaining the data presented in this paper will satisfactorily withstand a temperature of 75 degrees centigrade for 50 days

with a very small evaporation loss and a negligible increase in viscosity.

Mr. Pullen further suggests that the area of the pivot be pre-formed to give the correct contact area as shown by figure 2. It is not practical to do this as it would require that only 28×10^{-6} inches be ground off the end of the pivot to give the area necessary if a pivot with a radius of 0.0185 inches is used. A further difficulty is that the radius of the jewel cup is not held closely enough to allow the pivot contact area to be pre-formed even if it were mechanically possible.

Step Type Feeder Voltage Regulators

Discussion and author's closure of a paper by L. H. Hill published in the February 1935 issue, pages 154–8, and presented for oral discussion at the distribution and transmission session of the South West District meeting, Oklahoma City, Okla., April 26, 1935.

F. L. Snyder (Westinghouse Elec. and Mfg. Co., Sharon, Pa.): As pointed out by the author the development of the step type voltage regulator was the natural result of the experience of both manufacturers and operators with load tap changers on power transformers. As a matter of fact, there is nothing new about the theory of a step type regulator. Several manufacturers of electrical machinery have been building step type regulators for the past 10 years and there are several million kva of installed capacity of such equipment. Step type regulators of the type which manufacturers have been building for some time have, however, been too expensive for application to distribution circuits and the step voltage regulator of the general type described in this paper consists of a smaller and less expensive regulator which can be economically justified on distribution circuits. Apparatus of the same general type as that described is being built by several other manufacturers. (See "Step Voltage Regulators," F. L. Snyder, *Electric Journal*, June 1934).

Under the heading "Determination of Size of Step," some statements are made and some conclusions reached which are not substantiated by other manufacturers' experience. It is stated, for example, in comparing the half-cycling and full-cycling principles of operation that "the smaller the step the smaller the voltage and kilovolt-amperes to be interrupted and the smaller the contact deterioration." Let us take 2 regulators of this same general type, the one having 32 steps with half-cycling operation and the other 16 steps with full-cycling operation, the voltage and kilovolt-amperes interrupted will be exactly the same for both regulators and therefore the contact deterioration will be the same per switch operation.

The statement is made that "It may be seen that for $1^1/_4$ per cent steps with full-cycling operation there are 2 circuit openings and 2 circuit closings for each tap change. The duty is just twice what it is for a regulator using half-cycling operation and giving $^5/_8$ per cent steps." Let us assume that the 2 regulators referred to above operate over a definite percentage of their range; each regulator will have made exactly the same number of contact openings and contact closings and will be subject to the same contact deterioration. The duty will therefore be the same on each regulator.

The statement is made that "the use of $^5/_8$ per cent steps is advantageous also because with the fluctuating voltages encountered in average regulator service, the smaller steps will result in fewer tap changing operations." In support of this statement the assumption is made that the relays on both regulators under discussion would have the same setting. This would not be the case in actual practice since it is is universally recognized that the relay on a step voltage regulator must not be set to operate at voltage variations less than the voltage correction made by one operation of the regulator, since to do so would obviously result in hunting. The relay on the full-cycling operating machine must therefore be set to operate when the voltage varies from normal by $1^1/_4$ per cent instead of 1 per cent as assumed. With this relay setting corrected, the full-cycling machine will make one tap change instead of 9 while the half-cycling machine will make 2 tap changes for the variation in impressed voltage shown in figure 6 of the paper.

Furthermore, it does not appear logical to assume that the voltage variation shown in figure 6 is typical. It would seem more reasonable to assume, as the load varies from light load to full load, that the regulator will move progressively over the larger part of its range. Under such conditions the half-cycling operating regulator would again make twice as many operations as the full-cycling operation regulator and 4 times as many as the regulator designed for $2^1/_2$ per cent steps.

There is no doubt but that the step type voltage regulator has certain very definite advantages over the induction regulator, particularly for application to the higher voltage and higher kilovolt-ampere 3 phase distribution circuits. The method of tap changing used in the regulator described by Hill is similar to that used by other manufacturers of the same type of apparatus, although the actual mechanical details of the regulator construction differ. Most manufacturers mount the tap changer and the core and coil assembly side by side in separate compartments in the same tank instead of mounting the transformer above the tap changer, as described by Hill.

The spring driven snap switch mechanism used for driving the tap changer, with a quick break action, is not necessary to interrupt the circuit in the first half cycle, since other manufacturers of the same type of equipment are able to interrupt the arc in the first half cycle with a positive and solidly connected mechanical drive without the use of springs. This construction may have the advantage that it eliminates the motor brake and the pilot motor holding-in switch.

The automatic and antihunting control referred to is the same control scheme that is used for the operation of automatic induction regulators with the exception that a time delay is introduced between the making of the primary and secondary relay contacts. This time delay eliminates needless tap changes due to voltage swings and is necessary because the step type regulator varies the voltage in a certain definite predetermined amount for each operation while an induction regulator stops as soon as the voltage has been returned to normal.

L. H. Hill: The discussion has indicated that the conclusions reached in my paper concerning the use of $^5/_8$ per cent steps versus $1^1/_4$ per cent steps are not justified by operating experience. I do not agree with this conclusion, because all of the regulators manufactured by the company which I represent are in operation with $^5/_8$ per cent steps, and by actual observation of their operation in the field it is possible to easily determine that one $^5/_8$ per cent step is sufficient to balance the contact making voltmeter in many cases. By actually observing the operation of a regulator it will be noted that if the unit makes only one $^5/_8$ per cent step to balance the relay, it must clearly indicate that the $^5/_8$ per cent step is sufficient to balance the relay; hence, a $1^1/_4$ per cent step would not have been necessary, and would simply have provided overcorrection. As F. L. Snyder has agreed in his discussion, a $1^1/_4$ per cent step with full-cycling operation is the equivalent of 2 $^5/_8$ per cent steps with half-cycling operation; hence, a $1^1/_4$ per cent step represents twice as much contact deterioration as a $^5/_8$ per cent step.

Snyder points out that for regulators to operate over a given range the duty on the contacts is the same with $^5/_8$ per cent half-cycling steps as compared with half as many $1^1/_4$ per cent full-cycling steps. There is, of course, no difference of opinion concerning this, but the point is the duty on the contacts even when operating over wide ranges shows no advantage for the larger size of step. Regulators, however, operate under fluctuating voltage conditions, and as outlined in the paper, this is the condition which results in fewer operations when smaller steps are used.

Snyder takes issue with the fact that a comparison was made with $1^1/_4$ per cent steps and $^5/_8$ per cent steps using the same relay setting of plus and minus 1 per cent. He points out that with $1^1/_4$ per cent steps the relay setting should not be as close as plus and minus 1 per cent. This, however, is a pure admission on his part that the regulator with $1^1/_4$ per cent steps should not be used to regulate as closely as one with $^5/_8$ steps. The regulator described in my paper was designed to operate with the same relay settings which have been used with induction regulators, and the analysis of the size of step was made on that basis. If $1^1/_4$ per cent steps had been used, as Snyder points out, it would be necessary to set the relay contacts farther apart, which would not give the results which can be obtained when $^5/_8$ steps are used. Of course the reference to $2^1/_2$ per cent steps resulting in fewer operations again presupposes setting the relay contacts farther apart than is required for the type of operating service the regulator is designed for, and has no bearing on the discussion concerning a regulator designed for close regulation.

As a matter of fact, it is difficult to reconcile the views expressed by Snyder in this discussion, because the company which he represents builds their regulator, which is advertised as $1^1/_4$ per cent steps, full-cycling

operation, so it can be arranged to stop on the half-cycling position and thus provide the $^5/_8$ per cent step under consideration.

To summarize concerning the size of steps, the regulator described in the paper is designed to operate with $^5/_4$ per cent steps, and the control is such that if one $^5/_8$ per cent step is not sufficient to balance the relay, it will automatically make another step. It should be evident that this arrangement cannot help but result in fewer total operations, especially considering that the $1^1/_4$ per cent step is really equivalent to 2 $^5/_8$ per cent steps as outlined above.

It might be pointed out that the reason for mounting tap changer and transformers above one another instead of side by side is to reduce the floor space. The step regulators under consideration are designed to go into vaults used by induction regulators which would not be possible with any other arrangement.

The use of the quick-break mechanism is not because of necessity but rather because of superior features obtainable by its use. Tests on contacts to measure contact deterioration indicate definitely the much longer life obtainable by its use. The use of a quick-break mechanism as described, however, eliminates the need for a brake on the driving motor, with attendant maintenance.

The time delay in the control is not necessary because the step voltage regulator varies a definite predetermined amount but is used to avoid unnecessary operations resulting from voltage changes of short duration where a regulator operation is not required and where a regulator operation would often make service worse than before. Induction regulator operation would be improved if time delay were provided in its control. This has actually been done in some cases.

Regulation Beyond the Distribution Substation

Discussion and author's closure of a paper by P. E. Benner presented for oral discussion at the distribution and transmission session of the South West District meeting, Oklahoma City, Okla., April 26, 1935, and published in the August 1935 issue, pages 832–7.

V. C. Gillon (nonmember; Oklahoma Gas and Electric Co., Oklahoma City): Certainly this paper is indeed most appropriate at a time when capital expenditures for power generation and transmission systems are small and the expenditures for distribution systems relatively large. This condition, brought about by low industrial loads but continually increasing residential loads, has diverted more and more administrative and technical engineering thought to the distribution system.

In the paper it seems that the curves, figures 2 and 3, where the per cent voltage drop is plotted against the per cent rate at which the investment in primary and secondary system changes, would permit the economic solution to be determined only if the total annual charges had been plotted as the ordinate rather than investment.

One thought in connection with the application of the secondary autotransformer is that a regular 5 kva transformer can be added at a cost of approximately $110. The autotransformer costs approximately $35 for 2 kva. It is evident that 5 kva additional transformer capacity can be added for $75, or $15 per kilovolt-ampere, which is very reasonable indeed.

The economic importance of electrical losses has become of lesser consequence over the past number of years as continually decreasing production costs in the power plants have contributed to this pronounced trend. The low costs of losses provide opportunity for economical application of supplementary regulating devices which would not have been advisable a few years ago. However, the determination of the cost of losses does not simply involve the average cost of fuel per kilowatt-hour. A more thorough analysis of over-all energy cost to the company should be made; at times it may be that fixed charges on a portion of the transmission and generation investment should properly be a portion of the costs of losses, as well as fuel costs.

The author has discussed the problem of instantaneous regulation causing light flicker and various proposed solutions. The following discussion will present an attack upon the problem of what constitutes objectionable light flicker caused by starting of single phase air conditioning motors in residential areas.

Regardless of the rate of growth of residential air conditioning load or the ultimate customer saturation and load density created by it upon the electric service company's distribution system, there is a problem of economically providing facilities to prevent objectionable light flicker caused by these units on single phase lines. What limit should be placed upon the voltage drop produced by starting of a motor has been a matter of great divergence of opinion among public service company men and considerable discussion has been accorded this subject by an Edison Electric Institute committee, by which some valuable data have been contributed.

It has been generally agreed that objectionable light flicker is dependent upon both the magnitude and frequency of occurrence of the voltage change. Those in the business are entirely too conscious and critical of the service to be competent to determine from their own personal reaction just what flicker is objectionable. To most of us almost any apparent flicker is objectionable, though an average customer will likely never even be conscious of these voltage dips.

Proposals have been made by some of those concerned with this problem to have doctors, psychologists, and optometrists consulted in order to determine just what flicker is objectionable. We decided to impose conditions of light flicker upon groups of average customers, without their knowledge, in order to determine what flicker would cause them to complain.

An air conditioning compressor driven by a 240 volt, 3 horsepower, single phase repulsion-induction motor as a flicker producer was used. This machine was equipped with a time clock controlled line contact so that it could be left unattended and set to start up at certain fixed and regular intervals. An actual air conditioning unit was used because it was desired to simulate the flicker of an actual installation; that is, a unit which had the same current-time characteristics upon starting. The time intervals or frequency of starting of the unit were set at 20 minutes. The length of this interval was determined by the study of charts which were taken from 14 actual residential installations during the 1934 season.

During the high temperature days, the air conditioning units run continuously, though on cooler evenings, when residential customers are using lighting for reading, the units do not run continuously, but start up about every 20 minutes and run for a short time. The data taken on residential air conditioning installations indicate that the machines are not usually operated under fully automatic control except on very hot days when the units run continuously. On cool evenings, when the automatic control would cause the machine to start up most frequently, the customers usually shut the machine down with the manual control switch and, therefore, it is seldom that the machines start up more than a very few times a day.

This test machine was located in a company employee's garage in a good residential area; that is, a section of reasonably prosperous customers where there may be some future hope of having air conditioning installations. These residences also have lighting which corresponds to that in the more prosperous homes.

The machine was adjusted to start up every 20 minutes, each evening from 6:00 p.m. to 12:00 p.m. for a period of 3 weeks. It can be readily seen that a machine starting at such frequent intervals every day gives a very much accelerated test in comparison with permanent residential installations.

At one location a drop of 9.5 volts was produced on the 120 volt lighting circuits and affected thus the service of 7 customers for 21 consecutive nights. The load was supplied by 500 feet of No. 2 secondary wire on cross arm construction, and a 25 kva transformer. None of the customers whose service was affected by the starting of the unit registered a complaint with the company. Interviews with these customers revealed that they had not noticed any disturbance or unsatisfactory electric service, even though leading questions were asked them, such as to the flicker of their lights. One customer had been bothered by the noise of the motor upon starting but did not complain.

The flicker machine was moved to another residential location where a voltage drop of 10 volts was produced by starting of the motor and affected the service of 9 customers for a period of nearly 3 weeks.

In this latter area one customer complaint was received by the company. It was learned that this customer occupied a back bedroom in a house just behind the garage in which the flicker machine was located, and that the customer habitually read in bed late at night. The customer reported that the lights dimmed and that there was a loud buzzing noise in the alley. This customer seemed to be as much or more interested in eliminating the noise as in the light flicker, thinking perhaps that the noise indicated something wrong with the company's facilities and that we would like to know it.

Interviews with other customers in this area revealed that 2 of them had noticed the light flicker but they did not consider it sufficiently objectionable to justify their complaining to the company. The remainder of the customers in the area had not even noticed any light flicker.

Throughout the 1934 air conditioning season, data as to voltage drop and current upon starting of the units were accumulated, the summary of which is given here for several residential installations.

Rating of Motor		Volts Drop on Lighting Circuit	Number of Customers Affected
Horsepower	Volts		
1	110	13.5	4
3	220	8.0	4
3	220	7.1	8
$1^1/_2$	220	4.5	4
1	220	5.0	12
$1^1/_2$	220	7.5	2

All of these installations were operated during the 1934 season and there were no customer complaints as to unsatisfactory voltage conditions or light flicker received. These data were taken under typical conditions as they do and will exist upon the system in residential areas and yet no customer complaints were registered even under some rather extreme conditions of voltage drop.

It is believed these tests and experiences may indicate that an 8 per cent drop upon starting of an air conditioning unit is noticeable, but not seriously objectionable and may not cause the customers to complain. In the case of more frequent starting, however, such as elevators, this value must be much lower. Of course, there will be a few customer complaints from customers in the category of perpetual complainers but such exceptional cases can be remedied and the system economically designed for average conditions. These remarks should not be construed as meaning that the necessity for limiting starting currents of motors upon distribution systems is to be minimized.

John Oram (Dallas Power and Light Co., Dallas, Texas): Where it can be clearly shown by economic analysis that voltage regulation and not excessive energy loss is the limiting factor, supplementary regulating devices appear to have a particular field of application. This condition is closely associated with load factor or hours use of lines and equipment, type of service rendered, and other considerations, and therefore no general rules can be formulated to cover all conditions.

It seems fairly obvious that under conditions of low load factor and long branch circuits, or where the voltage supplied to such branch circuits is subject to wide fluctuations, a special voltage regulating device would be a reasonable solution.

There is danger, however, of going to the extreme of spending too much money for regulating voltage within narrow limits, especially in certain outlying and poor revenue producing sections.

It is my feeling that further research might be properly directed toward producing a type of lamp having less critical characteristics as to voltage and lumen output; in other words, less sensitive to voltage variation than the present types.

C. I. Hendricks (Texas Electric Service Co., Fort Worth): The paper describes means of mitigating voltage regulation difficulties an overhead distribution systems, the result of justified procrastination following our economic instability period of the past 5 years. Although there is no doubt but that we should correct regulation difficulties that now confront us, it would be wise not to overlook the paramount fact that our distribution systems should be so designed as to provide adequately for the domestic load increase incurred during the past 5 years and which, in all probability, will continue in the future. This thought can be accentuated by mentally visualizing the importance placed on domestic service continuity necessitated by the ever increasing use of domestic appliances.

The author very ably points out regulation limits for a well designed overhead distribution system and, also, describes unique means of arriving at the economic allocation of voltage drop throughout the distribution system. He then discusses methods of remedying incorrect voltage situations on a limited economic basis.

Undoubtedly economic reasons may, in many prevailing instances, dictate mitigation means of regulation correction; however, we should again stress, at the expense of repetition, the thought that a distribution system, embodying simplicity in design and having low inherent regulation qualities, will provide the most reliable service at a minimum operating cost.

The company with which I am affiliated has, to a limited degree, utilized autotransformers as a means of alleviating voltage dips on overhead secondary conductors caused by the starting currents of 120 volt fractional horsepower motors. However, the use of autotransformers should not be considered a panacea for all such instances. A careful diagnosis of certain cases reveals the fact that the application of an autotransformer can, regardless of capacity, be of little or no practical value in minimizing the voltage drop.

With the author's paper as a guide, calculations field tests to check them have been made in an endeavor to determine the efficacy of autotransformers as a means of alleviating voltage dips caused by starting currents of fractional horsepower 120 volt motors connected to overhead secondary lines. The results obtained were, in general, similar to those given by the author and, although time did not permit such a thorough study as reflected in the paper, the conclusions reached are accurate within reasonable limits.

In figure 10*B* of the paper it is shown that a standard 5 kva distribution transformer can satisfactorily be used with prescribed load requirements and voltage drop limits. The calculations and tests referred to clearly indicate that a standard 5 kva 4,000/119 volt distribution transformer, having a ratio of reactance to resistance of 1.16, will not be applicable when circuit voltage, power factor, and current characteristics are used as assumed by the author in figure 10*B*.

It is altogether possible that the author has considered a more recent design of distribution transformer; however, since relatively few distribution transformers have been purchased during the past 5 years, our problem, to a large measure, involves transformers of a vintage prior to 1930. Further calculations of conditions similar to those assumed by the author in figure 10*B*, produced results that permitted the use of autotransformers having lower kilovolt-ampere ratings than those illustrated by the curves in the figure.

It is concluded that, before the practice of autotransformers be adopted as a means of alleviating voltage dips on secondary lines, a careful analysis should be made, taking into consideration all pertinent operating factors such as resistance of conductor connections, relative drop through distribution transformer when using half of the secondary winding, power factor of increment current during peak and light load periods, actual conductor spacing, and other aspects.

In short, probably the practice of using autotransformers as a means to correct undesirable voltage situations is merely an expedient, unless this practice has first been economically justified for the distribution system under consideration.

P. E. Benner: Reduction in distribution system investment by the installation of supplementary regulating devices is most apt to obtain in fringe areas which are only partly built up, or in places where physical limitations prohibit the use of the regular type of construction. One especially attractive feature of the supplementary regulating device is its mobility. Transient conditions of load growth in fringe areas may require the installation of a pole type regulating device or an autotransformer in one location one year and in some other location a few years later.

Careful thought should be given to the idea that areas of low load density do not justify good regulation. This idea probably originated when rendering good service from the standpoint of voltage regulation required large investments in extensive primary facilities, but certainly should be reconsidered now in the light of the newly developed low-capacity low-cost regulating devices. Another phase of this same subject is the effect of good regulation on revenue, and it is believed that a conservative evaluation of this factor will often remove any doubt as to the desirability of improving voltage conditions.

As V. C. Gillon suggests, a rigorous solution of the problem of proportioning the voltage drop between primary and secondary circuits would be based on annual charges rather than investment. Realizing, however, that major parts of the annual charges of primary and secondary systems are a function of their respective investments, it was believed advisable to make this approximation for the sake of simplification. The tests described by him are very interesting and these and other similar tests might very well form the basis for establishing a practice regarding the permissible voltage fluctuations resulting from the installation of air conditioning equipment. Care must be taken, however, not to confuse the relatively infrequent voltage fluctuations caused by air conditioning

equipment with those caused by domestic refrigerators. The more frequent starting of the latter would necessarily limit voltage fluctuations caused by them to a much lower value than the 8 per cent suggested by Gillon.

The curves, figure 8, which show the application of auto transformers for reducing light flicker are based on the design of 2,400-240/120 volt distribution transformers which has been more or less standard for a number of years. Actual tests made on a stock 5 kva transformer gave the following results:

Per cent resistance and reactance of the transformer with both low voltage windings loaded to rated capacity and on a 5 kva base..... 2.12 per cent and 1.68 per cent, respectively.

Per cent resistance and reactance of transformer with one low voltage winding loaded to rated capacity and on a $2^1/_2$ kva base..... 1.66 per cent and 1.13 per cent, respectively.

The starting current considered was for a motor connected line-to-neutral so in figuring the transformer drop the resistance and reactance values with one low voltage winding loaded to rated capacity and on a $2^1/_2$ kva base were used.

The calculated drop through the transformer from the 25 ampere, 0.5 power factor starting current was 2.6 volts. The voltage drop in approximately 35 feet of No. 4 secondary wire would bring this up to 3 volts, which was the assumed limit.

The situation to which the curves of figure 8 apply is probably somewhat pessimistic in that a 25 ampere, 0.5 power factor starting current is larger than that generally encountered. Permissible secondary runs for other currents of the same power factor can be estimated, however, with the additional information that a 25 ampere, 0.5 power factor current has approximately 3 volts drop in 265 feet of No. 4 secondary. Using this figure, it can be readily determined that a $12^1/_2$ ampere, 0.5 power factor starting current will cause a 3 volt drop through a 5 kva distribution transformer and 300 feet of No. 4 secondary.

Design and Operation of Huntley Station No. 2

Discussion of paper by H. M. Cushing published in the June 1935 issue, pages 632–45, and presented for oral discussion at the power generation session of the summer convention, Ithaca, N. Y., June 25, 1935.

C. M. Gilt (Brooklyn Edison Co., Brooklyn, N. Y.): The engineers who designed the Huntley Station No. 2 had the good fortune of being able to make a combined design of distribution system and generating station without having to adapt the station to an existing distribution system. In so doing they were among the first to take advantage of the 2-winding principle which has been used in both generators and transformers. By means of this, circuit breaker current capacities and interrupting ratings are reduced, the need for bus reactors is eliminated or greatly reduced, the reactance between bus sections is high while the normal through reactance from generator to load is kept low. Associated with these advantages are 2 disadvantages, one of which is the fact that there is no independent control of voltage and phase angle of the 2 windings with the result that unequal loadings result in unequal voltages and phase angle differences between bus sections. It is especially important that voltage and phase angle differences be kept small when a low voltage network is fed directly from the generating station busses without intervening feeder regulation. Comparatively small phase angle differences may trip open and cause frequent operation of sensitive network switches on lightly loaded transformers or cause overloads on heavily loaded transformers. The other disadvantage resulting from the 2 winding designs is the impracticability of transferring load from one bus section to another through the transformer (or generator) tying the bus sections together. This condition may result in real loss in station economy if it requires operating units with loadings that differ materially from those giving maximum station economy.

These limitations have apparently been completely met in the Huntley Station design by the use of 2 feeder breakers per feeder and the ability to adjust the number of feeders on each bus to secure equal loadings. Large bulk power feeders automatically aid in balancing the load on the 2 windings of the generator transformers by means of the 2 primary windings of the feeder transformers, one of which apparently is connected to each of the busses. One or 2 generators can be operated and the load divided between them for maximum station economy by transferring load across the bus tie breakers, which the diagram indicates normally are operated closed.

While such complete flexibility in load adjustment is convenient, the experience of the Brooklyn Edison Company indicates that for its conditions it is not necessary, and no doubt the choice of 2 breakers per feeder was determined by other factors. It has been possible in Brooklyn to obtain adequate load balancing and adjustment between generators by connecting groups of 4 or 8 feeders to one generator or another, with some load transfer across the synchronizing bus to which all generators are connected through reactors. It is, of course, necessary to connect feeder cables to switch positions in such a way that reasonable load balance is maintained on the various feeder group busses. By this means it has been possible to operate so that the voltage difference between the windings of the 2 winding generator autotransformers does not exceed and is usually less than 2 volts, on the basis of 120 volts delivered, or 1 volt above and below the objective mean.

Feeder groups are connected to machines in such a way that it is possible to obtain the desired machine loadings for economy without exceeding phase angle differences between busses of greater than about one degree. These are generally practicable working conditions for network supply.

I am not a little surprised at the experiences described while the 22 kv system was operated solidly grounded, during which time cables which failed sometimes blew themselves clear of the failure without tripping the station breaker, sometimes leaving exposed live conductors. The Brooklyn Edison Company has operated a solidly grounded 27 kv cable system since 1923 on which feeder short circuit magnitudes are usually of the order of 300,000 to 400,000-kva, 3-phase value. So far as we can recall, there has been but one similar case. Upon investigation of a manhole that had been reported to have exploded, it was found that a 3-conductor, 27-kv cable joint had blown open and the arc extinguished itself without tripping the station breaker. The cable was taken out of service before the open joint broke down again.

M. Penn (Public Serv. Elec. and Gas Co., Newark, N. J.): From H. M. Cushing's, paper it is evident that the unusual conditions under which the plant would be operated were well understood in advance and the operating results show that these requirements were capably provided for. An outstanding part of the paper is the thorough analysis and codification of the requirements which the station must fulfill. The importance of clearly defining the problem and the objectives of any engineering project before designs are drawn cannot be over emphasized, though the task may sometimes be rather difficult and require considerable time. In this way all concerned with the design may work toward a common purpose.

This station while intended for low capacity factor operation seems to be a very complete 400 pound plant as far as heat saving and control equipment are concerned. The design, however, was intended to permit a low installation cost per kilowatt of capacity with low operating and maintenance costs. At the same time reliability and rapid response to load changes were primary considerations. The paper indicates to some extent the degree to which these objectives were accomplished, although whether or not low installation cost per kilowatt of capacity was obtained and low operating labor and maintenance costs as well, are not stated. This information would be very useful in order to determine whether a plant intended for low capacity factor operation and utilizing moderate steam pressure and temperature could be built and operated at any considerable saving over a high pressure and high temperature base load plant.

The tabulation of over-all operating performance indicates that very good fuel economy has been obtained for operation at low capacity factors. In 1933 and 1934 the annual heat rates are given as less than 14,500 Btu per net kilowatt-hour with capacity factors of 25.8 and 22.5 per cent. Table I shows that during these years the 80,000 kw generating units operated 15 per cent of the service hours at between 5,000 and 10,000 kw load and 42 per cent of the time in service at loads of 20,000 kw or less. Loads up to 90,000 kw were carried for short periods.

It is stated that 4 tons of coal per 24 hours are required to keep a 560,000 pound per hour pulverized fuel fired boiler within 100 pounds of line pressure. Low banking fuel consumption probably accounts to some extent for the low average heat rate of the station at low capacity factors.

The use of slag tap furnaces with boilers operating at such low average ratings seems unusual. The special igniting oil burners for starting pulverized fuel boilers is also a feature worth noting.

If the stacks at Huntley are steel as appears to be indicated, are they fully lined, or what provision has been made to prevent corrosion? At Kearny and Essex generating stations considerable corrosion of several lined steel stacks was recently discovered.

The operating record shown in table I does not indicate very high availability of main units although it is stated that turbines are not taken out for overhauling oftener than once in 2 or 3 years. The average unavailability for units 1 and 2 for 1933–34 was 19 per cent. Table I has a typographical error in the column "Hours Idle But Available" where the figures for No. 2 unit in 1932 and No. 1 unit in 1933 are interchanged.

The data given on starting time for these large units emphasize the value of the motor-operated turning devices to keep the turbine rotors straight, while the rapid increase of load under test shows the possibilities in an emergency.

The use of generators without direct connected exciters is somewhat unusual. Perhaps Mr. Cushing will give the reasons for the choice.

The most interesting item in the electrical layout is the application of the split bus scheme. This is an objective toward which we aim in the ultimate development of our 132 kv loop although we do not operate that way at present. In 1927 and 1928, Public Service Electric and Gas Company of New Jersey made a careful study of its 132 kv transmission network and carried these studies forward to a system capacity of 2,000 megawatts. The purpose was to determine a system of transmission which could be almost indefinitely developed without obtaining excessive short circuit currents or such severe disturbances to the system with 132 kv faults as to cause the system to pull apart, either within itself or from neighboring systems to which it might be tied. Provision was made for the adoption of a double bus system in which busses and bus sections could be tied together by utilizing the split windings of the connected transformers. In 1929, a 90,000 kva bank of transformer incorporating these features was purchased for Roseland switching station which serves to step down the voltage from 220 kv to 132 kv. The through reactance from primary to secondary was specified as $13^1/_2$ per cent, while the transfer reactance between 132 kv busses was specified as 114 per cent. We should like to learn from Mr. Cushing if the aim of balanced loads on both sides of the transformer was difficult to achieve in practice and, when unbalances do occur, what is their magnitude and effect. Also, how far is the split nullified by the cross connections between the 2 busses which occur in the sub-transmission network. Another point is that this scheme of short circuit protection places a definite limit on the transmission layout, since any substation high tension busses fed from different bus sections would short circuit the protective feature.

It would be interesting to find out if the practice of grounding through a 5 ohm resistor has, in the operation of this system, brought forth any data on overvoltages under single line to ground fault conditions or if any low frequency induction with the communication companies has been experienced.

The use of simple conventional types of switching equipment of modern design was certainly sound engineering in this case. In many instances a conventional masonry bus and switch structure, using modern equipment, will not only have practically all of the essential advantages of unconventional switchgear, but will be more adaptable to local conditions, more flexible for future requirements, and more economical, particularly for the main switching connections of a large generating station.

It would be interesting to learn more of the details of the very fast clearing of faults on the 22 kv cables when operating dead-grounded, as usually with a dead-grounded system, the fault current is severe and holds on until the protective relays function.

The designers of this station were very fortunate in not being handicapped by a large number of conditions which more or less dictate the detail design of the station. The 7 months' operation at a net heat rate of 13,812 Btu per kilowatt-hour shows that details relating to economy have been watched with care. This, plus the splendid operation under emergency conditions and the quick, economical methods of handling repairs to auxiliaries by means of monorails and hoists all reflect credit on the designers for having developed a layout which so admirably meets the requirements.

F. A. Allner (Pa. Water and Pwr. Co., Baltimore, Md.): H. M. Cushing's paper is commendable for its excellent analysis of the design of the power plant discussed; it is distinctly more than a description of another plant. In addition, for the benefit of power plant engineers at large, Mr. Cushing has laid bare with generous frankness such shortcomings as experience in operation have revealed.

The principles of plant design exemplified by Huntley Station No. 2 are of vital interest at the present time when power engineers are directing their thought to the supply of the increased load demands that appear imminent. Naturally the extension or rehabilitation of existing stations is given first consideration when the trend of the load curve indicates that additional capacity may be required, but in any sustained upward swing of the load a time soon comes when a major addition in the form of a new plant becomes necessary. Huntley No. 2 presents an alternative scheme of design to that apparently being given wide study and consideration during the past 4 or 5 years, i. e., high pressure and high temperature.

The steam pressure and temperature at the turbine throttle in Huntley No. 2 appear to be 425 pounds and 750 degrees, or what may be said to be low pressure and medium temperature when compared to the maximum conditions discussed for modern plants. However, the plant should be judged in the light of the economic results secured by it. Figure 12 shows a possible best heat rate of 12,300 Btu per net kilowatt-hour, and table II shows actual heat rates under load conditions that require a great number of starts of boilers and turbines and a large proportion of boiler banking hours. Certainly the thermal results secured under the existing conditions of load and what appears to be not the highest grade of coal, approach the best fuel economy so far reported for any steam-electric station. Moreover these thermal results are obtained by a plant which appears to have a somewhat unusually low cost per kilowatt of installed capacity. If the data in the paper about building and construction costs are correctly interpreted, the cost per kilowatt seems to be about halfway between the figures often quoted for total plant and incremental capacity costs. The paper therefore squarely raises the question of whether or not plant designers have overlooked the potentialities of existing design schemes in their efforts toward greater economy through the use of super pressures and temperatures. Is it possible that the depature from low to medium steam conditions is predicated upon the supposition that other elements of plant design are fixed or that their possibilities have been exhausted?

The paper does not indicate that the inherent quality of the design was due to the absence of any handicap of having to fit the station into an existing system, although upon first thought this might seem to be implied under the heading "Design Requirements." It is difficult to imagine how external matters could have seriously circumscribed the features which seem to have contributed largely to the general excellence of the design. Rather one gathers the impression from reading the paper that the points of novel merit in the design came about solely from judicious selection and arrangement of equipment and from a clear distinction between essentials and non-essentials.

At the risk of repetition of the contents of the paper, the features of design which reveal an independence of thought and which undoubtedly contributed to the low cost of the station, appear to be as follows:

1. A very compact switchhouse which in comparison with many others is remarkable for its simplicity and small volume.
2. A centralized location for the house service transformers and buses.
3. A compact boiler house of minimum height and containing large air heaters of minimum volume.
4. An almost vertical draft system.
5. An accessible boiler setting without economizers that is supported at the bottom instead of being hung from a structural framework.
6. A stack temperature of less than 300 degrees at full boiler load.
7. Absence of interior coal bunkers and coal elevating equipment.
8. Outdoor coal storage lot that also serves as a boiler bunker.

The design of the switchhouse and switching equipment merits close attention.

Turning to the matter of co-ordinating the design of the plant for use on a power system that is predominantly hydroelectric, it is noted that Mr. Cushing has listed "rapid response to sudden changes in load" initially in the design requirements, and elsewhere in the paper he has described speed-of-response tests with turbines and boilers. Quick response of equipment already in operation either floating or carrying minimum load is to be distinguished in this connection from the ability to start turbines quickly from standstill and boilers from a cold or banked condition, together with the related matter of economy of starting and stopping equipment. The first aspect of operation is essentially an emergency condition, and may occur with either steam of hydroelectric plants; the second is associated with the peak operation of either type

of generating plant. Hydroelectric units, of course, are almost ideally suited for quick starting from standstill, and in certain instances already described to the Institute they can be started and synchronized sufficiently quickly to avert serious consequences in the event of the emergency loss of other units on the system. Likewise when hydroelectric units are used for peak operation, the starting and stopping and equivalent banking losses are practically nil.

The load curves shown by Mr. Cushing indicate that the Huntley Station No. 2 is never shut down completely. When other plants on the system are available to carry the entire 24 hour load, the plant is operated at minimum load of 5,000 kw on one turbine and one boiler, with 2 other boilers in hot reserve. This is evidently operation for system protection in emergency, to facilitate which certain signaling and furnace lighting equipment were provided. Facilities of this nature are installed in most stations, and their addition would not modify the basic design of the plant.

On the other hand, when the plant is used for peak operation as shown by 2 of the typical load curves, load is nevertheless carried during the valley periods. The plant in consequence is not subject to the type of operation that may occur with steam relay plants when the hydro capacity in periods of plentiful water is greater than the valley load. On such systems the economy of boiler banking and of starting and stopping turbines and boilers is an item to be considered in the design of a steam relay plant. Mr. Cushing has provided a turning device on the turbines in order to minimize the starting period, really for the purpose of economy in starting since steam turbines have no value for instant starting in emergencies. Turning devices are also in common practice.

It, therefore, seems that the design of the plant was not prejudiced or modified in any material respect for the purpose of coordinating its operation with that of the hydroelectric plants on the system, nor even for the sake of rapid response to sudden changes in load. Any opinions that Mr. Cushing may have about the disadvantages of steam cycles and conditions different from those that were adopted may only be surmised from his paper, but it is likely that he would have objections to them also on the ground of their cost as compared to that of the scheme adopted.

One is led to wonder after reading the paper why the plant cannot be shut down entirely during load valley periods, and why it is necessary to keep 2 boilers in hot reserve for which 4 tons of coal are necessary per boiler per day. The furnace and boiler design and the system of combustion would appear to be favorable for quick starting from a cold or banked condition. Data of the time necessary to start a cold boiler and the fuel requirement for starting would be of interest in this connection. Also, it would be of interest to know, if the number of boiler starts shown in table II includes the lighting of burners for the purpose of holding reserve boilers within 100 pounds of line pressure.

The impression obtained from reading the paper is that the new 60 cycle system replaces in large measure the 25 cycle system in Buffalo, which had been served by an adjacent steam-electric plant of 305,000 kw capacity. Mr. Cushing does not mention whether or not the possibility of the rehabilitation of the 25 cycle station was considered in connection with the selection of a site.

F. R. Longley (Western Mass. Companies, Springfield): One of the most striking features of the plant, as described under the subheading "Electrical Connections," is the limitation of bus faults by means of the split winding transformers. If conventional reactors were used to give the through reactance of 5.46 per cent, the transfer reactance would be only 21.84 per cent as compared with the 50.4 per cent, which is obtained from the split winding autotransformers by means of the mutual magnetic coupling between windings.

It is well to bear in mind that the reactance obtained from split winding transformers is entirely different from and more advantageous than that provided by reactors.

It is stated in the paper that the voltage on the unfaulted bus section actually tends to rise; and that with the station extended to 600,000 kva in generating capacity, and 360,000 kva of 110 kv transformer capacity, the use of split winding transformers will limit the bus fault to 715,000 kva. It would be interesting to know the magnitude of this fault if split winding transformers were not used. The autotransformer capacity and the 110 kv transformer capacity connected to the 22 kv bus would total 960,000 kva. The bus fault, if split winding transformers were not used, could be several times this connected capacity, or several million kilovoltamperes.

Considering the reduction in short circuit current thus obtained without impairing the operating performance of the station, it would seem well for those of us who are planning future generating stations to give careful consideration to the use of split winding transformers and generators.

The single line diagram in figure 9 shows a large number of 22 kv switches normally open, any one of which if unintentionally closed would tie the 2 bus sections solidly together. Is there any arrangement such as interlocks to prevent such unintentional operation?

Under the subheading "Fault Protection" is a description of 22 kv cables burning themselves clear during faults in less than 3 cycles, when the system neutral was solidly grounded. This performance is indeed surprising. If it can be depended upon to repeat it may offer some possibilities for clearing faults that occur in manholes and vaults. Will the author elaborate on this, giving a description of the cable used at the points of fault and including copper size, insulating material and the thickness of insulation? What was the magnitude of the total fault current and the branch fault currents fed in from each of the 2 sides of the fault? Was the conductor burned in two or was the sheath and insulation merely stripped away leaving the conductor continuous?

Since the Huntley Station No. 2 was designed and built, further progress has been made in the use of high steam pressures, such as 1,200 pounds; the use of the mercury vapor steam cycle; and the location of station equipment out of doors.

For the information of engineers who are considering the construction of new steam plants, what part, if any, of these advanced features would the author incorporate in the design of the Huntley Station No. 2 if it were being designed today; and what part, if any, would he incorporate in the design of an equal size base load steam plant?

E. G. Bailey (nonmember; Babcock and Wilcox Co., New York, N. Y.): H. M. Cushing has described and given operating results showing the basic reliability and the economy of a power generating station which was well designed to serve as a backlog of reliability for the system. Mr. Cushing and his associates deserve a great deal of credit for initiating and working out details regarding coal handling and storage, pulverizers, feeders, lighting torches, burners, and slag tap furnaces.

The coal handling equipment deserves special consideration. In stand-by plants, where large quantities of coal are stored in overhead bunkers, the problem of spontaneous combustion is always present. This has been avoided by having the storage all out in a pile where it could easily be moved in case of spontaneous combustion, and with no coal, either raw or pulverized, in overhead bins.

The automatic oil lighting torches developed in this station have proved to be a very useful adjunct to a stand-by plant where frequent lightning up and quick response are so important. Such torches are also useful in every pulverized coal installation.

In designing fuel burning and steam generating equipment the problem of efficiency is divided between the combustion of fuel and the absorption of heat. Efficiency in the absorption of heat depends primarily upon the amount of heat absorbing surface one wishes to buy, the amount of which should be a function of the load factor and the fuel cost. Mr. Cushing has obtained adequate efficiency for his load conditions from the absorption of heat, while in the burning of fuel and development of heat he has put in a very efficient plant. The difference in cost between a plant designed for high combustion efficiency and one for moderate or low efficiency is so little that one can never afford to do otherwise than install a plant with good fuel burning efficiency, even with a low load factor. Mr. Cushing has built a low cost plant, but not a cheap plant.

Papers of this kind, written after sufficient period of normal operation, together with tests and operating data, are an invaluable aid to power station designing engineers and equipment manufacturers.

Huntley Station No. 1 was the scene of developing the first slag tap pulverized coal fired furnaces, and the soundness of the principle is evidenced by 80 or more furnaces of this type now being in successful operation. While the author mentioned 2,500 degrees fusing temperature as the upper limit, there are other stations that are successfully handling a somewhat higher fusing temperature. The development of the slag tap furnace has opened up entirely new possibilities in the use of low grade coals, and in the size and design of boiler units.

When the first pulverized coal unit for

Huntley No. 1 was selected 10 years ago, the list of pulverized coal fired plants of any kind were few, and the question of direct firing versus bin system was much debated. Space limitation was an important factor in the earlier installations, but direct firing proved so satisfactory that Huntley No. 2 also used direct firing, as have many other important stations.

Later experience has shown that direct firing has a definite advantage over storage systems in lower carbon loss. With a bin system, particles of coal become packed together, and when fed to the furnace are equivalent to coarser coal than the mill actually produced. This results in a greater carbon loss than prevails in direct firing, with proper pulverization, where each particle of coal is carried separately in the primary air.

The author brings out the question of rapid response of the coal burning equipment and shows that the unavoidable swell of the water in the boiler, due to increased rate of steam generation, limits the rate of load pickup. This problem is being studied more thoroughly, and further improvements can be obtained where conditions warrant.

Since this station was designed 5 years ago further improvements have been made in the reliability of fuel burning and steam generating equipment so that a spare boiler might or might not be needed, depending upon local conditions.

H. C. Albrecht (Phila. Elec. Co., Pa.): The Institute is fortunate in that this paper not only gives the design requirements of this plant and details of how these were met, but also includes results of operating experience for 4 years.

While the advantages of location of this new 60 cycle station adjacent to the existing 305,000 kw, 25 cycle station are listed, no mention is made of the possible disadvantages, from the standpoint of both generation and transmission, of concentrating all steam generation at one point for a system of the ultimate capacity planned.

It would also be interesting to know something of the future plans for the 25 cycle capacity and whether changeover to 60 cycles is contemplated.

It is rather surprising to note that the 80,000 kw generators do not include direct connected exciters. Their advantages have been generally recognized, and on the Philadelphia Electric system experience has been most satisfactory for over 20 years.

The statement is made that the turbine bay with a 100 foot span is designed to accommodate future units up to 200,000 kva tandem type. At Richmond station we are just completing the installation of a 165,000 kw, 183,333 kva tandem unit in a turbine bay with a span of 120 feet and were only able to get it in crosswise by being able to handle the generator rotor through an opening in the building wall into a court between the turbine and electrical bays.

The use of autotransformers rather than higher voltage generators is noted and it would be interesting to know where they are located.

In the supply of auxiliary service from the generator terminals, 2 transformers are used, protected by oil circuit breakers. When installing the 2 60,000 kw units at Richmond station in 1925, we recognized the advantages of supply of essential auxiliaries from generator leads, but also felt it very desirable from a cost and reliability standpoint to make this connection as short as possible. Therefore a single transformer bank was installed directly under the generator leads, eliminating oil circuit breakers and disconnecting switches. Reserve supply is obtained from station busses or an emergency house generator.

The statement that a thorough study of the proper voltage for auxiliary motors showed that a single 550 volt system had decided advantages over other voltages is most surprising. Our studies on the Philadelphia system have indicated that supply of motors over 25 horsepower at 2,300 volts and smaller motors at 220 volts has decided economic advantages, and experience of over 15 years has indicated high reliability. Advantage has been taken of full voltage starting on 2,300 volt constant speed motors.

For the 165,000 kw installation at Richmond now being made, hydraulic couplings are being used on condensate pump, and forced and induced draft fan drive, eliminating resistors and contactors.

D. F. Pennell (nonmember; Brooklyn Edison Co., Brooklyn, N. Y.): Some phases of mechanical design of Huntley Station No. 2 are similar to the lines used in Brooklyn at Hudson Avenue. Large generating units (80,000 kw) were installed and moderately high steam pressures and temperatures were used. The station uses all a-c auxiliary power with no house generators. Provision is made for an emergency supply of a-c power from the Niagara-Hudson system.

The effect of the depression is illustrated here somewhat, as in the revamping of Connors Creek, by a willingness on the part of the designer to take advantage of economies which might have been disregarded in other years. For example, one of the advantages given for placing Huntley No. 2 next to Huntley No. 1 was that economies would result from common use of equipment already installed, such as coal handling equipment, machine shop, first aid rooms. In addition, operating economies were anticipated through co-ordinated supervision and the possibility of a free interchange of operating labor between the 2 stations.

The most interesting point in this paper is the way in which the design has been made to fit the very unusual load conditions under which the station operates. The station with 160,000 kw installed may be called upon to operate a full capacity for prolonged periods or to float on the line due to the fact that it acts as stand-by for hydro stations. Its capacity factors are of interest:

Year	Capacity Factor
1931	8.1
1932	5.7
1933	25.8
1934	22.5

Due to the fact that this station acts as stand-by, it may be called upon for rapid increases in load in emergency. These changes are made at the rate of 10,000 kw per minute. Due to the fact that boilers are pulverized coal-fired they respond rapidly to load changes. Adjustable limits are put on turbine governors to prevent units from picking up enough load in the case of emergency to draw a slug of water over to the turbine. Once the units have picked up to the limit permitted, the operator moves the limit and picks up load on the units at a prescribed rate.

The results of load pickup tests are of great interest. To determine the rate at which load could be picked up, load on one unit was increased from 5,000 to 85,000 kw as rapidly as possible, the load being decreased on the other unit by the same amount at the same time. This transfer of load was made in 33 seconds without evidence of strain on either machine.

A similar test was made on the boilers, the steaming rate of one of the boilers being increased from 110,000 pounds per hour to 320,000 pounds per hour in 2.7 minutes. Under this condition the control shut off the feed water entirely and the boiler water level rose $7^1/_2$ inches. This demonstrated that at this station the allowable rate of load pickup was dependent on the increase in drum water level and not on the increase in combustion rate available. Figures 5 and 6 on page 637 are very interesting to examine.

The heat balance of the machines appears too complicated to install when sacrifices of single cylinder machines were made for saving in space and fixed cost. It would be hard to justify 4-stage feed heating with such a low capacity factor.

A minimum load of 5,000 kw is interesting in connection with an 80,000-kw unit and the features of the design which make it possible would be of interest.

R. A. Hentz (Phila. Elec. Co., Pa.): It was interesting to note from figure 10 that the designers of the switchhouse had adopted the group-phase indoor design. Of the 4 general types of switching station design, namely (a) group-phase indoor, (b) isolated-phase indoor, (c) outdoor, and (d) metalclad, the Philadelphia Electric has had experience at 13.2 kv with all but the latter. In the earlier generating stations the group-phase indoor was used. In the Richmond station, completed about 1925, isolated-phase was employed. However, cost considerations and a bad shutdown experienced with isolated-phase there decided the Philadelphia Electric Company in favor of the outdoor design for the next 13.2 kv switching installation to be built, which was the Westmoreland transmission substation completed in 1928. Unfortunately, space did not permit the use of the outdoor design at the Conowingo hydroelectric generating station, also completed in 1928. Group-phase indoor was used there.

The Westmoreland substation is designed along the same lines as used in the Philadelphia Electric Company's 66 and 220 kv substation; that is, completely outdoor with each of the 2 busses on opposite sides of the station. We have had one case of trouble due to opening a bus disconnecting switch under load. The resulting flash caused such inconsequential damage that the bus was ready to be put back into service in a few minutes, whereas similar faults in indoor compartment design have caused damage that required several hours to clean up. In our opinion the outdoor

design is more reliable and cheaper than indoor, though it does take up more ground area than the indoor type, particularly the isolated-phase construction.

It would be interesting to hear from the author whether such outdoor construction was considered for Huntley No. 2 and the reason for selecting the switchhouse design adopted instead of any of the other types referred to above.

F. W. Gay (United Engrs. and Constructors, Inc., Newark, N. J.): Huntley Station No. 2 has relatively large transformer banks connecting the 22 kv and 110 kv networks. If the station could have been designed with a generator and transformer adjacent, then each generator could have been connected through gang-operated disconnecting switches and relatively short leads to a tertiary transformer winding.

Incremental transformer capacity between the tertiary and 22 kv busses would have been needed and obviously the associated transformer bank would have to be temporarily disconnected each time its generator was connected or disconnected. The autotransformers and their associated 22 kv oil circuit breakers would not have been needed, but, on the other hand, additional 110 kv equipment would probably have been required.

S. M. Dean (The Detroit Edison Co., Mich.): To me the title of this paper seems narrow. What H. M. Cushing has really done is to outline the situation which existed on the Niagara Hudson system in 1929 and to show how Huntley Station No. 2 was designed to fit into that situation. His tabulation of the specific design requirements is excellent.

How the station was designed for quick response to load changes so that it might stand as running reserve for the protection of the western end of the Niagara Hudson system, and more particularly for the city of Buffalo, is most interestingly told. The devices employed to accomplish this quick response, and the curves of performance form a valuable part of the paper.

Also, the necessity for the plant operating at the low and widely varying annual capacity factors inherent in such a combined hydro and steam system and how refinements not consistent with such operation were kept out is nicely brought out. Again, somewhat detailed operating results are tabulated for a range of capacity factors.

While not new in principle, the split bus scheme of electrical connections employed is interesting. The high reactance between sections as used in combination with feeder reactors provides sharply localized voltage disturbances under fault conditions. That is not only desirable from the point of view of the electrical system but also lends itself to the requirements of the power plant auxiliary system in that the voltage disturbances on the main electrical system are not generally distributed over the auxiliaries. It is interesting to see how they accomplished this result.

I note that duplicate busses and switchgear are employed. It would be interesting to know what, in the operating experience of Mr. Cushing's company, caused them to go to this rather large expense in a plant otherwise so carefully designed to keep down costs.

In brief, Mr. Cushing's paper is unusual because it tells a rather complete economic story. It gives the background against which to judge the plant, sets forth the design requirements, shows to what degree these results were accomplished, and gives an idea of what it cost to do so. Such papers are not only useful to designers, but also to system engineers, and by no means their least value is to the younger engineers. It is an excellent paper and I hope we may have more of this character.

C. A. Powel (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): H. M. Cushing's paper is an excellent description of a job well done and covers the subject so thoroughly that there is not much left on which to comment.

It is interesting to note that the engineers' study showed it was more economical to design the generators for 13,800 volts and step-up to 22,000 volts by means of an autotransformer rather than wind the generators for 22,000 volts direct.

In most cases this will be true to a varying degree depending on whether graded insulation can be used in the generator winding or not. Until very large generator capacities are reached, 200,000 kva or more, there is no advantage in raising the voltage above 13,800 if only the generator is considered, but the difficulty of handling heavy currents and the danger of heating in wall beams if the generator and autotransformer cannot be kept in close proximity, will frequently justify the greater cost of high voltage generators even in units of the size here in question (100,000 kva). The split bus scheme used is certainly of advantage and is readily obtainable with an autotransformer. In some cases it may be difficult to obtain the necessary double-winding in a high voltage generator to adapt it to the split bus scheme.

The idea of purchasing the circuit breakers in a factory assembled structure is consistent with modern trends. These structures containing 0–33 and 0–44 breakers are of a simplified design which does not permit of speedy removal of the breaker, but this is justified in view of the bus and breaker arrangement selected and, as Mr. Cushing points out, presents a considerable saving in cost.

A statement is made that on occasion the frequency is regulated from Hell Gate station. It would be interesting to know what measures are taken to control load divisions for this setup.

A. R. Smith (nonmember; General Electric Co., Schenectady, N. Y.): H. M. Cushing's description of the Huntley Station No. 2 is a most complete one and illustrates how carefully their problems were studied in designing the plant and selecting equipment, with the result that they have a most appropriate one for a greatly fluctuating electrical load, which is always a difficult thing to take care of.

It is not clear as to what constitutes a generating unit as covered by table I which gives "hours idle, but unavailable." Perhaps, this includes more than the turbine generator. The record, however, is not a very good one. One of the reasons for a considerable out of service time was to make the turbines capable of quick starting to take care of the variable demand. Both units were found to be smooth at all loads, but No. 2 unit was sensitive to sudden changes in load and consequently much less stable than No. 1, although they were identical machines. In 1932, the rotor was returned to the factory for a thorough examination and some modifications, but the reinstallation of it showed no improvement.

In 1933 the rotor was again returned for a new shaft as a conclusion had been reached to the effect that there must have been some fault in the shaft which gave it such peculiar characteristics. This analysis was apparently correct, as the machine has acted normally ever since.

These 2 occasions on No. 2 unit would account for more than half of the total lost time listed in the tabulation for the 2 machines and were attributable to an unstable forging.

H. L. Wallau (Cleveland Elec. Illum. Co., Ohio): Nine requirements are set forth as having guided the engineering decisions made in the design of this plant. Let us consider them in order:

Rapid response to sudden changes in load. That the turbines selected meet this requirement to an extraordinary degree is shown by the results of the bold test made by the designers after the plant was completed, in which load was transferred from one unit to the other at a rate of 145,000 kw per minute.

The designers are also to be commended upon having devised a method of putting a unit of this size on the line in 25 minutes, if necessary. This time compares most favorably with the 20 minutes required for the Great Western Power Company's 35,000 kw units.

However, when one turns to the boiler plant one finds that due to the selection of a type of boiler with a single steam drum, the change of water level, even with normal steam pressure, limits the rate of pickup under operating conditions to 10,000 kw per boiler, 20,000 to 30,000 kw total, since ordinarily only 2 or 3 boilers would be on the line simultaneously. Had a multi-drum boiler been selected a considerably higher maximum pickup rate would have been feasible. An improvement in rate, if desired, could be obtained by the installation of auxiliary steam drums in the boilers.

This initial requirement, it is stated, called for a simple steam cycle. Four-stage bleeding, with 4 bleeder heaters, 2 evaporators, and an evaporator condenser, does not seem in entire agreement with the premise.

Maximum reliability. This requirement does not seem to have been met, apparently not because of faulty plant design, but because of trouble in major equipment, since the turbogenerator availability factor as determined from table I is 78.6 per cent. It is probable that corrective measures are being applied to improve this ratio.

It must carry its full capacity continuously for months at a time. This requirement, coupled with operating experience at Huntley No. 1, seems to have dictated the installation of a fourth boiler. Experience figures

are quoted showing the availability factors for boilers to be lower than for turbines and from which the conclusion is drawn that for unit type plants availability lies within the probable limits of 80 to 87 per cent. While granting the premises, I cannot agree with the conclusion, because the percentages of nonavailability include "scheduled cleaning and overhaul" and all outages are assumed as noncoincident.

In the case of schedule maintenance the length of outage is often governed by the need or lack of need of the unit for service. A job requiring 160 crew-hours may be done in 4 weeks by a single crew working 40 hours a week, but if the equipment is really needed, 3 crews will be put on, working 24 hours a day, and the job will be completed in one week. The reported availability factors, while based on experience, are low because in many cases there was no need to speed up the repair job.

Also, it will generally be the practice to overhaul both the boiler and turbogenerator units and accessories during the same period, so that even with overlap the total time unavailable will be the duration of the combined jobs from start to completion of both, but not the sum of their individual durations.

From table I the total elapsed time for both generators is found to be 68,841 hours, or an average of 34,420 hours per unit. From table II we find that the boilers were on bank for a total of 61,475 hours, and active for 76,996, hence available for service 138,471 hours, or an average 34,618 hours per boiler, which indicates apparently a 100 per cent availability factor.

Since 3 boilers will carry the full plant capacity the installation of the fourth does not seem justified in the light of this experience.

Low installation cost per capacity. This has been achieved. The total and unit cost is available to any one who will dig it out. Nevertheless, had the fourth boiler been omitted the plant cost would have been lowered by almost 5 per cent. However, the heat cycle chosen and previously referred to is a complex one for a low cost plant. A plant of comparable magnitude, 3 50,000 kw units, designed with but 2 stages of bleeding, no evaporators, no air preheaters, and working at 375 pounds at the throttle, 50 pounds less than Huntley No. 2, operated during the 12 months of 1934 under slightly less favorable conditions than did Huntley No. 2 during the last seven months of 1933, with better thermal economy. The average load was 58.8 megawatts as against 64.5, the capacity use factor 1.2 per cent lower, the net turbine water rate 145 pounds lower, and the Btu per net kilowatt-hour output 13,576 as against 13,812 for the Huntley No. 2 station.

The 4 multi-drum boilers have a maximum steaming rate equivalent to 3 of the Huntley No. 2 boilers. The costs per kilowatt of these 2 boiler plants are practically identical, the actual investment being somewhat less than that of the Buffalo plant. In this plant the saving of the heat loss from the generator air cooler was deemed worth while although the heat loss from the oil cooler is not recovered.

Low operating and maintenance costs. Figure 15 shows total relative costs for various monthly outputs and, making allowances for the fixed charges on the plant investment, this requirement has been reasonably met.

It must supply an expected 100,000 kw load in Buffalo. The criterion that 100,000 kw of load in Buffalo must be carried on this plant could be met with a 3 boiler plant of the type selected, 2 of which could furnish 1,056,000 pounds of steam, so here again the installation of a fourth boiler seems superfluous.

Relatively large units should be used. A choice of units of an individual capacity of about 15 per cent of the system peak load is in line with conservative engineering.

Initial ties of 210,000 kw for local load and 120,000 kw for interconnection. The initial installation of local subtransmission circuits of over 200 per cent of maximum load when these circuits are not only underground but in many cases feeding low voltage networks seems excessive. However, it affected the plant design only in the initial space requirements necessary for housing the 22 kv breakers and in the cost of both. The investment for the 22 kv and 110 kv feeders was kept low and the switch house layout made simple.

Building design must not restrict choice of future equipment. This requirement seems to have been met by the building design provisions which will permit of 200,000 kva tandem units being installed if found desirable so to do.

In conclusion, the most serious defect is the limited capacity of the steam drums of the boilers installed, restricting quick pickup of load, which defect can be remedied by the installation of auxiliary drums. If such a program were undertaken, the presence of the fourth boiler would greatly facilitate the change since 3 boilers would be available for normal operation, 2 of which could handle the maximum load of the Buffalo area.

Rehabilitation of the Conners Creek Plant

Discussion of a paper by R. E. Greene, published in the June 1935 issue, pages 610–17, and presented for oral discussion at the power generation session of the summer convention, Ithaca, N. Y., June 25, 1935.

C. M. Gilt (Brooklyn Edison Co., Brooklyn, N. Y.): The problem presented by the existence of more or less obsolete generating plants and the need for increased capacity is one that will become more pressing for many power companies as load increases during the next few years. The choice must be made between building a new plant and retaining the old for reserve and peak duty, building a new plant and scrapping the old one, or rebuilding the old plant. There is no general solution to the problem but each case must be settled on its merits.

Quite frequently an old plant can advantageously be kept for stand-by and peak load service, thereby postponing the investment necessary for new capacity. Its cost per kilowatt-hour generated may be extremely high and yet its annual cost may be materially less than the carrying charges on the equivalent new capacity. When the time comes that the old plant must be scrapped, it would usually be cheaper if the old plant were nonexistent and one could start fresh with no encumberances. Sometimes the old plant can be rehabilitated for a time at a low cost by changes in parts of the plant, or by superimposing high pressure units, that improve economies or increase the capacity or both.

Rebuilding an old plant usually requires retiring part or all of the old capacity with the result that while the net addition to capital for the modernized plant may not be great, the new money required for the additional capacity may be quite high.

The figures given in R. E. Greene's paper for new money plus the value of equipment from other locations amount to $20,826,610 for an increase in capacity of 150,000 kw, or $139 per kw. However, Mr. Greene states that the old plant would have to be retired shortly under any program, and would be of little value in the meantime. Recognizing the necessity for this retirement, 150,000 kw increased capacity has been obtained for $13,884,755 net addition to capital, or at $92.50 per kw, and a modernized and more efficient plant of 330,000 kw capacity has been obtained with a total book value of $30,367,200 or $92 per kw, a cost per kilowatt about the same as that of the old plant.

Comparing these figures with costs of totally new plants, it would appear that the choice of obtaining the added capacity by rebuilding the old plant rather than building a new one to supplement it was largely determined by the judgment that the old plant should be retired under any condition, plus the fact that by gradually rebuilding the old plant, the large initial expenditures associated with starting a new station would be avoided.

It would seem evident that a load district method of operation in which each generating station largely supplies its own district load, furnishes an incentive toward more rapid rebuilding or scrapping old plants than one in which new and economical plants feed the system as a whole and old plants can be relegated to short hour use as reserve or peak duty for the system as a whole.

C. A. Powel (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): Rehabilitation is always interesting because the problems it presents are much more difficult than in building a new plant. R. E. Greene's company selected a method of rehabilitation which worked out particularly well in their case because they were able apparently to utilize a great deal of the existing parts in the rebuilt assembly. I wonder if, under the circumstances, the statement is justified that high pressure units superimposed on the old machines would have resulted in higher maintenance and lower reliability, inherent in old equipment. In any scheme of rehabilitation if it is to be economical, considerable old equipment must be retained and the weak member in reliability may not be the main units. With superimposed turbines the life of the existing equipment enters the problem to no greater degree than it would if the station were left at its original pressure. When the decision has been made to replace the old boilers by higher pressure units, the question of the old turbinegenerators should be treated as a separate problem. The turbines need

not be rebladed or the generators rewound any sooner because of the superimposition of high pressure equipment, and these operations are about all that is necessary to maintain the life of the units almost indefinitely.

D. F. Pennell (nonmember; Brooklyn Edison Co., Brooklyn, N. Y.): The most interesting point for consideration in the paper on Connors Creek plant is the amount of old equipment it was possible to use in the rehabilitation. The following pieces of equipment were used of the original plant:

a. Building and foundations (with addition to turbine room).

b. Stacks.

c. Coal handling equipment.

d. Condensing equipment including condensers originally installed with 20,000 kw units but adapted to 30,000 kw units by use of improved tube layouts and extraction heaters, also condenser auxiliaries

e. Circulating water tunnels.

In addition to this, 2 30,000 kw generators were used that had been salvaged from Connors Creek and Delray No. 2.

Included in the construction of the new machines are the exhaust casings of 3 of the 20,000 kw units and the pillow blocks of the old 30,000 kw units. Nearly all the piping, including service piping, had to be replaced to meet the new requirements.

In spite of the amount of this equipment it was possible to salvage, the installed cost per kilowatt-hour does not reflect any great saving.

Original capacity	180,000 kw
Expected capacity	330,000 kw
Increase	150,000 kw
Net increase in book value = $13,880,000	
Cost per kw increased capacity = $92.50	

It appears that with the same investment 2 large units might well have been installed giving the same increase in capacity and thermal economy and that these units could have been added when, as, and if needed without interrupting normal operation of the old plant.

One statement made by R. E. Greene is interesting to note. He says, "At the start it was recognized that certain predilections existed in the minds of the operating staff, and it was agreed that these should be tested and followed out only when found to be sound." As a matter of practical design, it might be better to reverse this and follow these so-called predilections unless they prove on analysis to be unsound.

The author also states "the electrical system of the Detroit Edison Company is divided into load areas interconnected by ties for mutual help in emergencies." This electrical layout of the Detroit system appears to give the plant designer a somewhat different angle of attack than we would have in Brooklyn. It complicates the problem by making it necessary to predict not only changes in system load but to predict where these changes will occur. In New York, however, we build for the system load and due to adequate interconnections have the economy resulting from interchange of power. By this method we are able to supply the system base load with the most modern generating equipment, taking advantage of the economy of first cost and operation that goes with large generating units and using older stations for stand-by and peak load capacity.

One reason given for revamping the old plant is that in addition to high maintenance costs the "reliability would be not of high degree." This is a minor point but I feel that our experience is that old equipment properly maintained gives a satisfactory degree of reliability. Oftentimes it is more reliable than new equipment that tends toward the experimental.

Complex Hyperbolic Function Charts

Discussion of a paper by L. F. Woodruff published in the May 1935 issue, pages 550–4.

A. E. Kennelly (Harvard University, Cambridge, Mass.): The charts offered in the paper will be serviceable to transmission engineers and to all those who are interested in alternating current lines having at operating frequency an angle not exceeding 0.4 in size.

The charts possess an unusual feature from a mathematical standpoint. In order to find certain desired trigonometrical functions of the line angle θ $\left(\text{namely } \cosh\theta, \frac{\sinh\theta}{\theta}, \text{ and/or } \frac{\tanh\theta/2}{\theta/2}\right)$ one enters the curvilinear system of each chart with the size and slope of θ^2; i. e., $|ZY|$ and $\overline{ZY}$, then reading off the size and slope of the function on the semirectilinear ruled background. This unusual procedure reasonably claims a lessening of time and effort in the process.

The Sparkless Sphere Gap Voltmeter

Discussion and authors' closure of a paper by R. W. Sorensen, J. E. Hobson, and Simon Ramo, published in the June 1935 issue, pages 651–6, and presented for oral discussion at the selected subjects session of the summer convention, Ithaca, N. Y., June 27, 1935.

A. O. Austin (consulting engr., Barberton, Ohio): The authors have carried out a very effective method of checking root mean square values with means at the disposal of practically any high voltage laboratory. Anyone making high voltage measurements is continually running up against conditions upon which it is desired to make a check, and since the method involves no elaborate equipment it can be readily carried out. Where the wave form is good the method may be used for checking crest values. It would seem that the method is primarily applicable for calibration purposes. The capacitance calculations of the sphere gap can also be used very effectively for determining crest voltages which I believe have a wider application than the determination of root mean square values. With the close control of frequency the determination of voltage with an ammeter in series with a capacitor of known capacitance is very simple.

While the capacitance tap on bushings or condensers is one of the most useful methods in determining high voltages in the laboratory, it is necessary that the capacitance of the condenser supplying current to the insulating instrument does not change with voltage due to corona from the leads or field et up by external objects. It is hoped that the calculations in connection with the capacitance of spheres will be carried further and limits established so that the sphere gap may be used as a capacitor for direct checks upon the crest voltage. This is based upon the fact that $I = EC\omega$, hence $E = \frac{I}{C\omega}$. This method has proved to be very useful and makes it unnecessary to subject equipment under test to an oscillation following a discharge of a parallel gap.

The accuracy of this method of determining crest values depends primarily upon the accuracy of the capacitor. R. W. Sorensen's calculations would indicate that the sphere gap may be used to supply the needed capacitance. Irregularities which affect the discharge of a sphere gap also have an effect upon its capacitance, and will have to be determined within fairly close limits. It is to be hoped that R. W. Sorensen will continue his work and determine the necessary limitations. With a capacitor of known capacitance it is possible to use a ballistic method to determine transient voltages to advantage in many cases. With R. W. Sorensen's method it would be possible to show some of the irregularities of the sphere gap and to obtain a further check upon calibration curves.

For normal frequency tests it has been evident that the needle gap gave far more consistent results based upon transformer ratio than sphere gaps for normal frequency determinations up to 350 or 400 kv. The capacitance measurements for the sphere gap calls attention to the errors which may occur where an attempt is mane to measure crest transient voltages with a resistance in series with a gap.

It is to be hoped that the work outlined in the paper will be continued, and that the advantages and limitations of the various methods will be given due consideration as a single method will not give the best results for all conditions.

J. R. Meador (General Elec. Co., Pittsfield, Mass.): The authors have presented a very interesting paper on voltage measurement. It is especially timely since the A.I.E.E. standard sphere gap calibration curves are now being revised. It is important to have data taken by as many different methods as possible. Using the method of voltage measurement described by the authors, a check can be made on the 60 cycle calibration curves for sphere gaps, which have been recently recommended ("Calibration of the Sphere Gap," J. R. Meador, ELEC. ENGG. (A.I.E.E. TRANS.), v. 53, June 1934, p. 942–8; "Impulse Calibration of Sphere Gaps," P. L. Bellaschi and P. H. McAuley, *Elec. Jl.*, v. 31, June 1934, p. 228–32).

Although the experimental curve in figure 4 does not agree closely at large spacings

with the recommended curves mentioned above, it is about what should be expected if the position and mounting of the 100 centimeter spheres are considered. In figure 1, I have shown curves illustrating the general effect of gap position. These curves show the 60 cycle spark-over of a 50 centimeter sphere gap, (1) vertically mounted with the

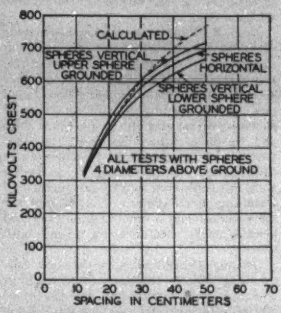


Fig. 1. 60-cycle spark-over of 50 centimeter sphere gap having one sphere grounded

lower sphere grounded, (2) horizontally mounted with one sphere grounded, and (3) vertically mounted with the upper sphere grounded. In all tests the spheres were approximately 4 diameters above ground. For comparison the calculated calibration curve for one sphere grounded is included.

The curve for horizontally mounted spheres agrees fairly closely with the calculated curve up to 40 per cent of diameter spacing. Above this spacing the test curve falls below the calculated curve by 3 per cent at 60 per cent of diameter spacing and by 7 per cent at 80 per cent of diameter spacing. The authors' figure 4 appears to have very similar characteristics. For spacings above ground of more than 4 diameters the difference between the calculated and tested curves probably should be slightly less. The curve in figure 1 for vertically mounted spheres having the upper sphere grounded shows a condition in which the effect of ground is considerably reduced.

I would suggest that the authors use their 100 centimeter spheres as the measuring device for calibration of other sizes of spheres having a more conventional mounting. Where voltages of a large range of magnitude are to be measured, several sizes of sphere gaps are necessary and it is usually more convenient to have them mounted in portable frames.

In connection with the use of this method of voltage measurement for apparatus testing, I would like to ask the authors whether the voltage can be raised to a predetermined value without adjustment of the weights. That is, is it necessary to raise the voltage and then measure it by adjusting the weights, or can all adjustments for a certain voltage be made before voltage is applied?

The principal advantages and disadvantages of the sparkless sphere gap voltmeter for general high voltage measurements, that were not mentioned by the authors, appear to be as follows:

ADVANTAGES

1. For high potential tests on completed apparatus the spark-over of a gap at the apparatus terminals is eliminated.

DISADVANTAGES

1. The device does not appear to be portable.
2. The wave shape of the applied voltage must be known since certain types of loads may distort the 60 cycle voltage wave appreciably.

J. B. Whitehead (Johns Hopkins Univ. Baltimore, Md.): The use of the electrostatic attraction principle for the measurement of voltage is old. The Kelvin absolute electrometer was one of the earliest methods proposed for the measurement of voltage. As an absolute instrument it has the great advantage that its calibration may be computed from its dimensions. In recent years various forms of the electrostatic instrument have been proposed for the measurement of very high values of voltage. Most of these like the Kelvin instrument are equipped with guard rings and when the electric field at the surface of the moving element is uniform, the calibration may be computed.

Professor Sorensen's proposal to measure voltage by the force of attraction between the 2 spheres of a sphere gap greatly extends the area of the attractive surfaces, thereby increasing the force of attraction and so extending the range of the instrument. However, it is not possible to compute the calibration; this must be separately determined owing to possible influence from surrounding objects, and in any event to the influence of the supports, on the distribution of the total field. That these effects need not be great in the lower range of any particular gap is shown by the agreement between his observations and those determined by the spark-over.

The curve shown between attractive force and voltage for any particular gap setting is interesting, in that it contains a maximum of force with decreasing value above a definite voltage. I venture to suggest the possible influence of space charges in explaining this apparent discrepancy. At the higher voltages local, and generally invisible point ionization may be expected from minute irregularities on the surface. The velocities of the resulting ions may be so great as to cause appreciable gaseous space charges near the sphere surfaces in each half cycle, which would have as their result higher values of gradient at the surfaces than that corresponding to the undisturbed field and so a counter polarizing e.m.f. over the total gap. Unequal potential gradients under alternating stress in solids has recently been reported by Böning.

Eric A. Walker (Tufts College, Medford, Mass.): The authors have made some refinements on a well known principle for measuring voltage. A high voltage voltmeter, electrostatic in character but having a different method for measuring the torque, was constructed some 10 years ago by Prof. C. L. Dawes at the Harvard Graduate School of Engineering. The general scheme was as follows: 2 25 centimeter spheres were used, both being insulated from ground, having between them a variable air gap. Between these spheres was supported on a galvanometer suspension a mechanism consisting of 2 3 centimeter spheres fixed to the ends of a metal rod about 10 centimeters in length. The center of the rod was soldered to the suspension so that the rod and spheres hung in a horizontal plane. The suspension was so oriented that normally the smaller spheres hung perpendicular to the center line of the large ones. When the potential was applied to the larger spheres the suspended mechanism would rotate and tend to line up with the electric field due to the attraction of the induced charges. A small mirror was mounted on the suspension and a beam of light so focused that its reflection from the mirror fell on a calibrated scale. This scale consisted of a strip of transparent celluloid bent so as to include about a 120 degree arc of a circle having a radius of 3 meters. As there was some tendency to oscillate in the suspended mechanism at low frequencies, 10 to 25 cycles per second, a dash pot and vane was fastened to the lower end to damp out any vibration. The high voltage elements were all electrostatically shielded.

By the mechanism the root mean square value of any high voltage wave could be read quite accurately. Unfortunately this type of meter does not have a linear calibration curve. No mathematical analysis of its performance was attempted but the meter was calibrated for various gap settings by means of a high voltage transformer, having a tertiary or voltage coil, which was fed from a sine wave generator. The meter was used for measuring continuous battery voltages up to 50 kv.

This meter has little value in breakdown tests on insulation unless the wave form of the testing voltage is known. Moreover, if the wave form is known, and does not change with voltage, the peak voltage may readily be calculated from the value indicated by the tertiary of the transformer.

K. B. McEachron (General Elec. Co., Pittsfield, Mass.): It seems to me that any method from which the geometry of the active parts may be calculated without the use of empirical relations should be of more fundamental nature than the sphere gap now in use. Therefore, I am of the opinion that other laboratories should follow the invitation given in the paper to check and extend this method of voltage measurement. Such work is to be undertaken in the high voltage engineering laboratory at Pittsfield, Mass.

However useful this method may be as a standard, I do not believe that it will supplant the sphere spark gap, particularly in the large sizes, on account of the greater space which would undoubtedly be required and its inability to measure transients.

No doubt ballistic measurements could be made which would give some measure of transients, but since the crest of the wave is desired and the wave shape may be unknown the ballistic method does not appear to be promising.

Conclusion 6 of the paper may be difficult to carry out when testing apparatus which flashes over as a part of the test since oscillations are frequently set up which will cause a flashover of the sphere gap even when the spacing is relatively large compared to the normal frequency sparkover potential.

For tests involving flashover it would be more desirable to have the sphere gap indicate crest potential rather than effective, since frequently the wave form may be seriously affected by the test piece.

The freedom of corrections for air density now applied to the sphere spark gap constitutes a definite advantage for the method described in the paper.

More data should be obtained with reference to the effect of surroundings and method of mounting the spheres whether vertical or horizontal. Additional data will also be needed on other sizes of spheres. All of this is work which should be undertaken by other laboratories to supplement and extend the work of the authors.

W. A. Hillebrand (Univ. of Calif., Berkeley): In spite of its limitations, the sphere gap as a spark gap voltmeter will continue to be used for 2 reasons, convenience and the fact that it measures crest values. However, the authors' demonstration that a pair of spheres may, with comparatively little auxiliary apparatus, be used as an electrometer with a high degree of accuracy, is a welcome contribution to the technique of high voltage measurement because it affords an independent calibration of the spark gap voltmeter or of a testing transformer itself.

Since the force between the spheres varies as the square of applied voltage, a one per cent voltage fluctuation results in a 2 per cent variation in attractive force. The resulting displacement tends to alter the force in the same direction, so that the method is inherently unstable unless the applied voltage is quite steady. Although the authors indicate that such fluctuations are rendered unimportant by the inertia of the spheres themselves, I would like to be reassured on this point. Can the authors indicate the permissible range of voltage fluctuation within which it is possible to use the sphere gap satisfactorily as an electrometer?

Also, have the authors made any calculation of the attractive force between 25 centimeter spheres up to 250 kv root mean square?

R. W. Sorensen: The many encouraging comments regarding the value of re-establishing a voltmeter which can utilize the mechanical forces between charged bodies as a measure of voltage, and the willingness of others to include work with the nonarcing sphere gap in their research programs are indeed pleasing rewards for the work done in presenting this paper. Its authors have had a real delight in watching the first simple experiment in their program (which consisted simply of suspending one sphere by a long rope near a second sphere rigidly mounted, applying potential to these spheres and noting the motion of the free one) grow into a device which gives very satisfactory readings of what may turn out to be true voltage values, although as yet we do not feel that sufficient work has been done to warrant calling our figure 4 a calibration curve. The reasons why this should not be done are insufficient cross checking to date with present accepted voltage standards for sphere gap sparking distances; the lack of other convenient standards with which to compare these results, and the fact that our laboratory conditions were such as to cause us to get our spark-over values of voltage with the spheres in a horizontal position rather than mounted vertically according to standard practice. If the relation between readings made with spheres horizontal and readings made with spheres vertical is the same for 100 centimeter spheres as that shown for the 50 centimeter spheres by Mr. Meador in his discussion, we will indeed find to the gratification of everyone our tests in close agreement with the proposed new A.I.E.E. sphere-gap spark-over values.

In response to J. R. Meador's suggestion that we use our 100 centimeter sphere nonsparking arrangement to check other sizes of spheres with conventional mountings, may I say that we are proceeding to do that very thing, and have already purchased for such tests a pair of 50 centimeter standard spheres.

Answering Mr. Meador's question, I would like to state that we can very conveniently place on the weight pan the proper weight for any given voltage and then raise the voltage to the value required to give a pull that will balance the weight.

The portability of the spark-over sphere gaps is a real factor in its favor and is a feature not too easily embodied in the design of nonarcing gaps, but I am not ready to say means will not be found whereby nonarcing gaps may be made portable. Also, it seems to me most of the 100 centimeter sphere gaps I have seen are quite securely mounted on brackets attached to building walls and hence are not very portable. Perhaps when we get acquainted with small force measuring gaps we will find ways for making them almost as portable as are the arcing sphere gaps of like size, hence it may be that even though our enthusiasm for the nonarcing gap has been based on its possible use as a primary standard supplementing the arcing sphere rather than supplanting it as questioned by K. B. McEachron, the authors of the paper have a sincere expectation of a rather wide run of nonarcing sphere gaps in high voltage testing.

Ballistic measurements for transients are a consummation greatly desired with this type of apparatus, and have been considered by the authors. In fact, a rather active program of investigation along those lines is now in progress. In this work there are difficulties set up by low mass desideratum for moving parts and features of construction and reading methods, but we still have hopes of finding solutions for these problems. For transients, particularly for very erratic wave forms I can quite agree with Mr. McEachron that crest potentials rather than effective voltage values are desirable, but for steady state or power frequency voltage testing it is highly probable that as our knowledge of the relations between voltage and insulation strength develops we will be more interested in effective rather than peak voltage values.

We have already set up models of rooms and sphere gaps for use in testing the effect of surroundings upon the forces between charged spheres and will have data from tests in due time. At the present moment I can report that we have found by a trial test with a $^1/_8$ scale model of our high voltage laboratory in which we use 12.5 centimeter spheres that voltage variations which cannot be noted on an ordinary a-c portable voltmeter cause more variation in the force between the 2 12.5 centimeter spheres than is caused by metal plates set up to represent the laboratory walls and ceiling. Arrangements are now being made to excite the transformers with a more constant voltage supply. We have used in our laboratory the method of measurement described by E. A. Walker and do not consider it as satisfactory for our purpose as the method we have described.

Dr. J. B. Whitehead's remark in speaking of guard rings reminds me of the great "bugaboo" we encountered in our plans for using some form of electrostatic meter. We considered electrodes of many forms and one by one abandoned them in favor of spheres with no attempt to use guard rings and we have realized our hope that surrounding objects would not produce enough disturbance to cause trouble. Our success with the spheres is due to my method of mounting which allows a free swing of the moveable sphere in one direction only and permits large clearance all about both spheres.

Our experience indicates that the surrounding objects influence force readings less than spark-over values and hence are less objectionable for our use of spheres than for the sphere gap voltmeter using spark-over distance as a measure of voltage. Also, I would disagree with Doctor Whitehead's statement concerning accuracy of calibration computations.

We feel quite certain that laboratory tests are going to show that the effect of surrounding objects, walls, etc., and even the effect of supporting shanks for the spheres, can be accurately calculated and accounted for in calculating the relation between force readings and voltage, with nonarcing sphere gaps.

The curve of figure 9 may teach us several lessons, one of which is why the spark gap voltmeter gets erratic at the larger spacings, but I doubt if we are at present prepared to say why the field strength and its influence on the force between spheres takes just the form shown by the curve.

We have made no checks to determine the permissible range of voltage fluctuations possible and cannot therefore exactly answer W. A. Hillebrand's first question, but in our work we have considered our source of voltage free from fluctuations to the extent required for good work. After a little experience with the nonarcing gap, one can by that means read voltages quite quickly, also the variations in voltage are gradual rather than sudden and are such that, as I have mentioned, they are quite unnoticeable on an ordinary portable voltmeter connected to the testing transformer voltmeter coil. I do not have with me a calculation for the forces between 25 centimeter spheres at different voltages, but such calculations may be quite readily made, as figure 8 and table III are applicable to any size spheres, simply by multiplying the sphere gap setting by the factor $R/50$ where R is the sphere radius in centimeters.

In conclusion may I point out that the deviations mentioned in the first paragraph of the résumé in our paper are caused by the erratic behavior of the spark gap voltmeter and not the sparkless gap voltmeter. The curve of figure 9 is the envelope of the ends of the curves of figure 10, and figure 4 is not to be considered as a calibration curve.

News

Of Institute and Related Activities

Great Lakes District Meeting and Student Branch Convention

THE meeting of the Great Lakes District of the A.I.E.E. will be held at Purdue University, West Lafayette, Ind., on Thursday and Friday, October 24 and 25, 1935. The Friday morning session of this convention will be devoted to the best papers selected from the various Student Branches of this District. All meetings, with the exception of the dinner meeting, will be held in the new electrical engineering building on the North Campus (directly on route 52 and 152 between Chicago and Indianapolis). Conference and club facilities including meals are available in the Purdue Memorial Union Building, 2 blocks from the meeting place. A varied technical program, a dinner, dance, inspection trips to the factory of the Duncan Electric Manufacturing Company in Lafayette and the various buildings and laboratories of the university have been arranged during the 2 day session to be followed by the university home-coming program and football game with Carnegie Institute of Technology on Saturday.

Technical Program

As may be observed from the accompanying tentative technical program, a wide variety of papers has been scheduled for presentation and discussion, most of which have had the approval of the national technical program committee and are being published in Electrical Engineering.

During the first session are included motor and meter design, motor starting methods and distribution problems. Particularly will the recently developed single phase and polyphase meters warrant an interesting discussion.

The second session is devoted to the very timely discussion of vacuum and luminous tube circuit theory and applications. "The Relaxation Inverter," recently described in Electrical Engineering, will be presented for further attention with new developments added by the author, Dr. H. J. Reich of the University of Illinois. Dr. C. S. Roys of the graduate staff of Purdue University, who is coauthor with Dr. Reich of a forthcoming textbook on electronics, and Dr. C. B. Aiken, formerly of the Bell Telephone Laboratories, who has recently joined the staff of the school of electrical engineering of Purdue University, will lead the discussion of this and possibly other papers of this group. "Firing Time of an Igniter Type of Tube" and the analysis of rectifier circuits by means of Fourier's series, both developments of the University of Michigan, have been approved as worthy contributions to the solution of these timely problems, while the University of Iowa presents a new electrostatic audio-frequency generator. Industry is also served by the discussions of applications of thermionic control to steel mill operations and of luminous lighting developments.

Previous District meetings have awakened the older generation of engineers to the worthy competition from Student members. The selected best papers, prepared by the Students of many of the universities of this District as listed upon the Friday morning's program, are no exception to this experience as to variety and quality of novel electrical engineering development. This is not a parallel session. All those registered will profit by the Student session.

Purdue University has specialized for many years in extra-high-potential research including the design, construction, and calibration of the surge generator, its accompanying cathode ray oscillographs and later the specialized development of the sealed-off cathode-ray oscilloscope with double image possibilities and its application to television. These will be discussed in papers and demonstrations to be presented by Prof. R. H. George and other local staff authors during the Friday afternoon session, while the University of Wisconsin contributes a study of potential distribution control over insulators, appropriately grouped under this specialized subject. The latest of a long series of lightning investigations on transmission lines, made by Lewis and Foust and published by the Institute, concludes this high potential program.

The oral discussion of these papers at the meeting in the foregoing manner is desirable but only discussion which is pertinent to the papers which have been published in advance will be acceptable for consideration for publication. Rules governing discussions of both unpublished papers and published papers are given in the following paragraphs on "Rules for Presenting and Discussing Papers."

Rules for Presenting and Discussing Papers

In general, the time allowed for the presentation of each paper should not ex-

Summarized Schedule of Events

Wednesday, October 23

7:00 p.m. — Dinner and conference for national, District, and Section officers as guests of Purdue University

Thursday, October 24

9:00 a.m. — Registration (Electrical engineering building)

9:30 a.m. — Opening Meeting. G. G. Post, vice president, A.I.E.E. Great Lakes District, *presiding*. (Main lecture hall, electrical engineering building)
Welcome: Dr. A. A. Potter, dean of schools of engineering, Purdue University
Technical Session: General Applications

12:00 noon—Adjournment (Luncheon available in Chestnut Room or cafeteria of Purdue Memorial Union Building)

12:15 p.m. — Luncheon meeting of the District executive committee

1:00-2:00 p.m. — Inspection trip leaving Purdue Memorial Union Building for campus and laboratories

2:30 p.m. — Technical Session: Electronic Tube Theory and Practice

4:30 p.m. — Adjournment

7:00 p.m. — Dinner, ballroom, Purdue Memorial Union Building. Dr. E. C. Elliott, president, Purdue University, H. H. Henline, national secretary, A.I.E.E., and other A.I.E.E. officers, speaking.

Friday, October 25

9:00 a.m. — Student Technical Session

12:00 noon—Adjournment (Luncheon available in Chestnut Room or cafeteria of Purdue Memorial Union Building)

12:15 p.m. — Luncheon meeting of committee on Student activities and Student Branch chairmen

1:00-2:00 p.m. — Inspection trip leaving Purdue Memorial Union Building for Duncan Electric Manufacturing Company factory in Lafayette

2:30 p.m. — Technical Session: High Potential Measurements

4:30 p.m. — Adjournment

5:00 p.m. — Television demonstration, lecture room 254, second floor, electrical engineering building, R. H. George and H. J. Heim, Purdue University

9:00 p.m. — Home-coming mixer dance, Ball Room, Purdue Memorial Union Building

Saturday, October 26

Morning—Informal university inspection and home-coming program

2:00 p.m. — Ross Ade Stadium, football game, Purdue University versus Carnegie Institute of Technology

Tentative Technical Program

In the following program, reference to the issue and page in ELECTRICAL ENGINEERING is given for all papers which have been published therein. Others may be published in subsequent issues.

Thursday, October 24

After 9:30 a.m. Opening Meeting—Technical Session: General Applications. G. G. Post, vice president, A.I.E.E., and Dr. C. F. Harding, Purdue University, *presiding*. (Main lecture hall, electrical engineering building)

Address: DARE WE BECOME EFFICIENT? J. W. Esterline, president, Esterline-Angus Co., Indianapolis, Ind.

SPLIT-PHASE STARTING OF 3-PHASE MOTORS, G. P. Tracy and W. E. Wyss, The University of Wisconsin Scheduled for Oct. issue

A NEW WATTHOUR METER, Stanley Green, Duncan Electric Mfg. Co. Scheduled for Oct. issue

MAGNETIC FIELDS IN MACHINERY WINDINGS, J. F. H. Douglas, Marquette University Sept. issue, p. 959–66

LOADS ON DELTA-CONNECTED TRANSFORMERS WITH MID-TAPS, N. G. Larson, Commonwealth Edison Co. Sept. issue, p. 931–4

* A-C ELECTROLYTIC CAPACITORS, C. F. Lomont and F. S. Dunleavey, The Magnavox Co. Scheduled for Oct. issue

12:00 noon—Adjournment (Luncheon available in Chestnut Room or cafeteria of Purdue Memorial Union Building)

12:15 p. m.—Luncheon Meeting of the District Executive Committee

1:00-2:00 p. m.—Inspection trip leaving Purdue Memorial Union Building for campus and laboratories

2:30 p. m.—Technical Session: Electronic Tube Theory and Practice. C. A. Cora, chairman, Central Indiana Section, A.I.E.E., and Dr. C. B. Aiken, Purdue University, *presiding*. (Main lecture hall, electrical engineering building)

* CHARACTERISTICS OF LUMINOUS TUBE CIRCUITS, C. M. Summers, General Electric Co.

AN ELECTROSTATIC AUDIO GENERATOR, E. B. Kurtz and M. J. Larsen, University of Iowa Sept. issue, p. 950–5

ANALYSIS OF RECTIFIER FILTER CIRCUITS, W. B. Stout, University of Michigan Sept. issue, p. 977–84

Address: RECENT ELECTRICAL DEVELOPMENTS IN THE STEEL INDUSTRY, R. H. Wright, Westinghouse Electric and Mfg. Co.

FIRING TIME OF AN IGNITER TYPE OF TUBE, W. G. Dow and W. H. Powers, University of Michigan Sept. issue, p. 942–9

THE RELAXATION INVERTER, H. J. Reich, University of Illinois Dec. 1933 issue, p. 817–22

4:30 p. m.—Adjournment

7:00 p. m.—Dinner—Ball Room, Purdue Memorial Union Building, E. C. Elliott, president, Purdue University, H. H. Henline, national secretary, A.I.E.E., and other A.I.E.E. officers

Friday, October 25

9:00 a.m.—Student Technical Session. E. B. Kurtz, University of Iowa and A. N. Topping, Purdue University, *presiding*. (Main lecture hall, electrical engineering building)

PARALLELING OF COMPOUND GENERATORS WITHOUT EQUALIZER, John Miles and J. F. Palm, Michigan College of Mining and Technology

SINGLE PHASE MAGNET DESIGN, W. L. Ringland, Purdue University

THE MAGNETRON ON ULTRA-HIGH FREQUENCIES, P. E. Haggerty, Marquette University

STRUCTURE AND OPERATION OF THE CHICAGO INTERCONNECTED SYSTEM, Charles McNamara, Lewis Institute

DEVELOPMENTS IN THE GENERATION AND DISTRIBUTION OF POWER AND THEIR EFFECT UPON THE CONSUMER, David R. Bair, University of Iowa

ANALYSIS OF LIGHTNING ARRESTER VOLT-TIME CURVES, A. W. Rankin, Purdue University

A DIFFERENT METHOD OF DETERMINING REACTIVE VOLT-AMPERES IN A THREE-PHASE THREE-WIRE SYSTEM, A. S. Webeck, University of Illinois

THE USE OF THE QUARTZ CRYSTAL IN RADIO COMMUNICATION, B. E. Montgomery, Iowa State College

A NEW VACUUM WATTMETER CIRCUIT, J. F. Chandler and J. C. Cunningham, Purdue University

DESIGN OF CORNICES FOR BUILT-IN LIGHTING, W. H. Budd, University of Michigan

SWEEP-FREQUENCY LIMITS OF GASEOUS DISCHARGE TUBES, W. A. Dipp, University of Illinois

THE ALUMINUM ELECTROLYTIC CONDENSER, W. A. Brastod, University of Minnesota

COLOR ORGAN, Brice Gilman, Milwaukee School of Engineering

STREAMLINING, Maurice Swanson, University of Wisconsin

MODULATION IN RADIO-TELEPHONY WITH A NOTE ON THE PHYSICAL SIGNIFICANCE OF SIDE BANDS, Cyril Baranovsky, University of Minnesota

12:00 noon—Adjournment (Luncheon available in Chestnut Room or cafeteria of Purdue Memorial Union Building)

12:15 p.m.—Luncheon Meeting of Committee on Student Activities and Student Branch Chairmen

1:00-2:00 p.m.—Inspection trip leaving Purdue Memorial Union Building for Duncan Electric Manufacturing Company Factory in Lafayette

2:30 p. m.—Technical Session: High Potential Measurements. A. G. Dewars, secretary, A.I.E.E. District 5; O. Kiltie, chairman, Ft. Wayne Section, A.I.E.E., and D. D. Ewing, Purdue University, *presiding*. (Main lecture hall, electrical engineering building)

* THE PRODUCTION OF IMPULSE VOLTAGES FOR SURGE TESTING, C. S. Sprague, Purdue University

CONTROL OF POTENTIAL OVER INSULATOR SURFACES, Edward Bennett and G. L. Fredendall, University of Wisconsin Scheduled for Oct. issue

* THE PURDUE CATHODE-RAY OSCILLOSCOPE WITH AN ELECTRONIC SWITCHING CIRCUIT FOR THE SIMULTANEOUS OBSERVATION OF 2 WAVES (Demonstration), R. H. George, H. J. Heim, and C. S. Roys, Purdue University, and H. F. Mayer, General Electric Co.

THE EFFECT OF ULTRAVIOLET ON BREAKDOWN VOLTAGE, G. L. Nord, Western Railroad Supply Co. Sept. issue, p. 955–8

LIGHTNING INVESTIGATION ON TRANSMISSION LINES—V, W. W. Lewis and C. M. Foust, General Electric Co. Sept. issue, p. 934–42

5:00 p.m.—Television demonstration, lecture room No. 254, second floor, electrical engineering building, R. H. George and H. J. Heim, Purdue University

9:00 p.m.—Home-coming mixer dance, Ball Room, Purdue Memorial Union Building

Saturday, October 26

Morning—Informal university inspection and home-coming program

2:00 p.m.—Ross Ade Stadium, football game—Purdue University vs. Carnegie Tech.

* These papers may be presented but they have not been accepted for publication at the time of going to press.

ceed 10 minutes unless otherwise arranged with the chairman of the program committee, Dr. C. F. Harding, Purdue University, West Lafayette, Ind., or unless the presiding officer meets with the authors preceding the session to arrange the order of presentation and allotment of time for papers and discussion. Each speaker unannounced by the presiding officer is to step to the front of the room and announce, so that all may hear, his name and professional affiliation.

Discussion of Unpublished Papers. Those wishing to discuss any of the unpublished papers should write to Dr. C. F. Harding (at the above address) for mimeographed copies. It is suggested that discussers be limited to 10 minutes each, and preference will be given to those who have sent copies in advance to Doctor Harding, chairman of the program committee. After these discussions have been given, the meeting will be opened for general discussion. The discussions of the unpublished papers will not be considered for publication.

Discussion of Published Papers. The same procedure governing the presentation of discussions of published papers should be followed as for the unpublished papers except that the written discussion to be submitted for consideration of publication should not be longer than the equivalent of 5 minutes' reading time. Discussion to be considered for publication should be based only upon the published papers and it must be submitted in triplicate (one of these copies to be the original, typed double spaced) to C. S. Rich, secretary of the technical program committee, A.I.E.E. headquarters, 33 West 39th St., New York, N. Y., on or before November 8, 1935. Discussion received after this date will not be accepted.

CONVENTION DINNER

Tickets at $1.50 per plate should be secured as early as possible at the Registration desk for the dinner to be held in the ballroom of the Purdue Memorial Union Building on Thursday evening at 7:00 p.m. Music and other entertainment will be provided during the dinner and brief remarks by President E. C. Elliott of the university, and the A.I.E.E. national officers will be enjoyed. The women are particularly invited to attend this dinner. No provision for dancing has been made for this evening as the customary home-coming dances may be enjoyed by all in attendance on the following Friday and Saturday evenings.

INSPECTION TRIPS

Although all of the buildings and laboratories of the university will be in normal operation, and open to all, throughout the 2 days of the convention, a more formal personally conducted tour, starting at the Purdue Memorial Union Building, has been planned for Thursday from 1:00 to 2:00 p.m. On Friday, at the same hour, automobiles will leave the same meeting place for an inspection of the plant of the Duncan Electric Manufacturing Company and other points of interest in Lafayette.

Purdue University is 1 of the 2 universities of the State of Indiana. The schools of electrical, chemical, mechanical, and civil engineering, science, agriculture, home eco-

nomics and pharmacy are located in West Lafayette, while those of arts, law, and medicine are located at Indiana University at Bloomington, Ind. The 4 schools of engineering are housed in separate buildings, those of electrical and mechanical engineering being particularly new, of large size and well equipped with commodious laboratories. The broadcasting station, WBAA, with its studios, and the short-wave amateur station W9YB will be found in conjunction with the department of communication on the third floor of the electrical engineering building, while the rather unique television station, W9XG is located near the Ross Ade Stadium, 1/4 mile north of the main campus.

TRANSPORTATION

It is expected that so many will travel by automobile that reduced railroad fares which are sometimes based upon a minimum number of certified railroad tickets will not be available. However, Lafayette, Ind., where the Fowler Hotel and Lahr House are located only one mile from the university in West Lafayette, may be readily reached via the Big Four, Monon, Nickel Plate or Wabash railroads. It is also located on national highways 52 and 152 between Chicago and Indianapolis as well as routes 25, 26, and 43 from east and west points.

REGISTRATION

All who plan to attend this meeting are urged to register in advance by mail, if possible, by writing to J. H. Bowman, chairman, registration committee, Purdue University, West Lafayette, Ind. Members and guests should complete their registration as soon after arrival as possible so as not to miss the opening session on Thursday morning. There will be no registration fee for members of the Institute and their immediate families or for students. Nonmembers, not students, will be charged a fee of $2. Tickets for the dinner Thursday evening at $1.50, for the student luncheon Friday noon at $0.75, and for the football game Saturday afternoon ($2.25 reserved seats) should be secured at the registration desk to avoid later congestion and delay.

Hotel reservations should be made directly with the hotels, the rates per day being as follows:

	Single	Double
Fowler Hotel		
With bath	$2.50	$4.00 and up
Without bath	2.00	3.50 and up
Lahr Hotel		
With bath	2.00	3.50 and up
Without bath	1.50	2.50 and up

Although the hotel accommodations will be limited on Friday and Saturday nights on account of the homecoming football game, they should be adequate, if reservations are made in advance, for Wednesday and Thursday nights. An adequate supply of satisfactory rooms in private homes will be available also at the registration desk.

The Memorial Union or student building on the campus of Purdue University, West Lafayette, Ind., which will be a central point for social gatherings during the Institute's Great Lakes District meeting, Oct. 24–25, 1935. The Memorial Union building is near the university's electrical engineering building, in which the technical sessions will be held

COMMITTEES

General Convention Committee—G. G. Post, vice president, District 5, *chairman;* A. G. Dewars, secretary, District 5; C. A. Cora, F. R. Finehout, D. H. Hanson, C. F. Harding, O. Kiltie, E. B. Kurtz, G. V. Mueller, and A. N. Topping

Papers Committee—C. F. Harding, *chairman;* D. T. Canfield, C. A. Cora, D. L. Curtner, D. D. Ewing, F. R. Finehout, D. H. Hanson, O. Kiltie, E. B. Kurtz, G. V. Mueller, L. D. Rowell, C. S. Roys, and A. N. Topping

Attendance and Publicity Committee—D. L. Curtner, *chairman;* J. N. Arnold, J. H. Karr, W. A. Knapp, T. R. Johnston, and R. C. Woodworth

Student Session and Papers Committee—E. B. Kurtz, *chairman;* H. N. Hayward; C. C. Knipmeyer; E. E. Reynolds; E. M. Sabbagh; A. N. Topping, Purdue A.I.E.E. Branch chairman; R. B. Immel; R. L. Kessel, *vice chairman;* and R. V. Morris, *secretary*

Finance Committee—G. G. Post, *chairman;* G. V. Mueller, *local chairman;* K. A. Auty, C. A. Cora J. W. Esterline, and F. Holmes

Reception and Registration Committee—J. H. Bowman, *chairman;* L. E. Beck, J. H. Karr, and C. S. Siskind

Transportation, Demonstrations, and Inspection Trips Committee—D. D. Ewing, *chairman;* C. B. Aiken, C. W. Caldwell, K. F. Dickinson, R. H. George, S. Green, H. J. Heim, W. A. Knapp, B. H. Short, and C. S. Sprague

Entertainment Committee—(Dinner, luncheons, etc.) D. T. Canfield, *chairman;* J. Bixler, P. S. Emrick, and W. A. Knapp

Women's Entertainment Committee—Mrs. C. F. Harding, *chairman;* Mrs. Bixler, Mrs. Canfield, Mrs. Dickinson, Mrs. Ewing, Mrs. Green, and Mrs. Holmes

Student Entertainment Committee—A. N. Topping, *chairman;* H. R. Imle, R. B. Immel, R. L. Kessel, and R. V. Morris

Housing and Convention Hall Arrangement Committee—G. C. Bialock, *chairman;* J. W. Hammond, R. B. Marshall, J. W. Walker

Additional Awards for 1934 Institute Papers

In addition to the national and District prizes for papers presented before the Institute during the calendar year 1934, as announced in ELECTRICAL ENGINEERING for June 1935, page 677, and July 1935, page 785, announcement now has been made of the award of prizes for Districts Nos. 8 and 9. These awards are:

DISTRICT NO. 8

Prize for best paper awarded to A. A. Kromeberg (A'28, M'34) and Mabel Macferran Rockwell (A'28, M'35) for their paper "Power Limits of 220 Kv Transmission Lines," published in ELECTRICAL ENGINEERING for November 1933, pages 758–66, and discussed at the Pacific Coast convention, Salt Lake City, Utah, Sept. 3–7, 1934.

Prize for initial paper awarded to F. C. Lindvall (A'26) for his paper "A Glow Discharge Anemometer," published in ELECTRICAL ENGINEERING for July 1934, pages 1068–73, and discussed at the Pacific Coast convention, Salt Lake City, Utah, Sept. 3–7, 1934.

Prize for Branch paper awarded to D. R. Tibbetts (A'35) for his paper "San Francisco-Oakland Bay Bridge Construction Radiotelephone System," presented at the Pacific Coast convention, Salt Lake City, Utah, Sept. 3–7, 1934.

DISTRICT NO. 9

Prize for best paper awarded to R. C. Hummel (A'29) for his paper "The Design and Operation of an Automatic All Relay Telephone Switching System for Small Communities," presented at a meeting of the Seattle (Wash.) Section, Feb. 20, 1934.

Prize for Branch paper awarded to K. M. Klein (A'35) and E. J. Harrington for their paper "The Influence of Ground Plane Proximity Upon the Polarity of Sphere-Gap Spark-Over," presented at a joint meeting of the Portland (Ore.) Section and Oregon State College Branch, May 19, 1934.

Future AIEE Meetings

Great Lakes District Meeting,
West Lafayette, Ind., Oct. 24–25, 1935

Winter Convention,
New York, N. Y., Jan. 28–31, 1936

North Eastern District Meeting,
New Haven, Conn., May 1936

Summer Convention,
Los Angeles, Calif., June 22–26, 1936

Middle Eastern District Meeting,
Akron, Ohio (date to be determined)

A.I.E.E. Directors Meet at Institute Headquarters

The regular meeting of the board of directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, N. Y., on August 6, 1935.

Present: *President*—E. B. Meyer, Newark, N. J. *Vice Presidents*—C. V. Christie, Montreal, Que.; Mark Eldredge, Memphis, Tenn.; R. H. Fair, Omaha, Neb.; W. H. Timbie, Cambridge, Mass. *Directors*—F. Malcolm Farmer, New York, N. Y.; C. R. Jones, New York, N. Y.; P. B. Juhnke, Chicago, Ill.; W. B. Kouwenhoven, Baltimore, Md.; Everett S. Lee, Schenectady, N. Y.; L. W. W. Morrow, New York, N. Y.; A. C. Stevens, Schenectady, N. Y. *National Treasurer*—W. I. Slichter, New York, N. Y. *National Secretary*—H. H. Henline, New York, N. Y. Present by invitation, I. Melville Stein, chairman, special committee on revision of Section territories.

The minutes of the meeting of the board of directors held June 26, 1935, were approved.

A report of a meeting of the board of examiners held July 24, 1935, was presented and approved. Upon the recommendation of the board of examiners, the following actions were taken: 10 applicants were elected and 19 were transferred to the grade of Member; 74 applicants were elected to the grade of Associate.

The finance committee reported disbursements for July amounting to $20,082.10. Report approved.

Proposed amendments to Sections 22 and 23 of the by-laws to bring them into conformity with the amendments to the constitution which were recently adopted by the membership were approved, subject to confirmation at the October meeting.

Announcement was made of the appointments by the president of Institute committees for the administrative year beginning August 1, 1935 (a list of the committees and representatives of the Institute appears near the end of the "News" section in this issue).

The board confirmed the reappointment by the president of C. E. Stephens as chairman of the Edison Medal committee for the year beginning August 1, 1935, and the appointment of the following members: F. J. Meyer, R. A. Millikan, and Marion Penn for terms of 5 years each; G. G. Post for the year beginning August 1, 1935, to fill the vacancy caused by President Meyer's becoming an *ex-officio* member; and Dr. H. S. Osborne for the unexpired term, ending July 31, 1937, of S. P. Grace (deceased). The board of directors elected from its own membership, to serve on the committee for terms of 2 years each, W. H. Harrison, C. R. Jones, and W. B. Kouwenhoven.

The appointment by the president of L. W. Chubb, N. E. Funk, and W. H. Harrison as members of the Lamme Medal committee for terms of 3 years each, and of A. M. MacCutcheon as chairman of the committee for the present year, was confirmed.

Special committees of the Institute were reviewed and reappointed. Representatives of the Institute on various bodies for the adminstrative year beginning August 1, 1935, were appointed.

C. O. Bickelhaupt (chairman, A.I.E.E. delegation), F. J. Chesterman, William McClellan, C. E. Stephens, and H. H. Henline (alternate) were reappointed representatives of the Institute on the Assembly of American Engineering Council for the year 1936. (The remaining member of the A.I.E.E. delegation, President E. B. Meyer, was appointed at the June board meeting to serve for the year August 1, 1935, to August 1, 1936.)

Prof. Charles F. Scott was reappointed a representative on the Engineers' Council for Professional Development for the 3-year term beginning in October 1935.

E. W. Rice, Jr., was reappointed a member of the Hoover Medal board of award for the six year term beginning in October 1935.

The following local honorary secretaries of the Institute were reappointed for terms of 2 years each beginning August 1, 1935: F. M. Servos, for Brazil; A.P.M. Fleming, for England; Renzo Norsa, for Italy; P. H. Powell, for New Zealand; A. F. Enstrom, for Sweden.

A progress report of the special committee on revision of Section territories was presented by Chairman I. Melville Stein, and was approved.

The board directed that suitable greetings from the A.I.E.E. to the Institute of Electrical Engineers of Japan be prepared, for conveyance by Dr. Dugald C. Jackson, who will lecture in Japan this fall under the auspices of the Iwadare Foundation.

Other matters were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.

Membership—

Mr. Institute Member:

Most of the Section membership committees for the coming year have been formed and are already at work.

Your co-operation in the past in suggesting to the chairman of your Section membership committee the names of those who, you feel, are worthy to be invited to join the Institute has been of the greatest help and we are hopeful that it is becoming a part of your Institute thought to do this at every opportunity.

By doing your part during 1934–35 the membership committee was able to accept the bogey of more applications for membership in any month than in the corresponding month of the previous year, and to meet it in 11 of the past 12 months.

Everett S. Lee

Chairman National Membership Committee

Lightning Reference Book May Be Issued

Several orders have already been received for the proposed lightning reference book which was announced in ELECTRICAL ENGINEERING for August 1935, page 907. This book, if issued, would include the full text and illustrations of most papers on the subject of lightning, published from 1918 to 1935 by the A.I.E.E., in addition to those published in the *General Electric Review*, the *Electric Journal*, *Electric World*, the *Journal* of the Franklin Institute, and perhaps the English translations of a half dozen or so of the more important foreign papers. A comprehensive cross-reference index of authors' names and paper titles would be included as part of the volume. In size, it would be similar to the A.I.E.E. TRANSACTIONS, comprising some 1,300 9 by 12 inch pages, making a book about $2^1/_2$ inches thick.

The lightning and insulator subcommittee of the A.I.E.E. power transmission and distribution committee has carried on an extensive canvass of the literature on lightning and its effect on electric power systems and apparatus, and more than 250 papers and technical articles have been indexed. In these papers are considered lightning characteristics, theory, laboratory and field tests, and protective devices used and their application and performance.

In order that this information may be readily available to those interested, it is proposed that the volume now under consideration be compiled. Although several orders have already been received, the number of orders is not yet large enough to warrant issuing the volume. For the benefit of interested persons, a coupon that may be filled in and mailed at once is included on page 8 of the advertising section of this issue. (If a sufficient number of orders is not received promptly, the proposal will be dropped.)

The Institute's Publication Policy and Services

A report on the publication policy of the Institute presented at the conference of officers, delegates, and members held during the recent A.I.E.E. summer convention at Ithaca, N. Y., June 24–28, 1935, by C. O. Bickelhaupt, chairman of the A.I.E.E. publication committee.

THE objects of the Institute are "the advancement of the theory and practice of electrical engineering and of the allied arts and sciences, and the maintenance of a high professional standing among its members." The publication service is one of the most useful and important means of accomplishing these purposes, and is a tangible record of service to the membership.

Historically, the publication procedure of the Institute may be divided into 3 distinct periods. Prior to 1920, 2 publications were issued to all members. Papers, discussions, and Institute news were published monthly in the PROCEEDINGS. Part of this material, together with some additional matter, was included in an annual bound volume designated as the TRANSACTIONS, which was regarded as the formal record of the Institute's technical activities.

The second period began in 1920 when the name of the monthly publication was changed to the JOURNAL with a change in format. Also, the TRANSACTIONS was removed from a general circulation basis and placed upon a nominal subscription basis that was intended to be self-supporting because it was expected that the TRANSACTIONS would continue to duplicate a large part of the material which it was planned to publish in the monthly. However, this period, which continued through 1930, saw an ever-widening difference in content between the JOURNAL and the TRANSACTIONS which, incidentally, was changed in 1928 from an annual to a quarterly publication. By 1928 the extent to which technical papers were published in the monthly had been reduced gradually until the JOURNAL content consisted principally of abridgments of technical papers. In the meantime, a supplementary service consisting of a wide and free distribution of individual pamphlet copies of technical papers had been made available to the membership. The thought there seemed to be that any member could secure pamphlet copies of those papers in which he was most interested, and that since this service was available it would be necessary to carry only abridgments of these papers in the JOURNAL for general circulation to the entire membership.

ELECTRICAL ENGINEERING INITIATED

The third period in the history of the Institute's publication policy was entered as the result of an extensive survey conducted by the publication committee during 1929–30. The monthly JOURNAL was changed beginning January 1931 to ELECTRICAL ENGINEERING, and the character and scope of its content was modified to meet the membership's indicated preference for a "more popular" monthly publication. This step, judging from the volume of correspondence received from members, met with wide approval.

However, with technical papers as then published in ELECTRICAL ENGINEERING reduced in many instances to abbreviated abstracts, the differences between the Institute's principal publications were emphasized and brought to a maximum. ELECTRICAL ENGINEERING was serving the demand for "popular material," the pamphlet service was attempting to meet the requirements for general distribution of complete technical papers, and the quarterly TRANSACTIONS was serving the triple rôle of record volume, purveyor of technical papers to those not receiving them in pamphlet form, and as the *only channel* through which discussions of technical papers were reaching *any* of the membership in printed form.

This publication procedure had its advantages, but it was developing rapidly into an exceedingly expensive program of publication, considering the service rendered. All papers involved the expense of double publication and many of them triple publication: first in pamphlet preprint form, then in the quarterly TRANSACTIONS, and in many instances also as rewritten for use in ELECTRICAL ENGINEERING. Finally, and in the face of impending heavy reductions in publication budgets necessitated by depression conditions and impaired income, it became evident that the amount of material published would have to be reduced drastically unless some simpler publication procedure could be developed.

UNIFIED PUBLICATION PLAN ADOPTED

Accordingly, to reduce costs while retaining the principal advantages gained through steady development, the publication committee and editorial staff again went exhaustively into the matter beginning in the fall of 1932. That effort led to the development and adoption of the so-called "unified publication plan" which, during the past 2 years, has resulted in greatly expanding the publication service to every individual member of the Institute, while at the same time permitting a reduction of 40 per cent in the publication budget as compared with that for the year 1930–31.

As now published, ELECTRICAL ENGINEERING and the annual TRANSACTIONS are identical. As a matter of production economy, the pages for the annual volume are printed month by month while the forms of the monthly publication are still on the presses, are accumulated during the calendar year, and issued at the end of the year as a complete reference volume covering the Institute's published technical material for the year. It is recognized that this simplified procedure may have some minor practical and theoretical disadvantages. However, its adoption has placed the TRANSACTIONS on a self-supporting basis for the first time, and has eliminated the inequities of an average annual deficit of some $17,000 which had to be borne by the membership at large for the benefit of those who received the TRANSACTIONS under the old publication procedure. Elimination of the costly process of attempting mass distribution of technical papers through the medium of pamphlet copies mailed to individual order, has resulted in an additional saving of some $7,500 per year. The expense of this special service, which was increasing rapidly, was by no means justified, being in effect a general assessment for a specialty service. Now, authors and others wishing reprints for special purposes are given the benefit of reprint service at actual cost.

As now published under the unified publication plan, ELECTRICAL ENGINEERING each month places in the hands of every member of the Institute (based upon the calendar year 1934, and *excluding* the special May 1934 anniversary issue) an average of:

77 pages presenting the full text of more than 12 A.I.E.E. technical papers.

14 pages conveying the full text of some 27 written discussions of A.I.E.E. technical papers.

Approximately 15 pages conveying 3 or more special articles on topics of timely general interest.

15 pages of news items covering Branch, Section, District, and other Institute activities, and miscellaneous items of current general interest.

The 199 pages of special material in the 50th Anniversary issue of ELECTRICAL ENGINEERING were published over and above the regularly scheduled material.

CO-ORDINATION OF PUBLICATION AND MEETINGS

It is of significance to note in this connection that all technical papers on national convention programs, and most technical papers on District meeting programs, have been published in full in ELECTRICAL ENGINEERING well in advance of the meetings, thus extending to every member the opportunity for participation in the discussion of each paper, whether in attendance or not. Further, this effective advance distribution of technical papers has materially relieved congestion at convention technical sessions by making possible immediate discussion of many papers without the necessity of taking time for oral presentation of the paper. Also, prompt publication and complete circulation has facilitated discussion of technical papers at District meetings in various parts of the country, giving the opportunity for active participation to more members, and making available to the membership at large a wider variety of thought on a given paper through the medium of subsequent publication of written discussions originating at such meetings. A good many Sections, too, have found technical discussion meetings built upon papers published in ELECTRICAL ENGINEERING to be an attractive supplement to regular Section meeting programs.

THE TRANSITION PERIOD

When the unified publication plan was recommended in June 1933 by the publication committee, it was on the basis of a publication schedule tentatively contemplating a transition from a post-publication to a pre-publication policy during a period

beginning with the July 1933 issue of ELECTRICAL ENGINEERING and being completed by January 1935. That program was considered in order to provide time for necessary and desirable preliminary steps, in order to spread over a reasonable working period the tremendous burden of work involved in making such a major change in publication procedure, and in order to take advantage of a natural break in the yearly production program then prevailing.

However, under the pressure of economic conditions the transition was precipitated in the fall of 1933. It was undertaken "from scratch" in an effort to realize within some 6 months—instead of the 18 months originally planned—at least the essential improvements and major economies of the new program. This more than doubled the publication burden. Not only was it necessary to continue to satisfy commitments developed under the old publication program where the established procedure was to "reach back" to previous meetings for material for the monthly publication, but it was also necessary at the same time to "reach ahead" under the provisions of the new publication plan which contemplated advance publication of most technical papers. With the effective co-operation of the technical program committee which is responsible for the arrangement of national convention programs and the handling of the technical papers involved, the advance publication of all papers on the program of the then current winter convention was completed with the January 1934 issue of ELECTRICAL ENGINEERING. Another year was required for the development of an even flow of new technical material as required under the new publication plan, and to work out other important problems involved.

The unified publication plan is now well beyond its transition stage, providing opportunity in line with original plans for the development of further and related refinements and improvements. This accomplishment is the result of many months of hard and continuous work on the part of the editorial staff. With unusual and difficult operating problems to handle, the staff has carried the burden of extra work involved in the transition to the unified publication plan only through contributing many hours of overtime to get the job done on time. The publication committee and the Institute owes a debt of gratitude for this loyal support.

It is the purpose of your publication committee and of the editorial staff to keep the policy and procedure governing the Institute's publications sufficiently flexible to meet the constantly evolving needs and desires of the membership, and so to develop the program and publications as may be necessary to serve as equitably, economically, and effectively as possible the tremendously wide range of interest of the thousands of members and Enrolled Students who are the American Institute of Electrical Engineers.

Student Convention Held by North Eastern District

The Student Branches of the Institute's North Eastern District, number one, held a convention at Rensselaer Polytechnic Institute, Troy, N. Y., on May 3 and 4, 1935. The student convention was held because there was no meeting of the North Eastern District this year on account of the holding of the summer convention at Cornell University, and this convention came after the school year was closed. Lodging was provided in the college dormitories at an extremely low rate.

Friday, May 3, was given over to an all day inspection of the Schenectady, N. Y., works of the General Electric Company. At the annual meeting of the Branch counselors and chairmen held that evening, the chairman and the committee members of the previous year were re-elected for the coming year. They are: W. B. Hall, Yale University, *chairman;* A. R. Powers, Clarkson College; and F. N. Tompkins, Brown University. At the evening meeting attended by all, E. O. Shreve, vice president of the General Electric Company, spoke on opportunities for the engineering graduate, and Mr. Darlington described and demonstrated vacuum tubes.

On Friday, May 4, in Sage Laboratory at Rensselaer, the following student papers were presented:

INDUCTION MOTOR CONTROL BY A THYRATRON CONVERTER, S. B. Farnham, Yale University.

A HIGH SENSITIVITY VACUUM TUBE VOLTMETER, W. R. Harry, Cornell University.

A PROPOSED METHOD OF INCREASING SIGNAL TO NOISE RATIO IN RADIO RECEPTION, D. B. Nason, University of New Hampshire.

A STUDY OF THE TILT OF RADIO WAVE FRONTS, W. H. Davenport, and F. G. Webber, Worcester Polytechnic Institute.

HARMONIC OPERATION OF A TRANSMITTING ANTENNA AND FEEDER SYSTEM, W. B. Plummer, Union College.

SOLUTION OF SPECIAL PROBLEMS IN PIPE FLOW BY MEANS OF ANALOGOUS ELECTRICAL CIRCUITS, D. J. Ball, Rensselaer Polytechnic Institute.

BEYOND THE MILKY WAY, T. N. Wilcox, Massachusetts Institute of Technology.

A NEW REVERBERATION TIME METER, L. H. Morrison, University of Maine.

APPLICATIONS OF THE THYRATRON TUBE WITH A FLOATING GRID, H. L. Blaisdell, Rhode Island State College.

CONSTRUCTION AND STUDY OF AN ARTIFICIAL TELEGRAPH CABLE, F. W. Gullo and D. A. Day, Worcester Polytechnic Institute.

NONLINEAR RESONANT CIRCUITS, K. N. Mathes, Union College.

EXPERIMENTAL DEMONSTRATION OF TORQUE INDUCTANCE RELATIONSHIP, R. Potter, Yale University.

The following prizes for excellence of presentation, offered by the North Eastern District, were awarded immediately at the close of the sessions.

First prize	$10	S. B. Farnham	Yale Univ.
Second prize	5	W. R. Harry	Cornell Univ.
Third prize	3	F. W. Gullo	Worcester Poly. Inst.

That evening there was a banquet in Russell Sage dining hall. The Institute prize of $25 for the best Branch paper from the North Eastern District written by an undergraduate, was awarded to Albert E. French, Clarkson College, for his paper entitled "The Place of Operational Calculus in Undergraduate Study of Electrical Engineering," which was presented a year previously at the District convention at Worcester, Mass. Stanley Pierce, a member of the Harvard Branch, gave an extremely interesting illustrated talk on his experiences as electrical expert with the latest Byrd expedition to Little America.

Attendance statistics are:

Clarkson Institute of Technology	9
Cornell University	20
Harvard University	1
University of Maine	8
Massachusetts Institute of Technology	6
University of New Hampshire	30
Rhode Island State College	10
Rensselaer Polytechnic Institute	51
Syracuse University	20
Union College	5
University of Vermont	21
Worcester Polytechnic Institute	31
Yale University	17
Total	229

Students 209 Faculty 20

The Purdue Campus, Location of a District Meeting

The campus of Purdue University as viewed from the air, spring of 1935. On this campus at West Lafayette, Ind., the meeting of the Great Lakes District of the A.I.E.E. will be held Oct. 24–25, 1935

Section Technical Committee

Activities of the Portland, Ore., Section

A report of the experiences with Section technical committees obtained by the Institute's Portland, Ore., Section during the past year, presented at the conference of officers, delegates, and members during the Institute's summer convention, Ithaca, N. Y., June 24–28, 1935, by John Bankus, chairman of the Portland Section for 1935–36, and secretary-treasurer for 1934–35.

THE matter of organizing technical committees in both Sections and Districts was discussed at considerable length at the Institute's 1934 summer convention at Hot Springs, Va. The chairman and executive committee of the Portland (Ore.) Section believed that the idea of establishing Section technical committees offered one of the most effective means for increasing the value of the Institute to the Section members. By means of a letter the chairman brought the matter to the attention of all members of the Section.

The executive committee of the Portland Section felt that as far as Portland is concerned the Section technical committees would function best if they were purely local in character without any connection with District or national technical committees.

The executive committee also felt that in organizing Section technical committees it would be advisable to start with not more than 3 committees, and after discussing the matter with interested members in the Section, technical committees were chosen on communication, industrial power applications, and transmission and distribution. These were selected because they appeared to have the greatest local interest. However, it was the executive committee's intention that additions or substitutions could be made as desired from time to time by the local membership.

The chairman of the different technical committees were chosen by the Section chairman. In appointing technical committee chairmen particular care was taken to obtain men who are not only competent but who are also greatly interested in the Institute and technical committee activities. The technical committee chairmen were made responsible for the programs and the proper functioning of their respective committees. However, notices of meetings were sent out by the Section secretary.

The carrying on of the local technical committee activities has not involved any large expense on the part of the Section. A comparatively small room is ample for holding these meetings. So far, through the co-operation of interested utility engineers and executives it has been possible to secure the use of a room with blackboard accommodations without charge. Notices of meetings are sent to all members and the expense of such notices is borne by the Section.

The programs for the past year have covered a wide variety of subjects, as will be seen by referring to tables I and II, which summarize activities of Section and technical committees. It will be seen from these summaries that the Section technical committees have contributed very materially to the year's activities of the Portland Section. For the 22 committee meetings, the total attendance was 352; when this is compared with the total attendance at the 9 regular monthly meetings of 639, the technical committee meetings are seen to have added some 55 per cent to the membership participation in the activities of the Section; it is of importance to note that different groups of members attended the meetings of the different committees, and that these members were largely in addition to those who attended the regular meetings. This increased activity in itself would amply justify the step which has been taken.

But the greatest benefit is believed to result from the effect which the technical committee activities have had on the membership, especially the younger members. These committee meetings have enabled a much larger number to participate in the Institute activities and there is a feeling on the part of the members that they are getting much more for their money.

The past year's experience of the Portland Section has shown that the technical committee activities afford an excellent opportunity for bringing out the talent which exists in the Section.

Table I—Regular Monthly Meetings

Date	Subject	Attendance
Sept. 17, 1934	Insulation and protection of transmission lines and stations; and multiple velocity theory of traveling waves	58
Oct. 16, 1934	Theory and construction of the expulsion oil circuit breaker	42
Nov. 27, 1934	Electric figures	127
Dec. 11, 1934	Construction features of Boulder Dam, power house, and 275 kv transmission line	80
Jan. 22, 1935	Transmission line studies for the Columbia River development	82
Feb. 26, 1935	Polarity characteristics of sphere gaps	60
Mar. 23, 1935	High voltage insulators and the A.I.E.E. tests	54
Apr. 22, 1935	Teletypewriter operation—transmission features	74
May 25, 1935	Joint meeting, Portland Section and Oregon State College Branch at Corvallis	62
Total attendance at regular meetings		639
Inspection Trips		
Dec. 8, 1934	Inspection of model of Bonneville project at government moorings	20
Apr. 22, 1934	Inspection of telegraph equipment in telephone building	74

Table II—Local Section Technical Committee Meetings

Date	Subject	Attendance
Industrial Power Application Committee		
Oct. 22, 1934	Fundamentals of electronic tubes	14
Oct. 31, 1934	Fundamentals of electronic tubes	16
Nov. 14, 1934	Fundamentals of electronic tubes	16
Nov. 28, 1934	Fundamentals of electronic tubes	15
Dec. 19, 1934	X ray apparatus with inspection of Westinghouse X Ray Lab	18
Jan. 9, 1935	Theory and application of photosensitive devices	17
Jan. 30, 1935	Industrial application of photoelectric tubes	19
Mar. 13, 1935	Conference on industrial operating problems (4 subjects)	20
Apr. 15, 1935	Conference on industrial operating problems (10 subjects)	22
Subtotal		157
Communication Committee		
Oct. 29, 1934	Problems involved in the construction of new transmitters for KOIN and KALE	18
Nov. 19, 1934	Theory of coaxial lines	15
Dec. 17, 1934	Vacuum tubes as high frequency oscillators	16
Jan. 21, 1934	Telephone and radio communication in the forest service	20
Mar. 18, 1935	Problems pertaining to program switching and studio technique	14
Apr. 21, 1935	New theories of detection and rectification of radio frequencies	12
Subtotal		95
Transmission and Distribution Committee		
Oct. 8, 1934	General features of Bonneville Dam	13
Nov. 5, 1934	Demonstration of oscillograph used for analyzing electrical apparatus phenomena	17
Dec. 10, 1934	Market possibilities for Bonneville power	20
Jan. 14, 1935	Developments in overhead and underground network protectors	15
Mar. 11, 1935	Electricity goes to sea (films)	14
Apr. 8, 1935	275 kv impulse oil circuit breakers for the Boulder Dam, Los Angeles line	13
May 27, 1935	Experiences with electrical installation at Dnieperstroy	8
Subtotal		100
Total attendance at all committee meetings		352

Student Conference Held by North Central District

The 8th annual conference of student Branches of the Institute's North Central District, number 6, was held at North Dakota State College, Fargo, April 12–13, 1935. There was a total registered attendance of 83, which included, in addition to R. B. Bonney, vice president of the North Central District, and W. G. Rubel, secretary of the District, the following student counselors and Branch chairmen:

Counselor	Branch Chairman	Institution
H. S. Rush	Ted Peterson	No. Dak. State Col.
F. W. Norris	E. G. Guenzel	Univ. of Neb.
R. E. Nyswander	W. A. McWhorter	Univ. of Denver
H. F. Rice	E. L. Johnston	Univ. of No. Dak.
B. B. Brackett	Geo. Fullencamp	Univ. of So. Dak.
G. H. Sechrist	Henry Crabtree, Jr.	Univ. of Wyoming
	R. C. Davidge	Univ. of Colo.
W. H. Gamble	Evan Jensen	So. Dak. State Col.

Sessions were held on Friday afternoon and on Saturday morning, and on Friday evening a banquet was held. A meeting of the student Branch counselors was held after the Saturday morning session.

The program for the Friday afternoon and Saturday morning sessions was as follows:

ADDRESS OF WELCOME, President J. H. Shepperd, North Dakota State College; with response by R. B. Bonney.

SELECTIVE ADMISSION OF STUDENTS TO ENGINEERING COLLEGES, Prof. H. F. Rice, University of North Dakota; discussion by George Fullencamp, University of South Dakota, and Henry Crabtree, University of Wyoming.

IS THE ENGINEERING CURRICULUM TOO TECHNICAL? Prof. F. W. Norris, University of Nebraska; discussion by Evan Jensen, South Dakota State College, and E. L. Johnson, University of North Dakota.

THE EFFECT OF GOVERNMENT OWNERSHIP OF PUBLIC UTILITIES ON THE ENGINEERING PROFESSION, Prof. W. C. DuVall, University of Colorado; discussion by Ted Peterson, North Dakota State College.

DEMOCRACY CHALLENGED, Dean A. E. Ninard, North Dakota State College

ENGINEERING AND THE HIGH SCHOOL SENIOR, Prof. R. E. Nyswander, Denver University; discussion by R. C. Davidge, University of Colorado.

SHOULD ENGINEERING GRADUATES LOOK TO LARGE OR SMALL COMPANIES FOR WORK IN THE FUTURE? Prof. J. O. Kammerman, South Dakota State School of Mines; discussion by Prof. W. H. Gamble, South Dakota State College.

A DEMONSTRATION OF HIGH FREQUENCY FEVER MACHINE, Foster Buck, North Dakota State College.

WILL THERE BE FEWER OPPORTUNITIES FOR ELECTRICAL ENGINEERING GRADUATES IN THE FUTURE? Prof. G. H. Sechrist, University of Wyoming; discussion by W. A. McWhorter, Denver University.

On Friday evening the delegates and some 65 other guests were entertained at a banquet and program given by the North Dakota State College Branch in the Waldorf Hotel in Fargo. The program was presided over by Ted Peterson, chairman of the local student Branch; Wesley Gilbertson and Harold Naegeli, both of this Branch, furnished entertainment. The address of the evening was given by R. H. Fair, recently elected vice president representing this District, on the subject of "Some Aspects of the Art of Utilizing Engineering Knowledge." Remarks of Dean R. M. Dolbe, of the school of engineering of North Dakota State College, brought the evening program to a close.

COUNSELOR MEETING

Chairman H. F. Rice called the meeting of the District committee on student activities to order, and after conducting some preliminary business, the question of location of the next conference was opened. A motion that the 1936 conference be held at the University of Colorado, at Boulder, was carried. Prof. W. C. DuVall of the University of Colorado was elected chairman of the committee on student activities for the ensuing year, and Prof. R. E. Nyswander of the University of Denver, was elected alternate. Following a brief discussion on the matter of stimulating more competition for the District prize for Branch papers, the meeting was adjourned.

Gustav Lindenthal, Bridge Engineer, Dies

Gustav Lindenthal, dean of American bridge engineers, died at his home in Metuchen, N. J., on July 31, 1935. His best known works are the arch bridge of the New York Connecting Railroad over the East River at Hell Gate, New York, N. Y., and the Sciotoville continuous bridge over the Ohio River, near Portsmouth, Ohio.

Doctor Lindenthal was born at Bruenn, Czechoslovakia, May 21, 1850, and came to the United States in 1874, joining the designing force of the Centennial Exposition at Philadelphia, Pa. In 1877, he went with the Keystone Bridge Company at Pittsburgh, Pa., and the following year became bridge engineer for the Atlantic and Great Western Railway at Cleveland, Ohio.

In 1881, he undertook private practice as a consulting engineer in Pittsburgh, Pa., and designed several bridges in that city, and other parts of the United States. In 1892, he moved to New York, N. Y., continuing his private practice, and designing several well known bridges. In 1902, he was appointed commissioner of bridges of New York City, and under his administration the Queensboro Bridge was designed. During this period, he also was a member of the board of engineers of the Pennsylvania Railroad tunnel in New York City. Doctor Lindenthal was chief engineer of the Hell Gate Bridge, 1907–17, and of the Sciotoville railroad bridge 1914–17.

A decade later, when Lindenthal was more than 75, he undertook a large public bridge program at Portland, Ore. In addition to his work on bridges, he served as designer or consultant on a number of important tunnel, dock, and terminal problems. Doctor Lindenthal had long given special consideration to the architectural aspects of bridges.

He had received the honorary degree of doctor of engineering from 3 institutions in Europe, and had received several prize awards in the United States. He was an honorary member of the American Society of Civil Engineers, and of other organizations in the United States and abroad.

Los Angeles Aqueduct Builder Dies

William P. Mulholland, nationally known hydraulic engineer and builder of the Los Angeles-Owens River aqueduct in California, died at Los Angeles, Calif., July 22, 1935. Doctor Mulholland was born in Belfast, Ireland, September 11, 1855, and came to the United States in 1872. From 1886 until his death he was with the Bureau of Water Works and Supply of the city of Los Angeles, Calif., as chief engineer and general manager. The work for which he was the best known was the construction of the Los Angeles-Owens River aqueduct which was built by the Bureau of Water Works and Supply, at a cost of $24,500,000, for bringing water 250 miles to the city from the Sierra Nevada Mountains, north of the city.

Doctor Mulholland also was one of the pioneer backers of the Boulder Dam project and did much of the preliminary work in connection with the $225,000,000 Colorado River aqueduct project of the Metropolitan Water District of Southern California, now under construction. In October 1923, he began surveys of possible routes for an aqueduct from the Colorado River; in 1928 the results of his studies were turned over to the Metropolitan Water District, formed in that year to carry out southern California's Colorado River water supply project.

He also was a consulting engineer, specializing in water supply and irrigation problems, and was chief engineer of the department of public service of the city of Los Angeles. He was educated in the public schools of Belfast, Ireland, and the Christian Brothers College in Dublin; in 1914, the University of California conferred upon him the honorary degree of doctor of law. He was a member of the American Society of Civil Engineers.

Member-for-Life List Brought Up to Date

Membership for life is granted by the Institute for either of the following 2 reasons: a member has attained a term of membership of 35 years; or has reached the age of 70 and has attained a term of membership of 30 years.

One feature of the 50th anniversary (May 1934) issue of ELECTRICAL ENGINEERING was the inclusion on page 825 of a list of all members who had been on the Institute's rolls for 35 years or more. While each member on this list was obviously a member-for-life, the list did not include every one who was a member-for-life at the time of that issue, as there were a few who had become eligible under the second classification.

The list which follows includes all those who have become members-for-life under this second classification during the past 5 years, as well as all those who became members-for-life on May 1, 1935, by virtue of having attained a membership term of 35 years. This list, together with the list given on page 825 of the May 1934 issue of

ELECTRICAL ENGINEERING, therefore includes all present members-for-life, regardless of classification:

Name	Date of Election	Eligible May 1
Abbott, W. L.	Oct. 25, 1901	1932
Atkins, C. G.	Oct. 25, 1901	1935
Barnes, H. H.	Feb. 28, 1900	1935
Barton, P. P.	July 12, 1900	1935
Beran, T.	July 25, 1902	1933
Blackwell, F. O.	Mar. 28, 1900	1935
Bowie, A. J.	May 15, 1900	1935
Bullen, D. R.	Mar. 28, 1902	1935
Cole, G. M.	July 25, 1902	1933
Dolph, J. C.	Sept. 25, 1903	1935
Dysterud, E.	July 26, 1900	1935
*Ensign, O. H.	Dec. 23, 1904	1935
Esterline, J. W.	Mar. 28, 1900	1935
Fish, F. A.	Mar. 28, 1900	1935
Fisken, J. B.	Apr. 24, 1903	1933
Gibbs, George	Apr. 28, 1905	1935
Hanscom, W. W.	Apr. 25, 1900	1935
Hawkins, C. C.	Nov. 20, 1903	1934
Imlay, L. E.	July 26, 1900	1935
Jacobus, D. S.	Sept. 25, 1903	1934
Kelsch, R. S.	May 20, 1909	1932
Lafore, J. A.	May 15, 1900	1935
Lundy, A. D.	Feb. 27, 1903	1933
McGraw, J. H.	Sept. 27, 1901	1932
Mixer, C. A.	Sept. 25, 1903	1934
Mortimer, J. D.	Mar. 28, 1900	1935
C. T. Mosman	Mar. 29, 1895—resigned May 1898; re-elected May 19, 1903	1935
Murphy, John	May 15, 1900	1935
O'Reilly, A. J.	Apr. 24, 1903	1933
Perkins, C. A.	Feb. 24, 1905	1935
Powelson, W. V.	Jan. 24, 1900	1935
Putt, Harvey J.	Mar. 27, 1903	1933
Russell, C. J.	Nov. 23, 1904	1935
Sichter, W. I.	Apr. 25, 1900	1935
Smith, E. A.	Dec. 18, 1903	1935
Smith, W. E.	Feb. 28, 1900	1935
Spencer, Thomas	May 19, 1903	1933
Steele, W. D.	Apr. 25, 1900	1935
Stevens, Theodore	Oct. 27, 1905	1935
Strong, J. R.	Mar. 22, 1901	1932
Sunny, B. E.	Feb. 27, 1903	1933
Thaler, J. A.	July 28, 1903	1935
Town, F. E.	May 15, 1900	1935
Turner, H. W.	Nov. 20, 1903	1934
Wallau, H. L.	May 15, 1900	1935

* Deceased June 1, 1935.

New Name Suggested for Mercury Vapor Converters

The word "mutator" has been proposed by Brown Boveri and Company, Ltd., Baden, Switzerland, as a general term to be applied to all forms of mercury vapor converters, with suitable adjectives to be applied to differentiate between rectifiers, inverters, frequency changers, etc. (For example, rectifiers might be called "ac-dc mutators," and converters might be called "dc-ac mutators.") The universal use of an accepted word such as "mutator" which is derived from the latin mutare (to alter, transform, change) and which might be used in all languages, is specially desirable to this company because its business is carried on in so many different countries. Other designations such as a valve, thyratron, etc., have the disadvantage of not being directly translatable into other languages, as is the case for such words as transformer, motor, generator, and regulator.

As an experiment, the Brown Boveri company introduced the word "mutator" in its December 1934 issue of *The Brown Boveri Review*. Informal inquiry seems to indicate that some commonly applicable term might find considerable favor in the United States, and the company's experiment in coining the new term will be watched with interest. The company reports that the word has been well received in England, especially in educational circles, and that the 2 most important engineering bodies in the Union of South Africa have adopted the term for exclusive use.

Comments of members of the Institute regarding use of the word "mutator" will be welcomed.

Ice an Unusual Aid in Construction Job

The problem of lowering concrete cable ducts a distance of nearly 2 feet, made necessary by regrading of a street surface in Brooklyn, N. Y., was recently solved in an unusual way by engineers of the Brooklyn Edison Company. In order to save the costly replacement of 2,700 feet of the duct and avoid interruption of service to Floyd Bennett Airport, the duct was lowered to its new position by the melting of cakes of ice. Under the direction of George W. Rainforth, supervisor of the subway bureau of the distribution department of the company, the first 300 foot section, weighing 64 tons, was lowered by means of 40 cakes of ice. The duct was uncovered for its entire length, and at 8 foot intervals undermined to insert the ice in cakes 21 inches high, half

A section of a 300 foot concrete duct line being lowered by ice, a block of which is shown (in circle) encased in sand to insure even melting

the size of the ordinary commercial cake. The remainder of the duct line was then undermined, and the ensuing exchange of thermal units lowered the concrete gently and evenly. Although not the first time ice has been used as a jack, it is rare that a job presenting such difficulties is consummated so expeditiously and inexpensively.

50th Anniversary of First A-C System in America

At the meeting of the board of directors of the A.I.E.E. held August 6, 1935, in Institute headquarters, New York, N. Y., the following self-explanatory resolution was adopted:

WHEREAS, on March 20, 1886, the first commercial alternating current electrical system was put into operation by William Stanley, at Great Barrington, Mass., and

WHEREAS, next March marks the fiftieth anniversary of the establishment of the alternating current system in America, be it

RESOLVED: That the American Institute of Electrical Engineers sponsor a suitable national celebration of this fiftieth anniversary of the alternating current system, and that the President be empowered to appoint a national committee to initiate and carry out this proposal.

Although plans have not yet been made, this coming memorial may possibly take the form of a large meeting in New York, N. Y., with broadcasting to each Institute Section. It will stress the 50th anniversary of the a-c system in the United States. It is of interest to note that a celebration of the 25th anniversary of the first commercial a-c electrical system in the United States was held by the A.I.E.E., Pittsfield, Mass., Section in 1911.

Thomas Alva Edison Foundation Is Incorporated

The Thomas Alva Edison Foundation has been incorporated for the purpose of creating a living tribute to the inventor whose genius gave to the entire world the first practical incandescent lamp and the phonograph; a major contribution to the electrification of industry and the home; inventions affording education, entertainment, and amusement to countless millions through the medium of motion pictures and radio; whose efforts improved telegraphy and perfected the telephone transmitter and in many other ways greatly benefited mankind.

The charter, filed under the membership corporation laws of the State of New York, provides a wide range of activity in which education is to play an important part.

It has "for its particular objects the advancement and diffusion of knowledge in the fields of physics, chemistry, and the engineering arts and sciences, both basic and applied."

Conceived by the Edison Pioneers, a body of co-workers with the inventor, and the A.I.E.E., and with the approval of the Edison family, the Thomas Alva Edison foundation is to carry out plans to perpetuate recognition of the world's progress emanating from the enventor's efforts.

Incorporators of the foundation are; William S. Barstow (A'94, M'99, F'12, and Life Member), president of the Edison Pioneers; Howel H. Barnes, Jr. (A'00, F'13, and past vice president); L. W. W. Morrow (A'13, F'25, and director), editor of the *Electrical World*, and Chas. F. Scott (A'92, M'93, F'25, HM'29, member for life and past-president), professor emeritus of electrical engineering at Yale University, representing the A.I.E.E.; and W. S. Mallory and F. A.

Scheffler (A'93, F'12, and member for life), representing the Edison Pioneers.

Mr. Barstow, in releasing announcement of the Foundation's incorporation, said: "It is planned by directors of the Edison Foundation properly to recognize the debt of the world to Edison's memory and to secure a fund with which to put this recognition into concrete form. What better or more timely task could be undertaken than one in which the focus of the entire world may be centered upon the works and memory of a man whose light now shines throughout the civilized universe: The week of October 21, 1935, is to be the starting point for nation-wide efforts to obtain such a fund. As the entire cost of the campaign itself will have been underwritten by friends of the inventor, every dollar thus secured is to be placed to the credit of the Thomas Alva Edison Foundation. One of the aims of the Foundation is to continue and perpetuate Edison scholarships, initiated by Mr. Edison, for the better preparation of American youth along technical educational lines."

American Engineering Council

New Service Initiated by A.E.C.

American Engineering Council is undertaking a new service for the benefit of the national, state, and local societies which hold membership in A.E.C., this service having for its purpose the aiding of the societies in their public affairs, public relations, and allied activities. It supersedes the supplement for state and local societies previously issued with its monthly "News Letter." Council states that the reason for assuming this responsibility is that it is anxious to do everything possible, within its limitations, to aid the affiliated societies with their social, economic, and political problems, in addition to co-operating with the national societies in their technical and professional activies.

This new service is designed for the exclusive use of member societies. For the benefit principally of state and local societies, secretaries of these societies are being extended the new service with the hope that they will find means to advise their members promptly regarding this information. Council suggests that this service be kept in a permanent file and that the members be notified as to its location and given free access to it.

The "News Letter" will continue to report the news of Council and to summarize the general news of interest to engineers, as of the 15th of each month, but the new service will be undertaken semi-monthly. Council welcomes suggestions for the improvement of its news services.

The first issue of this new semi-monthly service, dated August 15, 1935, summarizes the latest rules and regulations of a number of those government agencies entering the $4,880,000,000 work relief program of the federal government. Among the government agencies considered are the Works Progress Administration, Public Works Administration, Civilian Conservation Corps, Resettlement Administration, Federal Housing Administration, National Resources Committee, Public Health Service, National Youth Administration, and new census projects.

The accompanying item regarding the Engineers' Club of St. Louis also was abstracted from the first release of Council's new service.

Activities of the Engineers' Club of St. Louis

American Engineering Council reports that in the July 1935 issue of the *Journal* of the Engineers' Club of St. Louis, Mo., a well rounded picture of local club activities is presented. Of the 825 members of the Engineers' Club of St. Louis, 200 are serving on standing committees. It is stated that the club is the only engineering society in the United States that publishes a pictorial yearbook; for the 1935 number more than 95 per cent of the members furnished their photographs. A free employment service is maintained for all engineers in metropolitan St. Louis. An engineering library is owned by the club and is under the custody of the St. Louis Public Library. A membership card enables an engineer to draw books.

In 1926, the industries of St. Louis contributed $10,000 to the club's building fund, because they considered the club a character building enterprise, especially for the younger members in their engineering departments. Membership in the club, which felt the inevitable losses since 1929, practically held its own last year and is expected to increase through 1935. The membership committee is organized into a series of "baseball teams" whose competitive "batting averages" are reported each month. The club has no written rules governing the conduct of its members in the club building; the decision was to handle abuses when they arose, and none have arisen.

Competition and duplication of efforts between the club and local sections of national societies are eliminated under the policy that the advancement of engineering as a science be left to the national societies, and that the principal function of a local club is to devote its energy to the welfare of the members of the profession.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or to reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Registration of Engineers

To the Editor:

No one who heard Dr. D. B. Steinman's address on "Registration of Engineers" presented at the education session of the Institute's 1935 summer convention (and published in full in ELECTRICAL ENGINEERING for August 1935, pages 876–81) can escape one conclusion, *viz.*: the utter futility of debate as to whether or not registration should be. The fact that 31 states have accepted as essential the protection of the public against incompetence and fraud, and to that end have enacted measures providing for registration, is basic so far as registration per se is concerned.

There may be profit, however, in analyzing this legislation to determine its probable effectiveness and the extent and manner in which it affects the profession. If this analysis should make evident that in some particulars its effect on the profession is adverse, and if, without interfering with the stated purpose of the legislation, these factors can be modified, it would seem desirable to determine the procedure best suited to the obtaining of such modification.

Certain characteristics are essential to the success of regulatory legislation of this type. Primarily, it must meet a public need of sufficient importance to induce active enforcement. Secondarily, it must be so drawn as to interfere in the minimum degree with the reasonable operations of those whom it regulates.

If its provisions extend beyond what is necessary to the public need, or if it commands the support of only a fraction of those whom it affects, its modification or ultimate abandonment confidently may be predicted.

Dr. Steinman, an ardent advocate of registration, would have us believe that the very future of the profession lies in the extension and enforcement of such enactment and that only therethrough can the standing and standards of the profession be established and maintained. If he is right the question is one of major importance.

Present Extent of Registration

It is perhaps fortunate that the procedure has been in effect sufficiently widely to permit the gathering of some facts as to the extent to which the profession has arrayed

itself under the legislation, whether voluntarily or by enforcement.

In November 1934 American Engineering Council analyzed the 1930 census. 226,000 listed themselves as engineers. 214,000, or 95 per cent, were in the fields of civil, mechanical, and electrical engineering; 102,000 in the first and 112,000 in the other 2. The paper states that 85 per cent of the engineer population (or 192,000) are located in the 31 enacting states. It gives the number registered as 45,000, only 24 per cent of those affected.

The census recorded 44,400, or 44 per cent, of the civil engineers as exercising the relation in which the public needs to be protected, and 29,200, or 26 per cent, of the mechanical and electrical engineers. Of the total, 73,600, about 34 per cent, are in this relation. The total registration, therefore, is only 73 per cent of those registrable and listed as offering their services for hire or in public employment. Actually the fraction is less, since it is known that the registration includes many in private relation.

It would not appear from the above that registration has been adopted enthusiastically by the profession as a whole, nor even by those of the profession who are in that public relation whose control is the purpose of the legislation.

Equally, it would not appear that any measures of enforcement adopted had been outstandingly effective. For instance, the paper cites 348 violations—varying in character—as having received determinative consideration and of these 322 in the single state of New York. Undoubtedly there were more, but compared with the numbers involved almost any reasonable figure would be a negligible fraction.

Some Provisions of the "Model Law"

Obviously, there must be reason for this attitude. May it not be found in the probable effect of the legislation on the 66 per cent of the profession who are in private employment, as distinguished from the 34 per cent who occupy a public relation? Examination of the "model law" may provide some light.

Provisions which deny to qualified engineers the right to use the title of engineer in transactions which in no substantial degree affect the public interest, will surely not command the support of the individuals concerned. Yet these are the underlying bases of the "model law" and of much of the legislation.

Provisions that would compel the licensing of every member of the engineering staff of a corporation, irrespective of actual need, will surely not command the support of either the engineers involved or of the corporation. Yet this procedure is advocated.

The legislation to be practical must command extended respect and support. It must accomplish the actual need and attempt no more. That actual need is the protection of the public against incompetence and fraud. Whatever advantage the profession may gain must be incidental to this purpose.

That advantage will largely accrue to those members of the profession who offer their services to the public on a fee basis, or those in public employment: federal, state, and municipal.

The advantage to those in private employment is at least problematical. Registration will not increase their compensation. This will be based upon no formal standards, however authoritatively adopted, but on the employers' intimate knowledge and estimate of capability and desirability. The standards can take no cognizance of qualifications other than engineering per se. They are necessarily confined to the minimum qualification for the title. In fact, such men are actually handicapped. The effect of the legislation (using the "model law" to illustrate) is to forbid use of the title "engineer" to any unregistered or unlicensed person; this, whether or not he has public contact or responsibility and even though an acknowledged leader in the profession.

An engineer, formally "certified into the profession" under procedure now contemplated by the Engineers' Council for Professional Development (E.C.P.D.) would risk fine and imprisonment by unlicensed use of the title. Such a privately employed "certified" engineer could not use the title in contact or correspondence with his employer's customers, even though they are fully satisfied of his competency. And he must be licensed not merely in his own state but in that of the customer. A traveling engineer must be licensed in each state he visits. State reciprocity is hoped for but not achieved. A research engineer whose work is wholly within walls must be licensed. There is no differentiation between those offering their services to the public for hire and those who have no public function. The unwarranted cost and the handicaps involved are obvious.

In this respect the legislation differs from that of other professions. In law and in medicine it is directed to persons engaged in those occupations for hire and who offer their services to the public.

Fees and Costs of Registration

As to fees: The paper states that fees for the original registration certificate vary from $5 to $25. Figures given for 26 states in an analysis made by Western Society of Engineers indicate 16 states as requiring $25, 3 states $20 and 7 states $15. Of the 6 of the above 26 states which include the major engineering population, 4 require $25, 1—$20 and 1—$15. The "model law" suggests $25.

A fair average would probably be $20. This also is indicated by a suggestion of state acceptance of a $10 fee when an additional $10 fee has been paid to a central examining agency.

The paper gives renewal fees correctly in substance as ranging from $1 to $5. From the same analysis it appears that 1 state requires $10; 12—$5; 2—$3; 2—$2.50; 4—$2; and 5—$1. Five of these $1 states are included in the 6 with major engineering population; the sixth requires $5. A fair average might be of the order of $3.

The paper speaks of the cost as small. Is it so small? Assuming the above figures and a final registration of only $^1/_3$ of the 226,000 recorded in the 1930 census, the states will collect from the profession $2,260,000 for initial fees and $339,000 annually for renewals. And this covers only licensing in the registrant's home state. The amounts will be increased by the multiple licensing essential to many.

But fees alone may not measure the total cost. The paper expresses its belief that the profession needs to "make its influence felt in legislative councils." This can be done only by country-wide organization, if undertaken systematically, and funds will be required. Furthermore, there is no evidence that the present enforcement measures are effective, and more drastic ones may well be instituted. If they are employed, fees will surely not diminish.

The paper expresses the belief that in time legislators will be educated to appreciate that at least half the total cost of registration should be contributed by the state, since the law is primarily for the protection of the public. Is this not, perhaps, slightly too optimistic?

Is there not also perhaps too much of optimism in anticipating any general acceptance of that provision of the "model law" (section 9) requiring that all funds derived from registration shall be isolated and used solely to advance the purposes of the law? This is contrary to the fiscal policy of some states and the paper indicates none in which it is in effect. On the contrary New York made a profit of $300,000, Colorado established an engineering reference library from surplus, and Oregon's attorney-general approved an advertising campaign.

As the paper states, the fees are not intended as a source of revenue for the states, but so long as legislators are human this factor will probably not be absent.

State Boards of Registration

As to state boards of registration: The "model law" (section 3) provides most admirably for appointment by the governor from nominations made by representative engineering societies. But these positions carry compensation. Clerical and other assistants must be hired and expense incurred and reimbursed. Is one cynical in believing that there will be reluctance on the part of the practical politician in incorporating the provision? Turn then to the record.

But 2 states—Louisiana and Wisconsin—require nomination by engineering societies. Fifteen states leave appointment with the governor with provisions as to minimum age, registration, length of practice and diversification. Five add to these provisions only the requirement of membership in good standing in a recognized engineering society. Three leave appointment to state agencies other than the governor and one provides no method of appointment. Incidentally, there is no definition of "recognized engineering society."

Whatever may be the intent, is there such probability of the maintenance of a plane of service and ideals by boards so appointed as to warrant the transfer to them of the duty of establishing and enhancing the standards and the dignity of the profession?

Procedures Open to Engineers

Dr. Steinman may be right in saying that registration is the only means whereby legal force and sanction can be applied to certain problems of the profession, but is he right in implying that only therethrough

can the dignity of the profession be maintained and the public impressed with the fact that engineering is a learned profession?

Cannot the profession, by procedure of its own, evolve the minimum standards which are in its opinion necessary to the title of engineer, and can it not devise means for according that title to those who meet those standards and withholding it from those who do not?

Such standards would be prepared with registration constantly in view and probably co-operatively with the designated authorities. Standards so prepared would be almost automatically accepted and would be a major contribution to uniformity. Equally, they would be permanently without the field of politics.

When accorded the title of engineer should not the recipient (save when he offers his services to the public for hire) be left free to determine for himself the desirability of registration?

If this is the desirable condition, changes must be induced in much existing enactment. The first step in such a procedure would seem to be so to modify the "model law" as to assure for it the support of all elements within the profession. These modifications should be conceived with but a single purpose, *viz:* the adequate protection of the public against incompetence and fraud. There should be no attempt to bring within the law those whose registration is not essential to that purpose. Subject to these fundamentals they should be so drawn as to reflect practical considerations as exemplified in the legislation thus far enacted.

The "model law" brings within its scope all persons who do any of the things included within the definition of professional engineering, even though they do it without compensation. It provides:

> That in order to safeguard life, health, and property, any person practicing or offering to practice the profession of engineering***** shall hereafter be required to submit evidence that he is qualified so to practice and shall be registered as hereinafter provided; and it shall be unlawful for any person to practice or offer to practice the profession of engineering,***** in this state, or to use in connection with his name, or otherwise assume, use, or advertise any title or description tending to convey the impression that he is a professional engineer******, unless such person has been duly registered or exempted under the provisions of this act.

Section 2 defines the term "professional engineer" as one who is qualified to engage in engineering practice. It then defines engineering practice in detail, but with complete omission of any reference to holding one's self out to the public for hire as a professional engineer, thereby including all qualified engineers.

Section 17 provides that corporations, etc., may practice professional engineering only if such practice is carried on by registered engineers.

It exempts, section 20 (*c*), an employee or a subordinate of a person holding a certificate of registration "provided his practice does not include responsible charge of design or supervision." By inference it does not exempt such an employee or subordinate if the practice is consultation, investigation, evaluation, or planning—only design or supervision.

Unless some modification is made it would appear to be impossible for anyone not now meeting the requirements for a licensed engineer ever to become one. The law requires 4 or more years of active practice. The candidate cannot individually practice engineering without a license, the employer can use only licensed engineers and "the mere execution, as a contract, of work designed by a professional engineer, or the supervision of the construction of such work as a foreman or superintendent shall not be deemed to be actual practice in engineering work." (*Model Law*)

These provisions should be clarified to express accurately the intent, but one thing seems evident: The title "engineer" may not be used by anyone save under registration. Naturally the exemptees are debarred.

Surely the desire of the profession and of the individual will be that the title be employable, once qualification has been established, and subject only to the purposes of the legislation.

This clarification would result if the sections were reworded somewhat as follows:

> *Section 2. Definitions.* The term "professional engineer" as used in this Act shall mean a person who, by reason of his knowledge of mathematics, the physical sciences, and the principles of engineering, acquired by professional education and practical experience, is qualified to engage in professional engineering practice as hereinafter defined and holds himself out to the public for hire as practicing professional engineering.
>
> The practice of professional engineering within the meaning and intent of this Act includes any professional service to the public for hire, such as consultation, investigation, evaluation, planning, design, or responsible supervision of construction or operation, in connection with any public or private utilities, structures, buildings, machines, equipment, processes, works, or projects, wherein the public welfare, or the safeguarding of life, health or property is concerned or involved, when such professional service requires the application of engineering principles and data.
>
> *Section 17. Firms, Partnerships, Corporations, and Joint Stock Associations.* A firm, or a co-partnership, or a corporation, or a joint stock association may engage in the practice of professional engineering in this State, provided only such practice is carried on under the general supervision of a professional engineer, registered in this State.
>
> *Section 20. Exemptions.* The following persons shall be exempt from the provisions of this Act, to wit:
>
> (*c*) An employee or a subordinate of a person holding a certificate of registration under this Act or of any firm, co-partnership, corporation, or joint-stock association, authorized to practice professional engineering in accordance with the provisions of Section 17 hereof, or an employee of a person exempted from registration by classes (*a*) and (*b*) of this Section.

As to state practice in exemption: The analysis of 26 states made by Western Society of Engineers indicates that the laws as enacted in all except 6 specifically permit corporations, etc., to engage in the practice of professional engineering, provided those in responsible charge of the work are registered.

21 States exempt employees of registered engineers, 13 unqualifiedly, and 8 including the qualification that the work does not involve responsible charge. One which does not so exempt does exempt engineers employed by railroads or other interstate corporations whose employment is confined to such corporation. Other exemptions run to employees of public service corporations in varying terms.

Engineers Should Evolve the Standards

The "model law" provides for the setting up of standards by the states. Will not the dignity and standing of the profession be enhanced if it evolves for itself the standards which qualify for the title of "engineer"? Would not there be more assurance of appropriate standards and of their maintenance and uniformity than through legislative enactment? It is true that states may not delegate their powers unduly, but would not such a self-evolved standard lead in the fixing of state standards? Should not the profession actively forward the establishment of such a standard?

A procedure under contemplation by the E.C.P.D. would seem to provide a basis for such self-determination. Briefly it proposes:

> 1. The preparation by agreed methods of a list of approved engineering schools (the legislation demands such a list) and a uniform procedure in the granting of degrees.
> 2. Certification into the profession of engineering (carrying the right to use the title of engineer and to corporate membership in engineering societies) only after a period of practical experience and the establishment of qualification by examination or the equivalent.
> 3. Qualification standards to be at least equivalent and probably exceeding those established by legislation.

There is warrant for these changes in the legislation. The admitted animating purpose is the protection of the public against incompetency and fraud. A "certified" member of the profession in private employment could not be held incompetent if the standards on which his certification is based equaled or exceeded those of the legislation. His motive and opportunity for public fraud would be nil unless he likewise initiated a public relation and he would then be liable under the law.

It is believed that an embodiment of the suggestions herein made would be a step toward what must be the considered desire of the profession. It would afford the public the needed protection. It would put the profession in the desired dignified position before the public of initiating its standards of and by itself instead of having them imposed by law. It would substitute self determination for forced regimentation. It would make for uniformity of requirement. It would largely remove licensing from the field of political considerations. It would enormously simplify the process of enforcement. It would reduce the cost.

Very truly yours,

Arthur W. Berresford (A'94, M'06, F'14, member for life, and past-president)
418 Central Park West,
New York, N. Y.

Improving Section Meetings

To the Editor:

I suppose many Section chairmen face the same problem that I did while chairman of the Institute's Boston, Mass., Section in the matter of papers for their meetings. There seems to be a strong feeling in the Sections that they should have papers prepared especially for them by engineers of more or less authority on the subject selected and be presented in person before their meetings. I think this is entirely unnecessary and unwise.

It is quite a job for the Section officers to plan such a series of meetings during the Summer or early Fall carrying through their term of office. The individuals who are selected to be the authors are oftentimes busy on other things which seem to them more worth-while, and many times do not care to devote the time to prepare a special paper for the local group. I have found instances where an individual has been brought some 200 or 300 miles to present such a paper, and after having spent considerable time to prepare it (and probably he has prepared a very good paper) he then has the pleasure of presenting it before a small meeting, likely in many cases to be of the order of 30 to 50 individuals. It quite often happens that a good many of those present know very little about the subject, going to the meeting largely to meet their friends or perhaps with the thought of learning something about a subject in which they have only some passing interest.

I believe the value of any paper which is presented is, to a great extent, dependent on the discussion which that paper brings forth. At a meeting such as above mentioned there is apt to be very little discussion. Then, after the meeting has closed, the author is thanked by the Section officers and goes on his way and his paper received no further attention. This is too much of a burden all around. It is unnecessary and should be largely eliminated.

There are many valuable papers presented before the Institute's national conventions and District meetings, and while they receive much attention at these meetings, they can also receive, very profitably, consideration from many of the Sections at a later date. It should be no reflection on anybody to have such a paper presented at one or more Section meetings and thoroughly discussed by those present. It should not even be considered necessary for the author to present his paper in person, as that can readily be done by a local engineer who is familiar with the subject, and who very likely heard the original presentation and discussion. Such a procedure not only eliminates expense and trouble, but enables the individual member of a Section who was not able to attend the convention or District meeting to get much more out of the paper then he could by simply reading it and the discussion in ELECTRICAL ENGINEERING or the TRANSACTIONS. It is quite possible that it would bring forth additional valuable discussion which could be incorporated in the Institute's publications as a part of the discussion of that paper. This would also be helpful to the paper where time limitation prevented full discussion at the original presentation. I know that such a procedure is followed by some of the engineering societies in Great Britain and I have been surprised to read some of the discussions that a good paper brings forth in a local meeting.

I believe such a procedure would make the papers presented before the Institute of much more value to the local men and would make the meetings of local Sections more interesting and valuable to those present. As I said before, it would eliminate expense and nuisance, and here I mean the nuisance of more or less sand-bagging a busy man to prepare a paper when he does not feel the urge and when he knows that after being presented before a small group of people it will be buried and forgotten.

The technical program committee probably receives some papers that fail to meet requirements for a regular meeting of the Institute, yet at the same time have merit. Why not accept them for a Section meeting and so advise the Sections? Probably several sections would be glad to use such papers and the work of the authors would not be wasted.

These schemes seem to have considerable merit and should make the work of the Institute more valuable to the local member. I would like to see it tried out before some of our prominent Sections.

Very truly yours,

I. E. MOULTROP (A'10, F'29)
Boston, Mass.

Characteristics of a Group of Engineers

To the Editor:

There is food for thought in the article by Thomas Spooner in the December 1935 issue of ELECTRICAL ENGINEERING, pages 1571–6, in which he compares ratings of various qualities given to a group of engineers released during the depression from their first jobs with those given a group of their fellow workers who were retained.

There is some danger, however, of drawing incorrect conclusions from the table of "Faults and Weaknesses of Men Released" as engineers, unless the percentages deficient in each quality are compared directly with percentages deficient in the same qualities among men retained. For example, we find a very high percentage of men released rated as deficient in aggressiveness, and might conclude that aggressiveness is a requirement for engineering success, until we observe that almost as many retained engineers were rated as lacking in this quality. Aggressiveness cannot, therefore, apparently be regarded as a determining factor in engineering success in the company from which the data are taken.

The accompanying figure 1 shows graphically the comparison between the percentages of released and retained engineers for each of the qualities, as read from the charts presented by Mr. Spooner.

The graph indicates that the possession of an unimpressive personality, lack of ability to sell oneself, lack of initiative, and failure to improve oneself technically, which were characteristics of large percentages (26–45) of released employees, were found in a much smaller percentage of retained employees, and may therefore be regarded as factors determining retention.

In addition, ingenuity and analytical ability gain importance when viewed as means of differentiating between the 2 groups, for although the percentages of released employees rated as lacking in these traits are only 20 and 22, respectively, the percentage of retained employees rated in the same way is only 3 per cent in each case.

Diffidence, lack of aggressiveness, and insufficient evidence of ambition, which were named as faults of rather large percentages

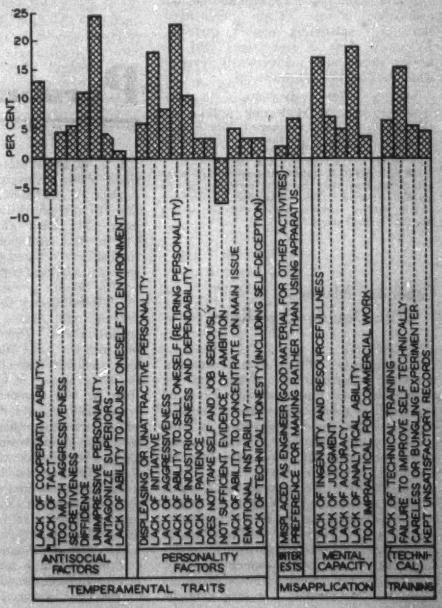


Fig. 1. Comparison of faults and weaknesses of men released and men retained

The percentages refer to the difference between the percentage of engineers deficient in the particular quality among those released and the corresponding percentage among those retained

Positive figures indicate a larger percentage in the released group; negative figures, a larger percentage in the retained group

of men released, are seen to be relatively unimportant as factors in retention, since these traits are found in percentages almost, if not quite, as large among retained engineers.

Lack of tact is actually a weakness of a larger percentage of the retained engineers than of those released.

The absolute significance of the difference in percentages depends on the number of cases in each group and these numbers were not given in the original article. But this graph indicating the relative importance of various qualities in differentiating between these groups may be of interest to those who read Mr. Spooner's illuminating article.

Very truly yours,

ELINOR G. HAYES
Hawthorne Works, Western Electric Company,
Chicago, Ill.

Electron Tubes for Resistance Welding

To the Editor:

In the January 1935 issue of ELECTRICAL ENGINEERING on page 90 appears a circuit diagram, figure 14, of an electron tube control for resistance welding (part of a paper "Application of Electron Tubes in Industry," by D. E. Chambers, pages 82–92). The author gives a good explanation of the theory of operation of the circuit. However, the action as he explains it, does not apply to the connections as shown in figure 14 of his paper.

I have found that if the grid and cathode connections of tube T4 are interchanged, that his explanation applies perfectly. Evidently these 2 connections into the timing circuit were inadvertently reversed when the diagram was drawn up.

Very truly yours,

W. M. BAUER (A'29)
Instructor in Elec. Engg.,
Northwestern University,
Evanston, Ill.

(EDITOR'S NOTE: Information received from the author indicates that the above correction can be made by reversing the 2 leads which connect the section labelled "timing circuit" with the section labelled "control circuit.")

Capacitor Motor With Double Cage Rotor

To the Editor:

It frequently happens that a capacitor motor is required to give a high starting torque, and a low slip when running at rated load. These requirements are antagonistic when a simple squirrel cage rotor is used, because a high starting torque calls for a high rotor resistance, whereas a low slip calls for a low rotor resistance.

The double squirrel cage rotor, when properly designed, is able to meet both of these requirements in the case of polyphase motors, where it has been used for some 30 or 40 years. So far as known the arrangement has not been used in capacitor motors. However, it seems possible that it should be useful for this purpose. It may even be that such rotors will save enough condenser capacity to cover their greater cost.

In 1929 W. J. Morrill ("The Revolving Field Theory of the Capacitor Motor," A.I.E.E. TRANSACTIONS, volume 48, April 1929, page 614) gave a method for calculating the performance of the ordinary capacitor motor. If the double cage is used, the same process will apply when Morrill's R_f and X_f are figured with the following values of R_2 and X_2,

$$R_2 = \frac{r''[r'^2 + (\delta x')^2] + r'[r''^2 + (\delta x'')^2]}{(r' + r'')^2 + \delta^2 (x' + x'')^2}$$

$$\cong \frac{r''[r'^2 + (\delta x')^2] + r'r''^2}{(r' + r'')^2 + \delta^2 x'^2}$$

$$X_2 = \frac{x''r'^2 + x'r''^2 + \delta^2 x'x''(x' + x'')}{(r' + r'')^2 + \delta^2(x' + x'')^2}$$

$$\cong \frac{x'r''^2}{(r' + r'')^2 + \delta^2 x'^2}$$

using $\delta' = S$ = slip of forward field; for the backward field, Morrill's R_b and X_b are figured from these same expressions for R_2 and X_2, except that $\delta = 2 - S$ is used. This simply means that in the single cage the rotor resistance R_2 and rotor leakage reactance X_2, both in stator terms, are "constants," while in the double cage they are functions of the slip and so each have different values in the 2 directions and different values at different slips.

In the above equations:

δ = slip in the polyphase motor formulas.
S = slip in the capacitor motor.

These equations are obtained from the equivalent network of the polyphase induction motor. The justification for using them here is that the gap flux in the condenser motor may be regarded as the resultant of 2 revolving fields which move in opposite directions. Each of these fields is physically identical with the revolving field in the polyphase machine. For this reason, the polyphase formulas must apply.

In the book "Modern Polyphase Induction Motors," translated from the German of F. Punga and O. Raydt by H. M. Hobart, will be found not only the derivation of these formulas, but rules for selecting the rotor proportions necessary to obtain a prescribed shape of speed-torque curve are given also. It seems possible that these rules will apply with fair accuracy also to the capacitor motor, or that they can be modified to fit. The symbols are:

r' = resistance of inner cage referred to primary main winding.
r'' = resistance of outer cage referred to primary main winding.
x' = leakage reactance of inner cage referred to primary main winding, counting only that part of the leakage flux which links with the inner cage alone.
x'' = leakage reactance of outer cage referred to primary main winding, counting only that part of the leakage flux which links with the outer cage alone. This is usually a small quantity and frequently is neglected.

That part of the rotor leakage flux which is common to both cages, such as rotor zigzag, and rotor tooth tip, is referred to the stator main winding and considered as part of the primary leakage reactance.

Very truly yours,

A. F. PUCHSTEIN (A'20, M'27)
Robbins & Myers, Inc.,
Springfield, Ohio

Personal Items

J. V. B. DUER (A'15, F'29) electrical engineer of the Pennsylvania Railroad, Philadelphia, Pa., has been appointed to the position of chief electrical engineer of the company. Mr. Duer was born at Poultney, Vt., in 1882, and graduated from Stevens Institute of Technology in 1903, with the degree of mechanical engineer. Upon graduation he became an electrical apprentice for the General Electric Company, spending one year at Lynn, Mass., and 2 years at Schenectady, N. Y. From 1906 until 1910, he was with the Long Island Railroad as wireman, electrical inspector, and chief clerk to the train master of electrified lines. In 1910, he was transferred to the Pennsylvania Railroad and for the following 3 years, while electric operation was being inaugurated into Pennsylvania Station, New York City, was foreman of motormen at New York, having responsible charge, qualifying, supervision, and discipline of men operating electric locomotives and trains, as well as supervision of the electric locomotives. From 1913 to 1919, he was assistant electrical engineer in charge of electrical work east of Pittsburgh and Erie, Pa., for the Pennsylvania Railroad, and was promoted to electrical engineer of that division in 1919. In 1920 his duties were extended to cover the entire system of the Pennsylvania Railroad, and he held this position until his recent promotion. In the recent project of electrifying between New York, Philadelphia, Baltimore, and Washington, Mr. Duer supervised not only the roadway construction, but also the designing and production of the new streamlined electric locomotives. Mr. Duer has served the Institute as a

J. V. B. DUER

A. A. KRONEBERG

F. C. LINDVALL

M. M. ROCKWELL

member of its committee on transportation for many years, having been chairman 1926–28. He has presented articles on electric traction before the Institute and other organizations. In 1922, he was a delegate to the International Railway Congress in Italy, and in 1930 was reporter for America to the International Congress on Electric Locomotives for Main Line Traction. He is chairman of the electrical section of the Association of American Railroads, and a member of the St. Nicholas Society of New York.

Mabel Macferran Rockwell (A'28, M'35) assistant engineer, Metropolitan Water District of Southern California, has, with her co-author, A. A. Kroneberg (A'28, M'34) been awarded the 1934 A.I.E.E. Pacific District prize for best paper, for their paper "Power Limits of 220 Kv Transmission Lines." Mrs. Rockwell was born in Philadelphia, Pa., in 1902. She was educated at Bryn Mawr College, and became interested in engineering through science courses there and summer jobs with Leeds and Northrup Company. She obtained her degree of bachelor of science in mathematics from Massachusets Institute of Technology in 1925. After one year, 1925–26, as Elwell fellow at Stanford University, Calif., working with the late Prof. Harris J. Ryan (A'87, M'95, F'23, and past-president) in the million volt laboratory, she received the degree of electrical engineer from that institution in 1926. She then entered the testing department of the Southern California Edison Company, Ltd., being engaged until 1928 on transformer testing, research, and development work; with others she obtained patent for the "Serjdetour" telephone protector. From 1928 until 1931 she was technical assistant to the operating engineer of the Southern California Edison Company, specializing in studies of high voltage power transmission and system stability. During this period she helped to work out the economic design of the company's proposed Boulder Dam transmission line, upon which the prize winning paper was based. Since 1931 she has been assistant engineer of the Metropolitan Water District of Southern California, at Los Angeles, being engaged in analysis of electrical problems connected with the Colorado River Aqueduct. These have included economic and engineering studies for the construction power system and the main transmission system. She also has done considerable work on the Colorado River power development problem. Mrs. Rockwell has presented 2 previous Institute papers, one of which "Parallel Operation of Transformers" received the 1929 initial paper prize for the Pacific District. As announced in Electrical Engineering for July 1935, page 787, Mrs. Rockwell and another Institute member, E. W. Rockwell (A'21, M'35) were married on June 7, 1935. She is a member of Sigma Xi.

R. W. Sorensen (A'07, M'13, F'19, and past vice president) senior professor of electrical engineering at California Institute of Technology, Pasadena, was honored at a special meeting held at Pasadena in June 1935, and attended by 120 engineers, scientists, educators, and city officials. A hand-illuminated parchment testimonial was among the gifts bestowed upon him, and a scroll was presented him by officers of the Institute's Los Angeles Section. The occasion marked 25 years of service given by Professor Sorensen to California Institute of Technology. Professor Sorensen, born at Alta Vista, Kan., in 1882, was educated at the University of Colorado at Boulder. Entering the test department of the General Electric Company at Schenectady, N. Y., in 1905, he became foreman of the test department the following year, a few months later entering the commercial section of the transformer engineering department of the company. In 1910, he became associate professor of electrical engineering at California Institute of Technology (then Throop Polytechnic Institute). He was made full professor in 1911 and has held that position continuously since then. In addition to his educational work, he has engaged in a consulting practice, and is very active in local affairs. He has served the Institute on many of its committees and other activities, and has presented several Institute papers.

A. A. Kroneberg (A'26, M'34) technical assistant to operating engineer, Southern California Edison Company, Ltd., Los Angeles, has, with his co-author, Mrs. Mabel Macferran Rockwell (A'28, M'35) been awarded the 1934 A.I.E.E. Pacific District prize for best paper for their paper entitled "Power Limits of 220 Kv Transmission Lines." Mr. Kroneberg was born in Ekaterinbourg, Russia, in 1899, and after being educated at schools in Russia came to the United States in 1923, when he entered the electrical engineering course of California Institute of Technology. Following graduation in 1926, he entered the training course of the Southern California Edison Company, Ltd., and became electrician at the Long Beach steam station. Mr. Kroneberg was appointed to his present position in 1931. He is a member of Tau Beta Pi.

W. E. Wickenden (A'07, M'13) president of Case School of Applied Science, Cleveland, Ohio, has been awarded the 8th Lamme Medal of the Society for the Promotion of Engineering Education, which was presented to him at the 43d annual meeting of that society at Atlanta, Ga., June 26, 1935. Mr. Wickenden was born at Toledo, Ohio, in 1882. After graduating from Denison University, Granville, Ohio, with the degree of bachelor of science in 1904, he took graduate work in electrical engineering at the University of Wisconsin, Madison for 2 years. After serving as an instructor at Rochester (N. Y.) Mechanics Institute, and at the University of Wisconsin, for a few years, he was, between 1909 and 1916, assistant professor of electrical engineering in Massachusetts Institute of Technology, Cambridge, becoming associate professor in the latter year. In 1917, he became supervisor of educational work for the engineering department of the Western Electric Company, New York, and the next year, manager of the company's personnel department. He later became chairman of the company's personnel committee. Doctor Wickenden joined the American Telephone and Telegraph Company, New York, N. Y., in 1921, as assistant vice president in charge of the recruiting and development of supervisory and technical personnel for the Bell system. Between 1923 and 1929, he was director of investigation for the Society for the Promotion of Engineering Education, and since 1929 has been president of Case School of Applied Science. Doctor Wickenden was president of the S.P.E.E. during 1933–34. He has presented many papers and addresses before the Institute and other societies, and is the author of "Illumination and Photometry." He is a member of several other societies, and has received a number of honorary degrees.

F.C. Lindvall (A'26) assistant professor of electrical engineering, California Institute of Technology, Pasadena, has been awarded the 1934 A.I.E.E. Pacific District prize for initial paper for his paper "A Low Discharge Anemometer." Professor Lindvall was born at Moline, Ill., in 1903. He was educated at the University of California and the University of Illinois, receiving the degree of bachelor of science from the latter institution in 1924. During 1924–25 he was with the Los Angeles (Calif.) Railway Corporation in electrolysis work. During 1925–28 he was teaching fellow at the California Institute of Technology, receiving the degree of doctor of philosophy in electrical engineering and physics in 1928. For the following 2 years he was in the engineering general department of the General Electric Company, Schenectady, N. Y. He has been assistant professor of electrical engineering at California Institute of Technology since 1930.

D. C. Jackson, Jr. (A'23, M'26, F'30) who has been head of the department of electrical engineering of the University of Kansas, Lawrence, is now director of Lewis Institute, Chicago, Ill. He will, however, devote some time to electrical engineering at the University of Kansas until February 1936. Professor Jackson was born at Madison, Wis., and after receiving the degree of bachelor of arts at Harvard University served in the U.S. Army as a coast artillery officer. He then entered the cooperative engineering course at Massachusetts Institute of Technology, where he received the degrees of bachelor of science and master of science in 1921 and 1922, respectively. In the latter year he went to the University of Missouri, Columbia, as an instructor in the department of electrical engineering, and 2 years later was appointed assistant professor in charge of electrical engineering at Trinity College, Duke University, Durham, N. C. In 1925 Professor Jackson went to Louisville, Ky., as professor of electrical engineering and head of the combined departments of mechanical and electrical engineering at the Speed Scientific School, University of Louisville, and since 1930 he has been at the University of Kansas. Professor Jackson is a member of the Institute's committee on education and the committee on power transmission and distribution, and has served as chairman of the Louisville Section and as a Branch counselor. He is also a member of The American Society of Mechanical Engineers and the Society for the Promotion of Engineering Education, and has presented a number of papers.

D. R. Tibbetts (A'35) in charge of design and operations, San Francisco-Oakland Bay Bridge Construction Radiotelephone System, San Francisco, Calif., has been awarded the 1934 A.I.E.E. Pacific District prize for Branch paper for his paper "San Francisco-Oakland Bay Bridge Construction Radiotelephone System." Mr. Tibbetts was born at Berkeley, Calif., in 1911. During summer vacations he did work on hydroelectric development for the Pacific Gas and Electric Company, in 1929, and for the dial central office installation of The Pacific Telephone and Telegraph Company; also installation of independent telephone and signal system, 1931 and 1932. He graduated from the University of California, Berkeley, in 1934, with the degree of bachelor of science in electrical engineering. During 1934 and 1935 he did consulting communications work for the American bridge division of the United States Steel Corporation, the department of public works of the state of California, and the East Bay Municipal Utility District. At present, and since 1933, he has held his present position.

D. C. Jackson (A'87, M'90, F'12, past-president and member for life) has accepted the invitation of the Institute of Electrical Engineers of Japan to deliver the Iwadare lectures on electrical engineering topics this year. Professor Jackson will leave Cambridge in September, arriving in Japan in October. As part of the Iwadare Foundation a series of lectures is given from time to time by noted American electrical engineers, for the purpose of bringing to Japan American advances and practices in the electrical art. In connection with Professor Jackson's retirement in June 1935 as head of the department of electrical engineering of Massachusetts Institute of Technology, Cambridge, after 28 years of service in that position, a brief biographical sketch appeared in Electrical Engineering for May 1935, pages 574–5. He recently was nominated by the Engineers' Council for Professional Development to be a member of the delegatory committee for the accrediting of engineering schools in region No. 1, and has been appointed to that committee.

R. H. Dearborn (A'07, M'14, F'30) head of the department of electrical engineering and since 1933 acting dean of the school of engineering and industrial arts at Oregon State College, Corvallis, has been appointed dean. He was born at Salem, Ore., and received the degree of bachelor of arts at Willamette University and of electrical engineer at Cornell University. Following graduation from the latter in 1900 he was employed by the Portland General Electric Company until he became professor of electrical engineering at the University of Oregon in 1902, establishing the department. Dean Dearborn was head of this department from 1904 to 1914, when he became head of the department of electrical engineering at Oregon State College with the combining of all the electrical engineering courses of the state at this college. He held this position since that time, and in addition during 1913–15 was electrical engineer for the Public Service Commission of Oregon. He occasionally has written technical articles.

C. B. Aiken (M'35) member of the technical staff of Bell Telephone Laboratories, Inc., New York, N. Y., who since the death of J. H. Morecroft (A'06, M'12, F'19) in 1934 has been teaching his courses in electronics at Columbia University, has been appointed associate professor of electrical engineering in charge of the department of communication engineering at Purdue University, Lafayette, Ind. Doctor Aiken received the degree of bachelor of science from Tulane University, and from Harvard University the degrees of master of science in electrical communication engineering, master of arts, and doctor of philosophy. Following experience in geophysical exploration work, he became a member of radio apparatus development department of Bell Telephone Laboratories, Inc., in 1928, and 2 years later was made supervisor in charge of broadcast receiver design. Doctor Aiken, a member of the Institute of Radio Engineers, is the author of a number of papers on radio broadcasting.

J. G. Barry (A'03) senior vice president of the General Electric Company, Schenectady, N. Y., was recently elected to an honorary vice presidency and has retired, although he will be available for consultation. Mr. Barry has been with the General Electric Company and its predecessor, the Thomson-Houston Electric Company, since 1890, going to Schenectady in 1894 as a member of the railway department. Later he became assistant manager of the department, and in 1907 was appointed manager. In 1917 the duties of general sales manager were added, and in 1922 he was appointed a vice president, serving as active head of the apparatus sales organization. Mr. Barry was for many years a member of the executive committee of the American Electric Railway Association.

K. M. Klein (A'35) electrical engineer, Oregon State Highway Commission, has, with his co-author E. J. Harrington, been awarded the 1934 A.I.E.E. North West District prize, for their paper "The Influence of Ground Plane Proximity Upon the Polarity of Sphere-Gap Spark-Over." Mr. Klein was born at Portland, Ore., in 1912, and graduated from Oregon State College in 1934 with the degree of bachelor of science in electrical engineering, having majored in power work. During the summer of 1931, he assisted in electrical testing on the Rogue River Bridge in Oregon, and since graduation has been in the employ of the Oregon State Highway Commission as electrical engineer. Most of his work has been with the bridge department in connection with movable span bridges. While a student at Oregon State College, he was secretary of the Student Branch of the A.I.E.E. He is a member of Eta Kappa Nu, Tau Beta Pi, and Sigma Tau.

O. H. Caldwell (A'13, M'22) formerly federal radio commissioner, and more recently editor of *Radio Retailing* and *electronics*, both published by the McGraw-Hill company, has become editor of *Radio Today*, a new magazine which is being brought out by Caldwell-Clements, Inc., New York, N. Y. Doctor Caldwell has served the New York Electrical Society as president 1932–34, and is a director of the Institute of Radio Engineers, and trustee of the New York Museum of Science and Industry. He is a member of radio committees of several organizations, and has become well known for his broadcasts over nationwide networks, in his effort to bring better radio reception to American homes. Joining the McGraw-Hill company as associate editor of the *Electrical World* in 1910, he edited *Electrical Merchandising* 1916–27, *Radio Retailing* 1925–35, and *electronics* 1930–35.

R. W. Warner (M'28) professor of electrical engineering, University of Kansas, Lawrence, has been appointed exchange professor at Massachusetts Institute of Technology for one year. Professor Warner is a graduate of Washburn College, Topeka, Kan., and of the University of Kansas. He was an instructor in electrical engineering at the latter and at the University of Wisconsin during the period 1921 to 1923, after which he was connected with the General Electric Company and the Kansas City Power and Light Company. He returned to the University of Kansas in 1928 as assistant professor, and the following year became associate professor. Professor Warner is also a member of the Society for the Promotion of Engineering Education.

B. S. Byng (M'20, F'29) vice chairman and joint managing director of Standard Telephones and Cables Limited, London, England, has been awarded a prize for his paper "The Engineer Administrator" presented before the Institution of Electrical

Roberts, J. M., asst. prof. of E.E., University of Louisville, Louisville, Ky.
Sabbagh, E. M., asst. prof of E.E., Purdue Univ., Lafayette, Ind.
Seaman, B. C., E.E., Elliott Co., Ridgway, Pa.
Seletzky, A. C., asst. prof. of E.E., Case School of Applied Science, Cleveland, O.
Starbird, Levi C., transmission and protection engr., Southwestern Bell Tel. Co., Dallas, Texas.
Warwick, George G., supt., Vancouver Pwr. Co., Lake Buntzen, Burrard Inlet, B. C., Canada.
Wennley, R. J., asst. general mgr., I-T-E Circuit Breaker Co., Philadelphia, Pa.

26 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before Sept. 30, 1935, or Nov. 30, 1935, if the applicant resides outside of the United States or Canada.

Adam, L. G., (Member), Amer. Tel. & Tel. Co., New York, N. Y.
Baker, E. M., Bartlett Hayward Co., New York, N. Y.
Bausch, K. M., G. M. Simonson, San Francisco, Calif.
Chappell, G. C., Libbey-Owens-Ford Glass Co., Rossford, Ohio.
Chisholm, C. E., Bd. of Transportation, New York, N. Y.
Conwell, E. M., (Member), Albuquerque Gas & Elec. Co., Albuquerque, N. M.
Dunkey, F. S., (Member), Magnavox Co., Ft. Wayne, Ind.

chusetts Institute of Technology, Cambridge, has been nominated for appointment as an additional representative of the Institute upon the division of engineering and industrial research of the National Research Council. Dean Bush has been a member of several Institute committees.

Joseph Hellenthal (A'14, M'23) electrical engineer, Puget Sound Power and Light Company, Seattle, Wash., has been elected chairman of the engineering section of the Northwest Electric Light and Power Association. Mr. Hellenthal is a member of the Institute's committees on automatic stations, protective devices, and membership.

K. C. Roy (A'31) is now sales manager of The Bengal Electric Lamp Works, Ltd., Calcutta, India. Mr. Roy organized the pioneer lamp manufacturing company in India, and is a director of Electro-Chemical Industries, Ltd., and Pioneer Glass Works, Ltd.

E. W. Allen (A'03, F'22) vice president, General Electric Company, Schenectady, N. Y., has been appointed a member of the apparatus sales committee and given supervision of the contract service department of the company.

H. A. Wagner (A'98, M'03, and member for life) president, Consolidated Gas, Electric Light and Power Company of Baltimore, Md., has been elected a trustee of Stevens Institute of Technology, Hoboken, N. J.

R. V. Sprague (A'08) former electrical engineer and superintendent for D. P. Robinson and Company of Argentina, Buenos Aires, is now general electrical foreman with the U.S. Bureau of Reclamation, Boulder City, Nev.

W. S. Potter-Hanwell (A'34) former chief electrical engineer in the irrigation department of the Egyptian government at Khartoum, Sudan, has engaged in practice as a consulting engineer at London, England.

C. C. Crane (A'25, M'31) former engineer for the Northern Indiana Public Service Company, Hammond, is now electrical engineer in the bridge division of the Michigan State Highway Department, Lansing.

I. C. Blickenstaff (A'34) former plant extensions engineer, The Chesapeake and Potomac Telephone Company of Virginia, Richmond, is now staff engineer for The Chesapeake and Potomac Telephone Companies, Washington, D. C.

E. O. Shreve (A'06) vice president, General Electric Company, Schenectady, N. Y., has been appointed chairman of the apparatus sales committee, which will direct the general commercial policies of the apparatus departments of the company.

A. K. Jones (A'16 and Life Member) formerly vice president and general manager, Cia. Cubana de Electricidad, Inc., Havana, Cuba, is now connected with Cia. Chilena de Electricidad, Ltd., Santiago, Chile.

J. P. Percy (A'26) former assistant superintending engineer for the Southern Sugar Company, Clewiston, Fla., has accepted the position of chief engineer with the Aguirre Sugar Company, Inc., Central Aguirre, Puerto Rico.

Ray Raneri (A'34) electrical engineer with the Public Works Administration, U.S. Department of Interior, who has been at Washington, D. C., is now at New York, N. Y.

M. O. Troy (A'08, M'12) manager of the central station department, General Electric Company, Schenectady, N. Y., has been given supervision of central station commercial engineering.

D. H. Lewis (A'25, M'32) general manager, St. Louis County division, Union Electric Light and Power Company, Webster Groves, Mo., has been elected vice president in charge of suburban operations.

L. E. Dickinson (A'08) general manager, Mississippi River Power Company, Keokuk, Iowa, has been named vice president of the company and other affiliate companies.

H. J. Annen (A'34) is now an electrician with the Gulf Refining Company at Port Arthur, Texas.

B. J. McNellis (A'34) formerly with the International Telephone and Telegraph Company, New York, N. Y., is now with the General Electric Company at Bridgeport, Conn.

E. W. Middleton (M'31) who has been local manager for the Cia. de Electricidad del Sud Argentina at Junin, is now operating manager for the company at Buenos Aires.

H. H. Darling (A'32) who has been an electrical contractor at Smithers, B. C., Can., is now service manager for Electrical Maintenance and Repairs Company, Ltd., Toronto, Ont.

D. C. Kennedy, Jr. (A'33) formerly with the Appalachian Electric Power Company, Roanoke, Va., is now in the test department of the General Electric Company at Schenectady, N. Y.

A. N. Stanton (A'29) formerly with the T.C.U. Radio Laboratories, Fort Worth, Texas, is now vice president and chief geophysicist of Geophysical Petroleum Surveys, Inc., Dallas.

E. O. Martinson (A'33) is now a junior engineer with the Mason-Walsh-Atkinson-Kier Company at Mason City, Wash., in connection with the construction of Grand Coulee Dam.

P. N. Vassil (A'35) is now assistant cartographic engineer with the U.S. Coast and Geodetic Survey, Department of Commerce, Washington, D. C.

P. F. Williams (A'07) former assistant electrical engineer, Commonwealth Edison Company, Chicago, Ill., is now with G & W Electrical Specialty Company, Chicago.

A. L. Henry (A'31) of Perry, N. Y., is now junior engineer with the Sprague Specialties Company at North Adams, Mass.

F. J. Boehm (M'25) vice president of the Union Electric Light and Power Company, St. Louis, Mo., for the past 15 years, has been made executive vice president.

A. F. Puchstein (A'20, M'27) development engineer, Robbins and Myers, Inc., Springfield, Ohio, has been appointed chief engineer.

Ernest Lienhard (A'31) former electrical engineer with Elmac, Inc., Manila, P. I., is now connected with Red V Cocoanut Products, Ltd., Lucena, Tayabas, P. I.

R. M. Garrison (A'33) former engineer with J. H. McEvoy and Company, Houston, Texas, is now connected with the Mission Manufacturing Company at Houston.

L. A. De Beer (A'30) until recently engineer, Cablerie de Dour, Dour, Belgium, is now chief of works at the Mons School of Mines, Mons, Belgium.

R. T. Ward (A'30) former engineer with the International General Electric Company, Schenectady, N. Y., is now in London, England, where he is a sales engineer for Aluminium Union Limited.

Obituary

Benjamin Stalker Read (M'23) president of the Southern Bell Telephone and Telegraph Company, Atlanta, Ga., died July 23, 1935. He was born at Carthage, Tenn., January 21, 1876. In 1890, he entered the service of the Cumberland Telephone and Telegraph Company, at Carthage, Tenn., as messenger boy and local agent. In 1903, he became manager of this company at Owensboro, Ky., and in 1904, manager at Chattanooga, Tenn. In 1904, he became district manager for the company with headquarters at Louisville, Ky., and in this and all of the positions which he subsequently held, his responsibilities included the supervision not only of engineering, but of construction, maintenance, and operation of the telephone plant. From 1908 until 1912, he was district superintendent for the company for Louisiana and Mississippi, with headquarters at New Orleans. After a few months in 1912 as general manager of the Bell Telephone Company of Missouri, with headquarters at St. Louis, he became that year general manager of the Missouri and Kansas Telephone Company, with headquarters in Kansas City, Mo. From 1914 until 1919, he was vice president in charge of operation of the Southwestern Bell Telephone System (now the Southwestern Bell Telephone Company) operating in several western states with headquarters at St. Louis, Mo. During a portion of 1919, he also served as a member of the supervisory staff, Bell system, under United States Telephone and Telegraph Administration, with headquarters in New York City. From 1919 until 1924, he was president of The Mountain States Telephone and Telegraph Company, with headquarters at Denver, Colo., and from 1924 until his death he was president of the Southern Bell Telephone and Telegraph Company and the Cumberland Telephone and Telegraph Company with headquarters at Atlanta, Ga. Mr. Read was president of the Telephone Pioneers of America in 1925. During the World War he was a member of the War Camp Survey Committee. He was a director of the Fourth National Bank of Atlanta, and a member of several clubs in that city.

William Henry Powell (A'08, M'10, F'12) engineer in charge of d-c design, Allis-Chalmers Manufacturing Company, Milwaukee, Wis., died July 8, 1935. Mr. Powell was born in England, September 14, 1867, and came to America at 3 years of age. He attended Cornell University at Ithaca, N. Y., where he was graduated in 1890 from the mechanical engineering course. He received the degree of master of mechanical engineering from Cornell University in 1901. During 1890–91, he was in the laboratory of the Westinghouse Electric and Manufacturing Company, entering the railway department of the Edison General Electric Company in 1891. During 1892–93, he was electrical draftsman for the Mather Electric Company, Manchester, Conn.; during 1894–95, instructor in electrical engineering at Lehigh University; during 1895–96, superintendent of the Perkins Electric Lamp Company, Hartford, Conn.; during 1897–1900, chief engineer of the Keystone Electric Company, Erie, Pa.; during 1900–01 a fellow in electrical engineering at Cornell University; during 1901–02, again chief engineer of the Keystone Electric Company, and during 1902–04, engineer in charge of controllers for multivoltage systems for the Crocker-Wheeler Company, Ampere, N. J. In 1904, Mr. Powell went as electrical engineer in charge of d-c motors and controllers for the Bullock Electric Manufacturing Company, Cincinnati, Ohio, which had just become affiliated with the Allis-Chalmers company of Milwaukee. During 1907–08, he was general superintendent and works manager of the Bullock Company, moving to Milwaukee in 1908, when he became electrical engineer in charge of d-c apparatus, remaining in this position for some 27 years. Mr. Powell is perhaps best known as the inventor of the "frog-leg winding," which improved commutation in d-c machines. He was a member of the Milwaukee Engineers' Society and of Sigma Xi. Mr. Powell had served the Institute on its committees on electrochemistry and electrometallurgy 1920–22, industrial and domestic power 1915–16, and standards 1914–15; and had been chairman of the Milwaukee Section.

Lewis Fussell (A'06, M'22) professor of electrical engineering and chairman of the department of electrical engineering, Swarthmore College, Swarthmore, Pa., died July 15, 1935. He was born at Media, Pa., April 22, 1882. In 1902 he received the degree of bachelor of science in physics from Swarthmore College, and in 1903, that of master of science in electricity from Swarthmore. He studied at Cornell University in the summer of 1904, and after entering the University of Wisconsin in 1905, received the degrees of electrical engineer and of doctor of philosophy there in 1907. He had started teaching at Swarthmore College in 1903, being an instructor in physics until 1905. During 1906–07, he was an assistant in electrical engineering at the University of Wisconsin. Since 1907, he has been teaching in the electrical engineering department of Swarthmore College. About 1910, he became assistant professor, and in 1921 professor in charge of the department. Professor Fussell spent several summer vacations in electrical manufacturing and operating companies, and had done considerable consulting work, being known as a specialist in public utility engineering. He had served the Institute on its committees on education 1924–25, and production and application of light 1928–29, and as chairman of the Philadelphia Section. He was the author of "The Self-Excited Polyphase Asynchronous Generator," a technical handbook (1903) and several technical articles. He was a member of the Illuminating Engineering Society, Institute of Radio Engineers, the American Association for the Advancement of Science, and of Sigma Tau and Sigma Xi fraternities.

Membership

Recommended for Transfer

The board of examiners, at its meetings held May 29 and July 24, 1935, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Dawes, C. L., assoc. prof. of E.E., Harvard Univ., Cambridge, Mass.
Penn, Marion, gen. mgr., elec. dept., Public Service Elec. and Gas Co., Newark, N. J.
Savant, Domenico P., prof. of E.E. and dean of engg., Georgia School of Tech., Atlanta, Ga.

3 to Grade of Fellow

To Grade of Member

Almquist, Carl T., assoc. prof. of E.E., Univ. of Oklahoma, Norman.
Bathe, C. E., supt. of standards and radio, Oklahoma Gas & Elec. Co., Oklahoma City.
Bedell, William B., telephone engg., Am. Tel. and Tel. Co., New York, N. Y.
Boyd, Spencer W., cons. engr., Newcomb & Boyd, Atlanta, Ga.
Capron, R. B., asst. distrib. engr., Utica Gas & Elec. Co., Utica, N. Y.
Carter, Leonard L., E.E., Anaconda Wire and Cable Co., Hastings-on-Hudson, N. Y.
Evans, M. F., elec. supt., Wright-Hargreaves Mines, Kirkland Lake, Ont., Can.
Farrar, W. B., E.E., Mississippi River Valley Div., U. S. Government Civil Service, St. Louis, Mo.
Heinrich, Walter A., vice president and chief engr., James R. Kearney Corp., St. Louis, Mo.
Holton, Theodore R., asst. E.E., Am. Steel and Wire Co., Worcester, Mass.
Howes, Douglas E., assoc. prof. of E.E., Norwich Univ., Northfield, Vt.
Kimberly, M. C., supervising line extension estimator, Commonwealth Edison Co., Chicago, Ill.
Lattimer, Irving E., engg. dept., Am. Tel. and Tel. Co., New York, N. Y.
Leerburger, F. J., senior asst. engr., Maurice R. Scharff, New York, N. Y.

Lindblom, R. E., assist. prof. of E.E., Univ. of Washington, Seattle.
McKim, James B., member of technical staff, Bell Tel. Labs., Inc., New York, N. Y.
Morris, E. W., control engr., Westinghouse Elec. & Mfg. Co., Los Angeles, Calif.
Price, Harold W., prof. of E.E., Univ. of Toronto, Toronto, Ont., Canada.
Purucker, R. E., engr., Public Service Commission, State Capital, Madison, Wis.
Roberts, J. M., asst. prof. of E.E., University of Louisville, Louisville, Ky.
Sabbagh, E. M., asst. prof of E.E., Purdue Univ., Lafayette, Ind.
Seaman, B. C., E.E., Elliott Co., Ridgway, Pa.
Seletsky, A. C., asst. prof. of E.E., Case School of Applied Science, Cleveland, O.
Starbird, Levi C., transmission and protection engr., Southwestern Bell Tel. Co., Dallas, Texas.
Warwick, George G., supt., Vancouver Pwr. Co., Lake Buntzen, Burrard Inlet, B. C., Canada.
Wensley, R. J., asst. general mgr., I-T-E Circuit Breaker Co., Philadelphia, Pa.

26 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before Sept. 30, 1935, or Nov. 30, 1935, if the applicant resides outside of the United States or Canada.

Adam, L. G., (Member), Amer. Tel. & Tel. Co., New York, N. Y.
Baker, E. M., Bartlett Hayward Co., New York, N. Y.
Bausch, K. M., G. M. Simonson, San Francisco, Calif.
Chappell, G. C., Libbey-Owens-Ford Glass Co., Rossford, Ohio.
Chisholm, C. B., Bd. of Transportation, New York, N. Y.
Conwell, E. M., (Member), Albuquerque Gas & Elec. Co., Albuquerque, N. M.
Dunleavey, F. S., (Member), Magnavox Co., Ft. Wayne, Ind.
Gaalass, G. L., Empire Sheet & Tin Plate Co., Mansfield, Ohio.
Gans, A. G., Bell Tel. Lab. Inc., New York, N. Y.
Griffith, H. C. (Member), Pennsylvania Railroad, Philadelphia, Pa.
Higbee, R. W. Jr. (Member), Amer. Tel. & Tel. Co., New York, N. Y.
Koch, H. F. (Member), New England Pr. Engg. & Service Corp., Fall River, Mass.
Kofoid, M. J., 4416 N. E. 10th Ave., Portland, Ore.
Lindberg, H. C., General Elec. Co., New York, N. Y.
Lomont, C. F. (Member), Magnavox Co., Ft. Wayne, Ind.
Mathews, L. E., 239 Keystone Place, Reno, Nev.
Morehouse, S. B., Leeds & Northrup Co., Philadelphia, Pa.
Oler, C. B. (Member), Gibbs & Hill Inc., New York, N. Y.
Peterson, R. R. (Member), borough Eng., Manhattan office, E. R. B., New York, N. Y.
Polk, O. H., University of Arizona, Tucson.
Quinlan, J. W. (Member), Indianapolis Bell Tel. Co., Indianapolis, Ind.
Rothfuss, E. A., Mason & Walsh Co., Fort Peck, Mont.
Sauberman, N. H., Ritter Hotels, Long Beach, N. Y.
Shoults, D. R., General Elec. Co., Schenectady, N. Y.
Swering, J. B., Hartford Steam Boiler Inspection & Insurance Co., Conn.
Thayer, N. B., Toledo Edison Co., Ohio.
Warren, H. S., Westinghouse Elec. & Mfg. Co., Los Angeles, Calif.
Wilkinson, R. I., Bell Tel. Lab. Inc., New York, N. Y.
Yeager, C. R., Hudson & Manhattan R. R. Co., New York, N. Y.

29 Domestic

Foreign

Basta, J. J., Kolben Co., Praha-Vysocany, Czechoslovakia
Canagarayar, R., Messrs. Laurence Scott & Electromotors Ltd., Norwich, England.
Kennedy-Potts, N. D., Port Elizabeth Tech. Col., Port Elizabeth, So. Africa.
Keshavan, V. K., Nagercoil Elec. Supply Corp., Nagercoil, So. India.
Peralta-Esquivel, A., Cia. Electrica de Limon, Port-Limon, Costa Rica, C. A.
Rao, B. I. Madhav, Sri Brahma Vidzambal Elec. Supply Corp. Ltd., Ramachandrapuram Post, via Tirumayam, So. India.
Scott-Taggart (Fellow), Harlow Laboratories, Frinton-on-Sea, England.
Thornton, N. (Member) Public Works Dept., Lahore, India.
Waliuddin, S., Fathullah Beg St., Hyderabad Dn., India.

9 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as it now appears on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Bock, F. S., 1642 W. Broad St., Richmond, Va.
Brune, Otto, 214 White St., Waverly, Mass.
Chiofalo, J., 203 Graham Ave., Brooklyn, N. Y.
Clark, S. W., Apartado 2687, Mexico, Mex.
Cole, Fred H., 1116 Washington Blvd., Oak Park, Ill.
Condon, E. J., Jr., Gen. Del., Phoenix, Ariz.
Ghosh, K. C., c/o Compagnia Generale Di Elettricita, 34 Via Borgognone, Milan, Italy.
Golikoff, A., Main P. O. Gen. Del., Moscow, U.S.S.R.
Greene, F. M., 656—50th St., Brooklyn, N. Y.
Haddad, Raphael A., 500 Riverside Drive, N. Y. City.
Kimball, Gordon S., 154 Elmer Ave., Schenectady, N. Y.
Martinoff, V. M., 2150 Queen St., Toronto, Ont., Can.
Nelson, Charles J., 1515 N. Lotus Ave., Chicago, Ill.
Rozelle, P. M., 2018 Chestnut St., Harrisburg, Pa.
Schellberg, Kenneth O., 4115—51st St., S., Seattle, Wash.
Schlosser, Walter H., Dominion Elec. Power, Ltd., Regina, Sask., Can.
Sillstrop, John P., Eldorado Towers, 300 Central Park West, New York, N. Y.
Spiegel, William F., 7 Stegman Court, Jersey City, N. J.
Vance, Paul E., c/o Marietta Mfg. Co., Point Pleasant, W. Va.

19 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

ELEMENTS of ELECTRICITY. By A. Zeleny. 2 ed. N. Y. and Lond., McGraw-Hill Book Co., 1935. 526 p., illus., 8x5 in., cloth, $3.00. A comprehensive first course in electricity, including much practical information.

PHENOMENON of SUPERCONDUCTIVITY. Ed. by E. F. Burton. Toronto, Univ. of Toronto Press; Chicago, Univ. of Chicago Press, 1934. 112 p., illus., 9x6 in., cloth, $2.50. A simple but rather comprehensive statement of the methods of producing and measuring low temperatures and an outline of the main facts of superconductivity.

SYMPOSIUM on ILLUMINATION. Ed. by C. J. W. Grieveson, with a foreword by K. Edgcumbe. Lond., Chapman & Hall, 1935. 229 p., illus., 9x6 in., cloth, 13s 6d. Ten lectures given in 1933 at London, under the auspices of the National Illumination Committee and the Illuminating Engineering Society, discussing theoretical and practical problems.

AUTOBIOGRAPHY of JOHN HAYS HAMMOND. 2 vols. N. Y., Farrar & Rinehart, 1935. 813 p., illus., 9x6 in., cloth, $5.00. At the age of 80 this famous mining engineer writes the story of a life that has been full of adventure in 3 continents.

RESEARCH, the Pathfinder of Science and Industry. By T. A. Boyd. N. Y. and Lond., D. Appleton-Century Co., 1935. 319 p., 8x5 in., cloth, $2.50. Explanation of the purpose and methods of research for the business man and the young man who thinks of it as a possible vocation.

(A) SOURCE BOOK in PHYSICS. By W. F. Magie. N. Y. and Lond., McGraw-Hill Book Co., 1935. 620 p., illus., 9x6 in., cloth, $5.00. Extracts of most significant portions of important original papers contributing to physics during the period 1600–1900.

(The) BOOK of STAINLESS STEELS. Corrosion Resisting and Heat Resisting Chromium Alloys. Ed. by E. E. Thum. 2 ed. Cleveland, American Society for Metals, 1935. 787 p., illus., 9x6 in., cloth, $5.00. New, larger edition containing the experience of specialists in the manufacture and use of heat and corrosion resisting steels.

CONTRACTS in ENGINEERING, the Interpretation and Writing of Engineering-Commercial Agreements. By J. I. Tucker. 3 ed. N. Y. and Lond., McGraw-Hill Book Co., 1935. 341 p., tables, 10x6 in., cloth, $4.00. The principles of law which are common to all branches of legal procedure, and their applications in engineering and business affairs, especially in relation to contracts.

ELECTRIC ELEVATORS, Their Design, Construction, Operation, and Maintenance. By F. A. Annett. 2 ed. N. Y. and Lond., McGraw-Hill Book Co., 1935. 495 p., illus., 9x6 in., cloth, $5.00. The design and construction of various types of elevators and equipment, and sound methods of inspection, maintenance, and repair, presented in a practical way. Includes new developments in cars, control and signal systems, and automatic landing.

ELECTROMAGNETISM. By H. M. Macdonald. Lond., G. Bell & Sons, Ltd., 1934. 178 p., tables, 9x6 in., cloth, 12s 6d. Develops a consistent scheme for the representation of electrical phenomena from the fundamental laws of electromagnetism, and the derivation of the more immediate consequences of these laws.

ELEKTROTECHNIK, Bd. 2, Pts. 3 and 4. Gleich und Wechselstrommaschinen. By G. Bolz, F. Moeller, and T. Werr. Leipzig and Berlin, B. G. Teubner, 1935. 129 p., illus., 10x7 in., cloth, 10 rm. An introduction to electrical engineering intended for engineers in general, as well as specialists.

ELEMENTS of STRENGTH of MATERIALS. By S. Timoshenko and G. H. Macullough. N. Y., D. Van Nostrand Co., 1935. 350 p., illus., 9x6 in., cloth, $3.25. An abridgment of Timoshenko's "Strength of Materials," designed primarily as a textbook for undergraduate courses in engineering schools.

ENERGIEÜBERTRAGUNG und-UMWANDLUNG mit WECHSELSTROM, einheitliche Theorie der Leitungen, Transformatoren und Maschinen. By P. Werners. Leipzig and Berlin, B. G. Teubner, 1935. 204 p., illus., 10x6 in., cloth, 18 rm. The fundamentals of a-c theory presented in a uniform way, using the basic concept of the quadripole.

ENGINEERING SHOP PRACTICE, Vol. 2. By O. W. Boston. N. Y., John Wiley & Sons, 1935. 485 p., illus., 9x6 in., cloth, $5.00. Continuation of the description of the basic processes of metal working given in volume one by consideration of production machines.

Les FILTRES ÉLECTRIQUES, Théorie, Construction, Applications. By P. David. 2 ed. Paris, Gauthier-Villars, 1935. 211 p., illus., 10x7 in., paper 50 fra. The general theory of electric wave filters and fundamental equations, with results grouped to permit practical use, and examples of applications.

Engineering Societies Library

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Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

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Industrial Notes

Record Size Electrical Equipment for Los Angeles.—Two of the world's largest hydrogen-cooled synchronous condensers will be built by the General Electric Co. for the bureau of power and light, City of Los Angeles, to be installed on the receiving end of the 270-mile transmission line from Boulder Dam. These machines will be rated at 60,000 kva, 13,800 volts, 60 cycles. The installation will be an example of one of the standard applications for synchronous condensers where they perform the function of controlling the power factor of the load so that regulation and losses of the line can be held within reasonable values, thereby controlling within limits the voltage of the receiving bus. Hydrogen cooling results in materially reducing windage losses with a corresponding saving in operating expense. The machines will be installed outdoors.

A 60,000-kva hydrogen-cooled frequency converter has also been ordered from the Westinghouse Electric & Mfg. Co. Rated at a capacity far greater than any previously built, the set will be used for interchanging power between the bureau of power and light and the Southern California Edison Co. and will be located at Wilmington, Calif. Initially, the 50 cycle end will be connected directly to a 50,000-kw steam turbine in the Long Beach plant of the Southern California Edison Co., approximately 4 miles distant. This turbine has been assigned to the city for standby service. Later, when the need for such standby service no longer exists, it is the intention to split the frequency changer into 2 units to be used as 60 cycle synchronous condensers on the Los Angeles end of the transmission line from Boulder Dam. The unit will weigh 600 tons and will be fully enclosed for outdoor service.

Locomotive Plant Nears Completion.—The construction of the Electro-Motive Corp. plant at McCook, Ill., will be completed about September 15, according to a recent announcement from the builders, The Austin Company. The Electro-Motive Corp., a subsidiary of General Motors Corporation, will manufacture Diesel-electric locomotives, principally for railroads. Orders involving more than $3,000,000 are already in hand. In the erection of the plant over 2,000 tons of structural steel was electrically welded. Power for the plant will be furnished by one of the latest model Diesel-electric power units designed for locomotive use.

Empire Sheet & Tin Plate Appointment.—George L. Gaalaas has been appointed by the Empire Sheet & Tin Plate Co. of Mansfield, O., as sales engineer of the electrical sheet department. For the past 9 years Mr. Gaalaas served as design and sales engineer and manager of the synchronous motor division of the Ideal Electric Mfg. Co.

Improved Timken Bearings.—Now being applied to Timken bearings as rapidly as the special equipment required can be built and installed is a major improvement in surface finish termed "mirror finish." This new finish is infinitely smoother than the standard finish and, according to the announcement, even though the measurements were made with equipment capable of measuring in terms of a millionth of an inch, it is impossible to find a flaw in the new finished Timken bearing surface. To achieve this remarkable uniformity in bearing surfaces, years of experimental work have been required. The "Profilograph," now used in the Timken plant as a gauge of mirror finished surfaces, consists essentially of a fine diamond point which acts as a tracer or detector, moving over the surface of the specimen. To this is connected an optical system which magnifies the movement of the detector. In order to record even the most minute irregularities in the finely ground surfaces of Timken bearings, it is necessary to apply a vertical magnification of 2,000 times to the system.

Littelfuse Labs. in Larger Quarters.—Due to increased business in radio fuses and fuse mountings, neon potential fuses, indicators and other new products, the Littelfuse Laboratories moved to larger quarters at 4238 Lincoln Ave., Chicago, on Sept. 1.

Trade Literature

Capacitors.—Bulletin GEA-1584C, 8 pp. Describes Pyranol capacitors for improving power-factor on railway signal-power transmission lines. General Electric Co., Schenectady, N. Y.

Eye Shields.—Catalog, 20 pp. Describes industrial head and eye protective equipment; illustrates new and improved products. Chicago Eye Shield Co., 2300 Warren Boulevard, Chicago.

Transformers.—Bulletin 320, 6 pp. Describes power, welding, and furnace transformers for standard and special requirements. Pennsylvania Transformer Co., 1701 Island Ave., N.S., Pittsburgh.

Insulation Testers.—Bulletin 400, 12 pp. Describes Standco insulation testing sets, including an announcement of the new dwarf megohmer which will be available shortly. Herman H. Sticht & Co., 27 Park Place, New York.

Gearmotors.—Bulletin 2203, 4 pp. Describes self-contained speed reducers with integral or attached motors which permit lowspeed drives with high over-all efficiency. Eight types are illustrated. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Wires and Cables.—Bulletin RE-1, 24 pp. Describes conductors more generally used in rural electrification, including copper, bronze, copperweld, composite conductors, etc. Service Entrance and Service Drop Cables.—Bulletin SE2, 16 pp. General Cable Corp., 420 Lexington Ave., New York.

Transformers.—Bulletin 1173, 6 pp. Describes distribution transformers, showing in a unique way both exterior and cutaway interior views of type SB transformers for 2,400 volt and 4,800 volt circuits, and type CB transformers for 6,900 volt circuits and higher. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Electrostatic Voltmeters.—Bulletin, 4 pp. Describes new electrostatic voltmeters in flush, projecting, and portable types. These instruments are suitable for direct connection on either a-c or d-c lines, for readings up to and including 3,500 volts, and are entirely independent of wave form, frequency and temperature. Prices are included. Ferranti Electric, Inc., 130 West 42nd St., New York.

Disconnecting Switches.—Bulletin 35-B. Gives complete data on ratings, dimensions, operating mechanisms, phase spacings, and insulator characteristics of hook operated and group operated disconnecting switches for rural line service up to and including 34.5 kv. Data is also included on steel mounting frames and cross arm hangers. Delta-Star Electric Co., 2400 Block. Fulton Street, Chicago.

V-Belt Drives.—Catalog, 48 pp., and price list. The installation and operation of V-belt drives is discussed and the book has been simplified for use so that any drive can be completely designed and the delivered price determined from this one text. A section on the care of V-belt drives outlines an easy way of checking tensions, and discusses the effect of oil, water, steam, dust, and chemical fumes. The Gates Rubber Co., Denver, Colo.

Cables.—Bulletin GEA-1278B, 28 pp. Describes in detail 4 major improvements on paper-insulated cable—compack-strand conductor, paper insulation applied in graduated layers, treatment with carbon-dioxide gas, and hydrogen-processed lead-sheath. In addition the 4 general types of paper-insulated cable—oil-filled, shielded Type H, nonshielded, and Pyranol—are described in detail. Insulation thicknesses and other data are also included. General Electric Co., Schenectady, N. Y.

Aircraft Instruments.—Catalog, 12 pp. Describes electrical indicators and other electrically actuated instruments designed for aircraft use, including radio compass indicators and other navigation aids, electrical tachometers, panel ammeters, voltmeters and temperature indicators of both resistance and thermocouple type. Details of the Weston synchroscope, designed to reduce vibration by keeping engine speeds in synchronism in multi-engined planes, is another feature of the bulletin. In addition to electrical and mechanical specifications the catalog contains a group of dimensional drawings to facilitate choice and location of instruments on panels. Weston Electrical Instrument Corp., Newark, N. J.

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Front Cover

17,000-volt mercury-vapor rectifier tubes glowing with purple light under full load as they supply plate current for the 50,000 watt transmitter of station WOR at Carteret, N. J.

Western Electric Co. Photo

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In This Issue—

USEFULNESS of the cathode ray oscillograph has been extended greatly by development of means for using it as a multielement instrument. Two types of equipment for this purpose are described in 2 papers in this issue: One describes an electron tube circuit which enables 2 or more waves having frequencies in simple multiple relationship to each other to be portrayed (*pages 1095–1100*); the other describes mechanical auxiliaries for use in circuits that permit of the repeated application of the waves to be observed (*pages 1045–7*).

HEAVISIDE'S operational method of circuit analysis is achieving greater importance as a tool for regular use in engineering problems. For readers who have had ordinary mathematical training, but who are not familiar with the operational method, the fundamental characteristics of this method are outlined in this issue, operational equations are developed for a few typical circuits, and methods of solving these equations are indicated (*pages 1037–45*).

TO REDUCE radio interference from pin insulators, low resistance conducting coatings commonly are applied to the heads. By extending the coating to cover the entire head and by using a coating of higher resistance, the voltage at which interference begins can be raised considerably without materially lowering the flashover voltage of the insulator (*pages 1084–7*).

THE method of symmetrical components may be applied in determining the optimum values of external resistance and reactance which should be used for split phase starting of 3 phase induction motors which are to be operated from single phase lines. The calculated results obtained by this method are found to be quite accurate (*pages 1068–72*).

HARMONICS in the input current to a network containing any number of linear and nonlinear resistances when a sinusoidal voltage is applied may be determined by a semigraphical method. Such a method, restricted to nonlinear resistances having the same d-c volt-ampere characteristic regardless of direction of current, is presented in this issue (*pages 1055–7*).

TESTS on unbleached, unsized linen paper show that the chemical changes caused by overheating of cellulose insulation in service may result in failure of the insulation even within a range of temperatures not generally associated with dangerous physical effects (*pages 1088–94*).

SEATTLE, Wash., was host to a highly successful Pacific Coast convention of the Institute held in that city August 27–30, 1935. A complete report of this convention including a number of interesting snapshots taken during its progress are contained in this issue (*pages 1122–4*).

RATE of wear of electrical brushes is shown by recent tests not to depend entirely on mechanical forces, but to be related intimately to the conduction of current across the contact between brush and rotating part (*pages 1050–4*).

EXPERIMENTAL models through which electric current is passed may be used to map magnetic and dielectric flux lines. Two methods, both using materials of relatively high resistance, are available (*pages 1032–6*).

A STATIC frequency changer using thermionic tubes for transforming from 60 to $25^2/_7$ cycles and rated at 300 kva has been constructed. It is designed so that it later can be operated as a rectifier (*pages 1063–7*).

IN AN effort to meet demands for better performance in watt-hour meters and for adaptability to changing service requirements, a meter embodying several new features has been developed (*pages 1073–84*).

ELECTROLYTIC capacitors for alternating current are coming into increased use, but further refinements are necessary before many potential uses of these devices may be made satisfactorily (*pages 1058–63*).

ELECTRIC furnace developments which have taken place in Europe during the last year or so have been summarized by a leading authority on the electrometallurgical industry in Europe (*pages 1048–50*).

STANDARD wave shapes are desirable for performing impulse tests on electrical apparatus. Methods of producing waves having predetermined time constants have been developed (*pages 1100–04*).

LAST CALL for the meeting of the Institute's Great Lakes District to be held at Purdue University, West Lafayette, Ind., Oct. 24–25, 1935, is being issued (*page 1125*).

The Engineer and the Modern World

A Message From the President—

SHARING THE WEALTH has been a topic of wide discussion in recent months, but, strangely enough, practically nothing has been said of the production of wealth.

Wealth, in its broadest sense is something for which people exchange their own labor and services. To my mind engineers have done more to increase the production of wealth than any other group of our citizens. For his efforts along these lines the engineer has received little credit and a great deal of criticism. In the popular mind he is held responsible for so complicating our civilization as to cause a disorganization of the entire economic system.

During the course of recorded history the engineer has completely reversed his rôle in society. Originally there were none but military engineers whose job was to cause destruction of enemy fortifications and the greater the destruction the higher was the engineer's reputation among his associates. It is true that his work involved such construction as earth works, towers, and military engines, but such work was merely incidental to the larger program of destruction which is the basic object of war.

The history of modern engineering is generally considered to have begun in 1829 when Stephenson produced the first successful steam locomotive, but I always consider that it began in the work of Newcomen and Watt in the development of the automatic steam engine. Neither of these men had any very lofty purpose in starting their investigations. They had in mind the necessity for cutting operating cost of pumping water from coal mines by substituting steam for the muscles of men and animals. However, whatever their original object was, it is generally agreed that their work in perfecting the steam engine liberated the human race from the drudgery which had been its lot from the beginning of time.

Prior to the application of power to the tasks of agriculture and industry the common man was only a little better off than an animal. His daylight hours were consumed almost entirely in an individual struggle for subsistence.

I think that if we are honest with ourselves we will admit that practically none of us is either mentally or physically able to make a good living or even a bare existence by our own unaided efforts. The close cooperation of individuals, each carrying on his specialized work, has raised our scale of living to the point where the poor man today has infinitely more in the way of comforts and luxuries than the rich nobles of past ages. For this condition the engineer is largely responsible because he has multiplied a millionfold the potential effectiveness of each individual in his capacity to produce wealth and has opened for each of us almost boundless horizons.

Those who quarrel with the machine age blame the engineer and say that he has made man a slave to his machines, but I cannot subscribe to this view. The work of tending the automatic machines in use by industry today is not one-tenth as monotonous or exhausting as the heavy manual labor which had to be performed by our forebears less than 2 centuries ago. What appears to have been overlooked is the enormous increase in the productive capacity of the individual and the fact that the increased production in each trade and industry makes it possible to exchange this larger output for more necessaries and luxuries produced by other groups.

Not only has the engineer improved the material condition of his fellows, but by releasing men from long hours of drudgery has had a profound effect on the culture of the world. Perhaps with some justice the engineer can be criticised for stopping there and not taking a mo e important and commanding part in the actual management of the world so largely created by him. This situation cannot be remedied instantaneously, or by decree, but it can be corrected to the benefit of society as a whole.

In the first place, I believe that the fundamental training of our present and future engineering students should cover a field much broader than mathematics, physics, chemistry, and allied technical subjects. The engineer should have a thorough grounding in economic subjects, and in his education should be given sufficient cultural background to enable him in after years readily to recognize, understand, and evaluate what is going on in the world.

In the second place, I would urge each engineer to take an active interest in things outside engineering which, after all, covers only a relatively small part of the field of human activity.

Progress today is made not by a single genius but by a common effort. In professional bodies, such as the Institute, the idea of co-operative effort has proved itself. As a group having certain general and technical interests in common we tend to act more effectively and with greater devotion to the common good than we could as segregated individuals. The future of society in general appears to depend more and more upon the vitality of such functional groups. One of our greatest problems may well be to extend professional ethics and ideals to the areas of industrial and public life.

The Institute has sought to reconcile scientific progress with compassion for humanity, and the highest stimulation of individual achievement with the widest distribution of social benefits. A realization exists that social and economic aspects of our profession must be taken into greater account. We cannot limit ourselves entirely to purely technical matters.

The engineers and scientists who have provided present-day society with its astounding equipment and conveniences, have given relatively little thought

to the deeper effects of their achievements upon the lives and characters of men, communities, and peoples. The ability to discover and develop more and better goods and services and the capacity to produce them have been achieved. But how to divide the benefits of engineering progress between the spiritual and material has not yet been learned well enough by business to maintain without disastrous fluctuations the steady flow of enjoyment through well ordered production, distribution, and consumption.

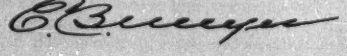
The dissemination of sound information on these subjects to society as a whole with its capacity to follow thought with action, surely will clarify the present confused situation and lead to workable solutions. Society does not relish fog with its dangerous, unpleasant impediment of the journey and its doleful sirens; it loves sunshine and full speed ahead. The steady sunshine of sound prosperity is all around us ready to be enjoyed as soon as wise leadership and intelligent following will break through this man-made mist of stupidity.

As professional men we cannot assume a *laissez-faire* attitude with the vast social and political experiments being conducted during the present period. Although it is neither recommended nor desirable that we abandon our professional activities to deal with social problems, it is extremely necessary, particularly so at this time, that we study the application of scientific thought to our social and political structure. Engineers are urged to apply their characteristic methods of reasoning to these problems in the same way as they deal with all types of natural phenomena.

It is a matter of common observation that there is much room for improvement in the relationship between individuals. The very complexities of modern life may be partly responsible for the independent and individualistic attitude that is so prevalent today. It seems almost certain that little or no social improvement is to be expected unless real stress is laid on the improvement of man's attitude toward other men, individually and collectively. It is for that reason that I particularly stress the importance of the true spirit of helpfulness of our profession and the necessity for a proper individual attitude.

Our work in the Institute is the biggest and best thing that comes to us and it can produce from within us the biggest and best of all we personally contain. Fundamentally we are working together in a common interest which lies in everything that makes for the greater development of the American Institute of Electrical Engineers.

We can be justly proud of the great engineering progress made, particularly during the past few years, and the future will depend entirely on how we, individually, carry on the sound policies established by the Institute and through which it has grown and expanded to its present position of preeminence.



Two Methods of Mapping Flux Lines

Two methods of magnetic and dielectric flux mapping by means of experimental models are described in this paper. Both methods use resistance models, through which current is passed; electrical conductivities of model parts are adjusted to correspond to magnetic or dielectric permeabilities of corresponding parts of the original design, and paths of electric current flow and electric equipotential lines in the model correspond to magnetic or dielectric flux lines and equipotential lines in the original design. Low melting point waxes with carbon or graphite inclusions are particularly suitable for model making purposes due to easy working properties and ready control of the electrical conductivity.

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PLOTTING flux maps by the method of curvilinear squares is at best a tedious method of estimating flux distribution; and in the case of magnetic and electrostatic circuits containing elements of different permeabilities and dielectric constants, accuracy is difficult to adhere to. Unfortunately, the most commonly utilized magnetic and dielectric structures in engineering practice do not lend themselves to mathematical solutions of flux distributions, and accuracy in design depends in large measure upon trial and error methods.

The 2 methods of flux mapping described in this paper require experimental models and measurements, but they greatly increase the accuracy of flux mapping. For both methods, resistance models are used, and either method may be used for mapping magnetic flux or dielectric flux lines. Electrical conductivities of model parts are adjusted to correspond to magnetic or dielectric permeabilities of corresponding parts of the original design, and alternating or direct current is passed through the model. If magnetic flux lines are being studied, the

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paths of electric current flow and electric equipotential lines in the model correspond respectively to magnetic flux lines and magnetic equipotential lines in the original design. If dielectric flux lines are being considered, the paths of electric current flow and electrice quipotential lines in the model correspond respectively to dielectric flux lines and dielectric equipotential lines in the original design.

One method described in this paper involves, for the determination of magnetic flux lines, the making of electrical *conductivities* of model parts proportional to magnetic permeabilities of design parts; current is passed through the model between 2 contact strips, each of which is placed on a section of model surface which is known to be a *magnetic equipotential surface*. Electric equipotential lines in the model then correspond to magnetic equipotential lines. This method may be designated hereinafter as the electromotive force-magnetomotive force method.

The other method described involves, for the determination of magnetic flux lines, the making of electrical *resistivities* of model parts proportional to magnetic permeabilities of design parts; current is passed through the model between contact strips which are placed, not along magnetic equipotential surfaces, but along 2 known *lines of magnetic flux*. Electric equipotential lines in the model then correspond to magnetic flux lines. This method may be designated as the electromotive force-flux method.

These 2 experimental methods applicable to magnetic flux determination also are suitable for use in dielectric flux problems, it being necessary only to substitute potential difference for magnetomotive force, dielectric constant for magnetic permeability, and dielectric flux for magnetic flux. For the sake of simplicity, only magnetic flux cases will be considered in the following problems.

A Typical Example

As an example, part of a cross section through a motor or generator armature and an opposing field pole is shown in figure 1. One full tooth is shown in the drawing and parts of the adjacent 2 teeth are shown. The part of the field pole piece opposite the armature teeth is shown, and the cross sectioning is carried well below the tooth roots and well up into the pole piece.

Magnetic flux lines flow down through the pole piece and across the air gap, entering the armature teeth and flowing through to the section below the tooth roots. Lines A-A and A_1-A_1 are lines of magnetic flux, and it is noticeable that these particular lines chosen are straight and located on the centerlines of tooth and armature slot, respectively. These 2 lines therefore lie along planes of symmetry in the armature and field pole as established by the design, and advantage is taken of this circumstance, as will be shown later.

Magnetic equipotential lines are drawn in as the horizontal lines (except in the air gap). B-B and B_1-B_1 are magnetic equipotential lines, and it is noticeable that a short distance above the pole face and a short distance below the tooth roots, these lines are almost straight and parallel to the pole face. Thus by going to a depth below the tooth roots and above the pole face only slightly greater than the slot width of the armature, lines may be drawn parallel to the pole face and will substantially coincide with the magnetic equipotential lines.

Simple magnetic flux problems involving flux lines between equipotential surfaces separated by a homogeneous medium are commonly solved on an experimental basis by resistance models in which voltage difference represents magnetomotive force and current flow paths magnetic lines of force. However, such solutions have been limited to equipotential surfaces separated by a single medium.

The Electromotive Force-Magnetomotive Force Method

In any design where magnetic lines of force may be present, advantage may be taken of the similarity of the law $B = \mu H$ (where B is the magnetic flux density, μ is the permeability of the medium and H is the intensity of the inducing force) to $I = GE$ (where I is the current density, G is electrical conductivity and E is the electric field intensity). In a scale model of a magnetic circuit, it is therefore necessary to substitute materials with the same ratios of electrical conductivities to each other that the original design exhibits in ratios of magnetic permeabilities of the corresponding parts to each other. Substituting electromotive force for magnetomotive force will then result in equipotential electric surfaces similar to magnetic equipotential surfaces in the original, and electric current flow lines similar in distribution to the magnetic flux lines in the original design. Designs which may be represented effectively by flat models in 2 dimensions such as in figure 1 are most readily solved.

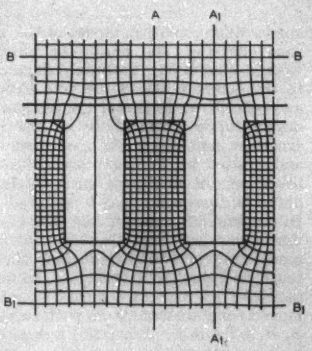
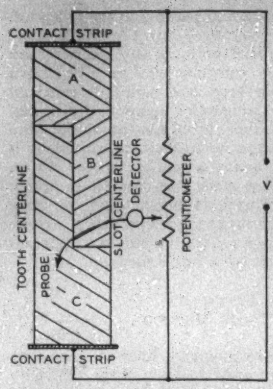


Fig. 1. Flux map of section of armature and pole piece

Thus, to obtain the distribution of magnetic flux in a field pole piece of a given shape with a known air gap and an armature of given design as of figure 1, it is only necessary to make a plane model of the pole piece from a sheet of material of suitable electrical



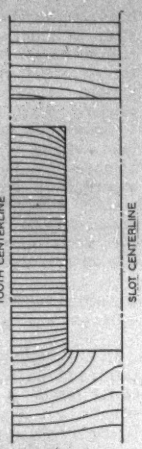


Fig. 2 (left). Resistance model for electromotive force-magnetomotive force method

Fig. 3 (right). Magnetic equipotential line plot by the method of figure 2

Armature and pole piece bounded by tooth and slot center lines

Air gap conductivity 0.005 mhos per cubic centimeter, armature and pole piece conductivity 0.5 mhos per cubic centimeter

conductivity, another model of the armature of the same material, and to fill the intervening air gap with a conducting material whose conductivity is to the conductivity of the pole piece and armature as is the permeability of the air gap in the original design to the permeability of the pole pieces and armature material. The model may be terminated and limited by known planes of symmetry established by the design in question, both as to equipotential lines such as B-B and B_1-B_1 and flux lines. In the smallest detail of the case of a slotted armature somewhere near the center of a field pole, the model may be terminated along the center lines of tooth and slot (A-A and A_1-A_1 in figure 1), and by parallel lines to tooth root and pole face surfaces removed some distance from such surfaces as B-B and B_1-B_1 in figure 1. When this is done, a model such as is shown in figure 2 is obtained.

Voltage is then applied to contact strips fastened along equipotential lines as in figure 2, and the model is explored by means of a probe connected to a voltmeter or a potentiometer to establish experimentally the contours of the electric equipotential lines existing in the model, which correspond to magnetic equipotential lines. The experimentally obtained lines are then transferred to paper on which the design under investigation is sketched as in figure 3. With the equipotential lines established, it is comparative y simple to sketch in the flux lines by the method of curvilinear squares.

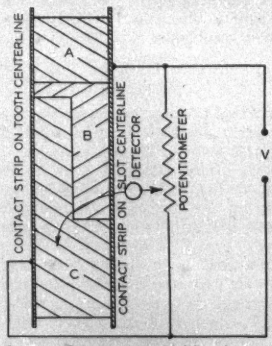
The equipotential lines in figure 3 were plotted from data obtained from a model such as the one shown in figure 2. The conductivity ratio selected was 100/1, conductivity being proportional to permeability. The resistance materials used were wax compositions described later, whose characteristics are shown in figure 7.

The Electromotive Force-Flux Method

Where definite planes of symmetry are established by a design, and when the model may be reduced to a plane figure without materially altering flux distribution, a faster and more accurate method of determining flux distribution may be employed.

The equation $I = GE$ may be rewritten in the form $E = I/G$. In this form E corresponds to B in the equation $B = \mu H$, I to H, and $1/G$ to μ. Since $1/G$ is the volume resistivity of the model material, then the equation may again be rewritten $E = \rho I$ where ρ is the volume resistivity and is analogous to the permeability μ in the magnetic case. And by changing model conductivity ratio to the reciprocal of the ratio used in figure 2 as demanded by this new relation, lines B-B and B_1-B_1 of figure 1 become lines of electric current flow and lines A-A and A_1-A_1 become electric equipotential lines corresponding to magnetic flux lines.

Therefore, if it is possible to establish 2 magnetic equipotential lines as B-B and B_1-B_1, and the paths of 2 magnetic flux lines as A-A and A_1-A_1 in figure 1 to bound the region to be investigated, this new relation may be applied. In this instance voltage is not applied to the model in the same manner as before.



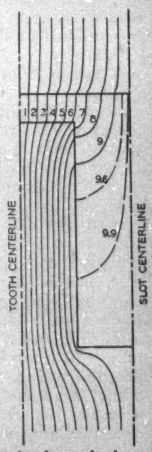


Fig. 4. Resistance model for electromotive force-flux method

Pole piece A, air gap B, armature C

Fig. 5 (right). Magnetic flux line plot by the method of figure 4

Armature and pole piece bounded by tooth and slot center lines

Air gap resistivity 2 ohms per cubic centimeter, armature and pole piece resistivity 200 ohms per cubic centimeter

Here electric equipotential lines are correlated to magnetic flux lines, and paths of electric current flow are correlated to magnetic equipotential lines. Likewise, in the model the resistivities instead of the specific conductivities of the various parts are now proportional to the magnetic permeabilities of the corresponding parts in the original. Contact strips are placed along flux lines established by symmetry as in figure 4. The model is then explored with a probe and a voltmeter or potentiometer as was done in figure 2. The experimentally obtained electric equipotential lines are then plotted on a drawing of the parts under investigation, and correspond to the magnetic flux lines as required by the above relations.

A model with the same proportions as the model used to obtain data for figure 3 was used to obtain the data of figure 5. However, conductivity ratios were reversed as noted above using wax compositions in the model, and magnetic flux lines were plotted instead of magnetic equipotential lines.

By superimposing figure 3 upon figure 5, the flux map of figure 6 is obtained, and it is seen by inspection that very good results are obtained. Most of the curvilinear squares approach true squares and flux line and equipotential line crossings are in the main right angle crossings. By using larger models and with greater care, quite accurate results are obtainable. The models used here were about 2 by 10 inches in size and somewhat small for the work.

Experimental Difficulties to Be Avoided

In utilizing either the electromotive force-magnetomotive force or the electromotive force-flux method there are a number of experimental difficulties to be avoided. The first consideration is the question of conductivity or resistivity ratios in different model parts. In representing designs in which iron or steel magnetic paths are used in combination with air gaps, permeability ratios may vary from about 100/1 to several thousand/1.

From an inspection of figure 4 it is apparent that for the case of a slotted armature and a smooth pole face, the flux distributions at the interfaces of armature and air gap, and pole face and air gap are determined almost entirely by the shape of the air gap part of the model since this is the low resistance path in the model and its edges are in parallel with the relatively high resistance paths corresponding to the iron circuit. It is evident that large changes in resistivity ratios may be experienced with but small effect upon air gap flux distribution. As an extreme case, the air gap distribution may be obtained with armature and pole piece parts removed from the model. The armature and pole piece model parts may then be placed in position and if the resistivity ratio is assumed to be 100/1, the variation in flux distribution in the air gap at a given point will be of the order of one per cent or less. Thus, for ratios between $\infty/1$ and 100/1, the variations are probably less than one per cent.

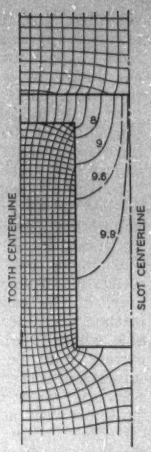
The flux distribution in the armature and pole piece model parts is determined by the flux distribution at the air gap interfaces and by the angles at which

Fig. 6. Magnetic flux map of armature and pole piece

Flux map obtained by combining figures 3 and 5

Ratio of iron to air gap permeabilities, 100

Model terminated on armature tooth and slot center lines



flux lines enter the interfaces. The law of magnetic refraction, $\tan a / \tan b = \mu_a/\mu_b$, where the tangents are those of the angles of departure from the normal to the point of incidence of the magnetic line with the plane of separation of regions of magnetic permeability μ_a and μ_b, completely determines the paths of flux lines entering armature and pole face with a given interface distribution.

With a permeability ratio of 1,000/1 a flux line at 45 degrees to the normal in the iron would have a divergence of 3.4 minutes from the norma in air after traversing the interface. A change in permeability ratio or conductivity ratio from 1,000/1 to 100/1 would result in the same case with a divergence angle in the air gap of approximately 0.5 degrees. In this case also, it is seen that relatively large changes in ratio will exert but small influence upon flux distribution when ratios are large to start with.

Examining figure 2 and imposing the approximate air gap distribution obtained from the examination of figure 3, it is apparent that the high conductivity armature and pole piece parts will accept the interface flux distribution imposed by the air gap shape, and that potential drops in these parts will be attained with but negligible effect upon the potential drops across the air gap since they are of different orders of magnitude in a series circuit.

Thus, it is evident that air gap shape controls approximate air gap flux distribution, and flux distribution in the interfaces controls flux distribution and potential drops in armature and pole piece. Also, when conductivity ratios are large in the model, of the order of 100/1 or larger, comparatively large changes in ratio may take place with but small effect upon flux distribution.

The above does not hold true when saturation phenomena take place, such as magnetic saturation in iron parts. Unless saturation is carried in iron parts to high values, air gap flux distribution is but little affected; but when magnetic saturation is con-

siderable, flux distribution in iron parts may be changed appreciably due to permeability changes. Such changes usually are not serious until parts of the design are worked well above the knee of the saturation curve. Unless resistance materials are used in the model which match the magnetic saturation curve of the iron with similar conductivity or resistivity versus voltage curves, absolute accuracy cannot be obtained.

In the electromotive force-magnetomotive force method of flux mapping, there are at present no materials which may be interchanged easily for the iron parts in the model to exhibit such saturation phenomena since they would have to show an increase of resistance for an increase in voltage. However, in the case of the electromotive force-flux method, nonlinear resistance materials are available whose characteristic curves of voltage versus current may be made to approximate magnetic saturation curves due to a falling resistance characteristic with increases in voltage. Resistance materials with inclusions of silicon carbide, of which "thyrite" is an example, exhibit such nonlinear resistance characteristics. In the majority of cases it is not necessary to add the refinement of matching magnetic saturation curves and ordinary resistance materials are sufficient.

The selection of suitable workable resistance materials for the construction of models may be a source of trouble in obtaining resistance ratios of the order of 1,000/1. Thin metal sheets may be used in very simple models, but such models are low resistance models and contact resistances and contact differences of potential introduce large errors. Soldering of contact surfaces introduces surplus material and causes errors; equipotential contact strips are also difficult to place in low resistance models without contact resistance difficulties. Thermoelectric effects also cause errors in low resistance models with d-c excitation.

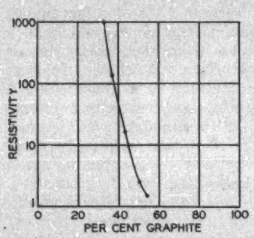


Fig. 7. Model resistance material

Resistivity in ohms per cubic centimeter of wax and graphite mixtures at 25 degrees centigrade

Superla wax and flake graphite

The use of carbon or graphite plates cut to the proper shapes with mercury as the high conductivity medium results in quite large errors due to contact resistances.

Electrolytic models are in general unsatisfactory due to polarization and diffusion capacity effects. For instance, using alternating current to excite the model and a potentiometer with a pair of telephone receivers as the detector, a null point cannot be found on the model unless the potentiometer arms are corrected to the proper phase angle for each point. Electrolytic polarization introduces harmonics of the fundamental excitation voltage in the model in addition to phase angle rotation of the fundamental.

Wax Models

High resistance models may be made using wax with graphite, carbon, silicon carbide, etc., inclusions. Figure 7 is a characteristic resistivity curve of a wax with varying proportions of graphite added. Quite wide resistivity ratios may be obtained by controlling the amount of graphite, etc. The wax is melted, the resistance material added and well mixed in.

In making models, the melted compositions are poured into shallow forms or molds at a temperature just above the melting point of the wax. Too high a pouring temperature will result in settling out of the graphite. After the wax has set, the forms are removed and the remainder of the model is poured using the mixture of the other resistivity value. Metal contact strips along equipotential lines should be placed in position before pouring the wax. If hot contact strips are placed in cold wax, high resistance joints result.

Cross section lines are readily ruled on the wax surfaces, and for photographing, equipotential lines may be plotted directly on the wax with a stylus.

After use, such resistance materials may be broken up and remelted for further use. Model parts may also be cut from previously cast flat plates.

Three dimensional models may be made in soft wax and explored by means of an insulated probe with an exposed tip. Potential values at various depths and at various locations may be obtained without much difficulty. Such models are particularly well adapted to dielectric flux mapping in insulators which do not yield to other methods of analysis.

In obtaining potential values for plotting equipotential lines or flux lines, the probe may be moved about on the model until the desired balance point is located. A voltmeter may be used to indicate the potential of a point, although this is not recommended since the current required to operate a voltmeter is usually large compared to currents normally flowing under the area covered by the tip of the probe. A vacuum tube voltmeter would be satisfactory in most cases however.

The most satisfactory method of obtaining potential measurements is by means of a potentiometer and detector as shown in figures 2 and 4. Either alternating current with a galvanometer or telephone receivers, or a d-c source of power with a galvanometer detector is quite satisfactory and independent of variations in voltage or frequency of the power supply for low frequency models.

Flux maps shown in this paper were obtained from models with a potentiometer, telephone receivers, a low voltage vibrator as a source of power at about 200 cycles per second, and wax-graphite resistance materials with resistivities of 2 and 200 ohms per cubic centimeter.

Operational Method of Circuit Analysis

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For that broad group of electrical engineers not familiar with Heaviside's operational method and its value in the analysis of electrical circuits, this article presents briefly some of the fundamental characteristics of the method and explains how it is applied; its application is illustrated by the formulation of operational equations for a few typical circuits. Although intended primarily to impart only the fundamentals of the subject to an engineer who has had ordinary mathematical training, it is hoped that the article also may serve as an introduction and guide to further study.

APPLICATION of operational methods to circuit studies has been growing rapidly within recent years, and more and more this form of analysis is achieving greater importance as a tool for regular use in handling engineering problems. The operational calculus is found to be of invaluable service in the solution of transients and in the treatment of dynamical systems, whether of an electrical or a mechanical nature. The steady advance made in the general knowledge and use of the Heaviside operational method is shown by the increasing number of technical papers that employ it.

This article has been written because of the spreading interest definitely indicated in operational circuit analysis, and the desire on the part of many who are unfamiliar with it to understand something of the principles of its application. The intention here is not to treat with the mathematics as such or with recent developments in the operational calculus. Merely, it is the aim to present what to the writer are some of the fundamental characteristics of the operational method, to show the formulation of the operational equations for a few circuits, and to discuss briefly some of the methods by which the solutions to these equations may be obtained. Stress is given the physical reasoning behind the steps.

Nature of Transients

Studies in engineering and physics give rise to problems on simple circuits, networks, and systems, these problems relating to any one of the major fields of electricity, mechanics, heat flow, sound, etc. Those of particular interest here are on transients in electrical circuits. The divisions of the field of electrical engineering in which transient analysis is of importance are many, as indicated by the applications Gardner has listed.[1]

In general, the study of electrical transients is the investigation of the response of such systems to disturbances produced in them. Specifically, the analysis of transients in electrical circuits involves the determination of the variation of charge, current, voltage, power, or energy with time while the system is undergoing a readjustment. It is inherent in all physical systems that even though the disturbing force may be applied instantaneously, time is required for the system to pass from one steady state condition to another. Time, therefore, is the independent variable, the quantity under investigation the dependent variable, to be expressed in the end as a function of time.

Heaviside's Objective

Briefly stated, the objective of Heaviside in analyzing circuits was to express the solutions of the problems in terms of functions of his operators, and then to assign such significance to these relations that their interpretations would be the *correct* solutions to his problems. The solutions were to be obtained as directly as possible, and were to give answers without further adjustment by way of any consideration of constants or functions of integration to include boundary conditions, as must be done in solving differential equations. The great majority of problems with which Heaviside treated involved systems initially at rest, the disturbing forces thus being zero for all values of time less than zero, and taking on their normal variations after zero time. Heaviside took advantage of this fact and sought to obtain solutions that automatically applied to such boundary conditions, his developments leading to this form of operational mathematics.

The operational equation, which is the initial expression for a problem in terms of operators and the circuit constants, must contain, therefore, all information necessary to solve the problem completely. The solution to the operational equation is to be the same as that for the differential equation after initial conditions have been included, and is to yield at once the total result, which for circuit transients is the transient plus the steady state variations of the quantity studied.

Heaviside's own method of interpreting his operational functions, and in converting them into explicit functions of time, appears to be one almost entirely experimental. It would seem that he must have applied his method to problems having known solutions, and in this way determined how well his general rules worked and what he could or could not do. No doubt such steps provided him with the body of rules which he used in his analyses but on which he gave little or no discussion in his technical

Written especially for Electrical Engineering, based upon an oral presentation before the A.I.E.E. San Francisco Section, San Francisco, Calif., Feb. 8, 1935.

1. For all numbered references see list at end of article.

papers. Because he studied circuits of the linear type on which a direct voltage was impressed at time $t = 0$, he had as a guide the solutions of the differential equations for those circuits. The solutions of simple problems were not difficult to obtain. His aim was to secure the same results by means of his operators without having to make recourse to differential equations or to problem boundary conditions, once the operational equations were written. By comparing operational forms for the same problems with the solutions obtained otherwise, the significance of these forms was indicated.

It may be well to state at this point that once an operational function is found to be related definitely to a given form of solution, the same operational expression met in any other problem will carry the same interpretation. Its translation in terms of a time function may be written immediately. The operational expressions with their time function equivalents, as a table, therefore become fundamental to the working use of the operational calculus as the integral table is to the ordinary calculus.

The correlation existing between the operational calculus and classical mathematics has been brought about in relatively recent years, and the mathematical material presented today in support of operational methods was not touched upon by Heaviside. Very much of it, of course, did not exist then, and mathematical rigor as a defense for his developments did not appeal to Heaviside, particularly in view of the fact that he was obtaining correct results for complicated problems. He was concerned primarily that his mathematics give him accurate answers in a quick and satisfactory way. Guided greatly by intuition and his wealth of knowledge on the physics behind his circuit studies, he developed the operational calculus now ascribed to his name.

Formulation of the Problem

The first step toward the solution of a problem is the derivation, from the fundamental *physical* relations of the system, of the *analytical* equations that adequately are to represent the system. The mathematical expressions thus obtained become the shorthand statements of the conditions surrounding the problem, and are to convey the same thoughts that otherwise would be stated in a longer way by words. That is, the mathematical formulation of engineering problems is nothing else than the symbolizing of physical ideas. The effort required to symbolize a problem depends upon the end desired, whether steady state conditions only are to be considered, or partial studies of the aspects of transient phenomena are to be carried out, or the complete solution including both transient and steady state relations is to be found.

Not all problems can be formulated in this manner because of the complexities encountered, and the difficulty in considering all the variables and the way in which they possibly should be introduced. The phenomena under treatment in this discussion are those that may be described by linear differential equations or the operational calculus.

Methods of Solution

The second step in the solution of a problem consists of carrying out the formal mathematical operations by which the initial circuit equations may be said to be solved. The resulting system equations usually will be expressed also in symbolic form, consequent calculations giving numerical results. Fundamentally, the methods of solving engineering problems fall into 2 major divisions. The first of these is qualitative, based upon reasoning from the physics of the problem together with reasoning from past experiences. The second division is quantitative, under which experimental schemes and mechanical devices may be employed as well as mathematics. Because of its power as a tool in the analysis of circuits, the operational calculus is becoming more prominent and is supplanting other forms of solution in many instances.

The Operator and the Unit Function

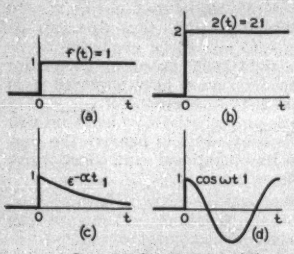
The operational calculus generally is typified by 2 symbols, the operator p, and the unit function **1**. The operator in its use probably is more mathematical than physical, the unit function more physical than mathematical. Operators are symbolic quantities indicating certain steps to be followed, or calling attention to given interpretations to be recognized. Operators are not new and engineers are familiar with many of them, for example, the trigonometric symbols "sin," "cos," "tan," etc.; the logarithmic and exponential notations; the operators j, and a (the latter met in studies on symmetrical components); and others such as D ($= d/dx$, d/dt, etc.). These quantities point to definite processes to be performed, although they are not always considered as operators.

The operator p in the Heaviside calculus [2,3] initially is to represent the time differentiator d/dt. Further, it is desired that this operator bear the reciprocal relation such that $1/p$ denote an integration. To make the operator as useful as possible it also should obey the ordinary rules of algebra. In addition to p indicating an operation, those who are acquainted with the solutions to linear differential equations will observe that it is the variable in the characteristic equation. The symbol p as used in the Heaviside operational calculus thus has several different interpretations.

If the purposes Heaviside had in mind are to be achieved, the operator p may not be defined presumptively. Its interpretation depends upon the physical nature of the problem at hand, and its meaning will change with transformations of the operational equations that contain it. The operational equation may be obtained from the corresponding differential equation by making the substitutions for the time differentiators, i. e., $p = d/dt$, ... $p^n = d^n/dt^n$, with the accompanying reciprocal relations $1/p = \int dt$, etc. In problems on transmission lines and in heat flow appear expressions containing p to half powers, i. e., $p^{1/2}$, $p^{3/2}$, etc. In no sense, though, does $p^{1/2}$ imply $(d/dt)^{1/2}$. Such a relation does not exist, and no significance may be

attached to it. Fractional powers of p must be interpreted as they are met, and in view of the problem itself. The operator p, as it appears in its various manners, is not subject to any single definition and may not be characterized completely as yet.

The unit function,[3, 4] 1, is a discontinuous function of time, and is defined as the function plotted in figure 1*a;* it is a function that is continuously zero until the time $t = 0$, and continuously unity thereafter. It thus displays the discontinuous form of the disturbing force, as illustrated further by the 3 other graphs of figure 1. The unit function is not



$f(t) = 0$ from $t = -\infty$ to $t = 0$ and $f(t) = f(t)$ from $t = 0$ to $t = +\infty$

For simplicity, the complete description of these conditions for the disturbing force is given in the form $f(t)1$, the unit function to show the discontinuity

Fig. 1. Significance of the unit function

mentioned explicitly by all writers on operational calculus, but even when omitted in discussion or in their mathematics it usually is implied. Its principal use is to avoid a great many unnecessary words, for once it has been defined only $E(t)\cdot 1$ need be written to indicate an electromotive force that is applied at time $t = 0$ and thereafter has the value $E(t)$. Without the notation it would be necessary to explain that this is what is meant.

The following characteristics thus represent essentials in the operational method:

1. $p = d/dt$, $p^2 = d^2/dt^2$, ... $p^n = d^n/dt^n$; p is the time differentiator.

2. $\frac{1}{p} K1 = \int_0^t K1dt = Kt$ (which may be written $Kt1$, if desired); the definite integral from zero time to time t

   $\frac{1}{p^2} K1 = \int_0^t\int_0^t K1dt^2 = \frac{Kt^2}{2}$, ...

   $\frac{1}{p^n} K1 = \frac{Kt^n}{n!}$, by repeated applications of $\frac{1}{p} K1$; the inverse process of differentiation, but a definite integration.[5]

3. $p\frac{1}{p} K1 = K1$; p obeys the ordinary rules of algebra.

Formulation of Operational Equations

With the foregoing discussions kept in mind, one turns next to the formulation of the operational equations for several simple circuits in order to investigate the manner in which they are expressed. Figure 2 shows a few typical circuit diagrams, these having been chosen purposely to illustrate certain fundamental features in deriving the operational equation. Space does not permit the inclusion of merited discussions on other circuit conditions of importance; these must be left to the reader to study.

Figure 2*a* represents a circuit of resistance and inductance to which is applied a direct voltage of E volts at $t = 0$, the current response being desired. From Kirchhoff's second law that, when taken with the proper algebraic signs, the sum of the voltages around a closed loop is zero, the differential equation for the circuit becomes

$$-Ri - L\frac{di}{dt} + E = 0$$

or

$$L\frac{di}{dt} + Ri = E \tag{1}$$

The 2 terms involving the current carry negative signs with respect to the impressed electromotive force because these 2 voltages are in opposition to it.

Replacing the time derivative by the operator[6] p and introducing the unit function to call attention to the form of the applied voltage, the operational equation for the circuit becomes

$$Lpi + Ri = E1 \tag{2}$$

Treating p algebraically, the operational solution for the current is

$$i = \frac{1}{Lp + R} E1 = \frac{E}{L}\frac{1}{p + \frac{R}{L}} 1$$

$$= \frac{E}{L}\frac{1}{p + \alpha} 1 \tag{3}$$

where $\alpha = R/L$. The operational impedance function for the circuit is designated by $Z(p) = (Lp + R)$. Solving the problem means finding a correct interpretation of $1/(p + \alpha)$ operating upon unit function.

For figure 2*b* there results (all capacitances in the examples are assumed initially uncharged)

$$Ri + \frac{\int idt}{C} = E \tag{4}$$

which in operational symbols becomes

$$Ri + \frac{1}{C}\frac{1}{p} i = E1 \tag{5}$$

and from which

$$i = \frac{1}{R + \frac{1}{pC}} E1$$

$$= \frac{E}{R}\frac{p}{p + \alpha} 1 \tag{6}$$

where α now is $1/RC$. Just as a note of interest, those familiar with the elements of circuit theory will recognize in α, for both of these circuits, the reciprocal of the circuit time constants.

In like manner to the above developments, the

operational solution for the total current in the circuit given by figure 2c is

$$i = \frac{1}{Z(p)} E1 = \frac{1}{r + \dfrac{(R + pL)\left(\dfrac{1}{pC}\right)}{R + pL + \dfrac{1}{pC}}} E1$$

$$= E \frac{p^2LC + pCR + 1}{p^3LCr + p(CRr + L) + (R + r)} 1 \qquad (7)$$

It may be observed that the operational impedance function as first written in terms of the circuit elements is identical in form to that obtained for the equivalent impedance of a series-parallel circuit when expressed in terms of complex quantities. The operator p replaces $j\omega$. One initially may handle circuits in this manner, later substituting the proper operational equivalents for the corresponding circuit elements and reducing the resulting algebraic equation to its simplest form.

The circuit of figure 2d assumes a current of constant magnitude i suddenly forced through a parallel combination of capacitance and inductance. The resulting circuit voltage, which now is desired, is

$$e = Z(p)i1 = \frac{pL \cdot \dfrac{1}{pC}}{pL + \dfrac{1}{pC}} i1 = \frac{pL}{p^2LC + 1} i1$$

$$= \frac{i}{C} \frac{p}{p^2 + \alpha^2} 1 \text{ (as usually expressed)} \qquad (8)$$

where for this circuit $\alpha = 1/\sqrt{LC}$.

The circuit of figure 2e is the same as that of figure 2d, but the current now is sinusoidal in form, the switch being closed at the instant the current is passing through zero and increasing positively. Since the impedance function for the circuit is the same as that just found, the voltage across the circuit elements becomes

$$e = Z(p)i1$$

$$= \frac{I}{C} \frac{p}{p^2 + \alpha^2} (\sin \omega t) 1 \qquad (9)$$

The particular point to be emphasized here is that the operand is the entire part of the expression $(\sin \omega t)1$, and $p/(p^2 + \alpha^2)$ operates upon it as a whole. In other words, $\sin wt$ may not be treated simply as a multiplying factor, thus to retain its identity, nor may $p/(p^2 + \alpha^2)$ be evaluated by itself. The entire right-hand member, except for the constant term I/C, must be interpreted as a unit. This process is to be shown later.

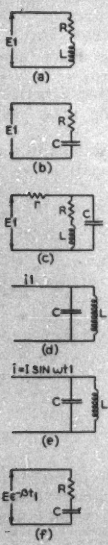
In order to handle properly the right hand member of equation 9 it is convenient to convert the time function $\sin \omega t$ to its operational equivalent which later is shown to be

$$\sin \omega t = \frac{p\omega}{p^2 + \omega^2} 1 \qquad (10)$$

The operational equation for the voltage therefore is found to be

$$e = \frac{I}{C}\left(\frac{p}{p^2 + \alpha^2} \frac{p\omega}{p^2 + \omega^2}\right) 1 \qquad (11)$$

from which, with correct interpretation of the



$$L\frac{di}{dt} + Ri = E \qquad Lpi + Ri = E1 \qquad i = \frac{E}{Lp + R} 1 = \frac{E}{L} \frac{1}{p + \dfrac{R}{L}} 1 = \frac{E}{R}\left(1 - e^{-\frac{R}{L}t}\right)$$

$$Ri + \frac{\int i dt}{C} = E \qquad Ri + pCi = E1 \qquad i = \frac{E}{R + \dfrac{1}{pC}} 1 = \frac{E}{R} \frac{p}{p + \dfrac{1}{RC}} 1 = \frac{E}{R} e^{-\frac{t}{RC}}$$

$$iZ(p) = E1 \qquad Z(p) = r + \frac{(R + pL)\left(\dfrac{1}{pC}\right)}{R + pL + \dfrac{1}{pC}} \qquad i = \frac{p^2LC + pCR + 1}{p^3LCr + p(CRr + L) + (R + r)} E1$$

$$e = Z(p)i1 \qquad Z(p) = \frac{pL \dfrac{1}{pC}}{pL + \dfrac{1}{pC}} \qquad e = \frac{pL}{p^2LC + 1} i1 = \frac{i}{C} \frac{p}{p^2 + \dfrac{1}{LC}} 1 = i\sqrt{\frac{L}{C}} \sin \frac{t}{\sqrt{LC}}$$

$$e = Z(p)i1 = \frac{pL}{p^2LC + 1} I \sin \omega t1 \qquad e = \frac{I}{C}\left(\frac{p}{p^2 + \dfrac{1}{LC}} \frac{p\omega}{p^2 + \omega^2}\right) 1 = \frac{IL\omega}{\omega^2LC - 1}\left(\cos \frac{t}{\sqrt{LC}} - \cos \omega t\right)$$

$$Ri + \frac{i}{pC} = Ee^{-\beta t}1 \qquad i = \frac{1}{R + \dfrac{1}{pC}} Ee^{-\beta t}1 \qquad i = \frac{E}{R} \frac{p}{p + \dfrac{1}{CR}} \frac{p}{p + \beta} 1 = \frac{E}{1 - RC\beta}\left(\frac{1}{R} e^{-\frac{t}{RC}} - C\beta e^{-\beta t}\right)$$

Fig. 2. Circuit diagrams and associated equations illustrating the application of the operational method

quantity within the parentheses operating upon unit function, the solution is reached.

The last illustration, given by figure 2*f*, involves the same point made in the previous example. The expression for the current here is sought, whence

$$i = \frac{1}{R + \frac{1}{pC}} E\epsilon^{-\beta t} 1$$

$$= \frac{E}{R}\left(\frac{p}{p+\alpha}\,\frac{p}{p+\beta}\right) 1 \tag{12}$$

where $\alpha = 1/RC$. The same statements hold as before for the operation of the entire quantity within the parentheses on unit function. Both problems indicate the requirement of converting a time function, other than a constant, in the operand into its equivalent operational form before proceeding to the final solution. For the last circuit, however, there is another method, Heaviside's shifting theorem, which will remove the exponential term from the operand. There are several ways of treating this problem.

To summarize briefly, the operational equation is an expression in terms of constants of the circuit and functions of the operator p. It is simply the formulated statement, expressed in symbols, of the physical problem under consideration. For a single circuit it stands exactly for the differential equation with its surrounding conditions which otherwise might be written, and its initial form may be obtained directly from the differential equation if desired. For a system or a network of n loops, there results a system of n simultaneous operational equations just as there also may be derived a system of n simultaneous differential equations. The operational equations, properly interpreted, must give solutions identical to those found for the differential equations with their boundary conditions included. Operational equations hence may be said to represent in abbreviation the actual equations, differential or integral, for the problem, together with the special form of boundary conditions which implies that the system initially is at rest.

Solutions to the Operational Equations

It is necessary next to determine the interpretations for the operational equations, and, for value to the reader, to solve those developed in the preceding section of this article. Setting up the operational equation for a circuit is relatively simple, but to obtain its solution is an entirely different matter. Leaving aside any discussion of the so-called classical methods of solving circuits, i. e., by differential or integral equations, attention is restricted to purely operational modes of attack of which there are in general several for most problems.

Solutions to operational equations may be found in several ways, prominent ones of which are:

1. Interpretations of operational expressions from known solutions. The operational equation for a specific circuit must yield the same result as that found by other means, e. g., by differential equations. Heaviside interpreted the operator $p^{1/2}1$, for instance, as $(\pi t)^{-1/2}$ from the known solutions to heat flow problems.[7]

2. Long division of the operational equation to obtain a series, each term of which then is evaluated. The method includes binomial theorem expansions. Heaviside referred to this method as "algebrizing."[8]

3. Heaviside's expansion theorem.[9–17]

4. Partial fraction expansion of the operational equation into recognizable parts, a method identical to that employed in the integral calculus to assist in the evaluation of integrals, and a standard method in the theory of differential equations for many years.[18,19]

5. Heaviside's shifting theorem, to remove exponential time factors from the operand.[20–23]

6. Borel's theorem, relating to the product of 2 functions.[23–25]

7. Contour integration of the equivalent Fourier integral.[26–30]

8. Carson's integral equation.[31–38]

Some of these methods will be illustrated by application to the problems presented in figure 2.

Reasoning From Known Solutions

The solutions for the currents in the circuits of figures 2*a* and 2*b* are known readily—in fact, these 2 problems are perhaps the first ones discussed in any elementary study of transients. After the general solutions of the respective differential equations have been obtained, substitution of initial conditions gives the particular solutions. Determination of the constants of integration depends upon the physical relations that, in the first circuit $i = 0$ when $t = 0$, and in the second circuit, $i = E/R$ when $t = 0$. The currents are expressed explicitly as functions of time and are, respectively

$$i = \frac{E}{R}\left(1 - \epsilon^{-(R/L)t}\right) \tag{13}$$

and

$$i = \frac{E}{R}\,\epsilon^{-t/RC} \tag{14}$$

Since the solutions of the operational equations are to yield the same results, of necessity, then the interpretations of equations 3 and 6 follow immediately. Comparison of equations 3 and 13 gives

$$\frac{E}{L}\,\frac{1}{p+\alpha}\,1 = \frac{E}{R}\left(1 - \epsilon^{-(R/L)t}\right)$$

whence

$$\frac{1}{p+\alpha}\,1 = \frac{1}{\alpha}\left(1 - \epsilon^{-\alpha t}\right) \tag{15}$$

as a general relation. Similarly, comparison of equations 6 and 14 gives

$$\frac{E}{R}\,\frac{p}{p+\alpha}\,1 = \frac{E}{R}\,\epsilon^{-t/(RC)}$$

whence

$$\frac{p}{p+\alpha}\,1 = \epsilon^{-\alpha t} \tag{16}$$

It may be observed that whatever α may be

$$\frac{p}{p+\alpha}\,1 = p\left(\frac{1}{p+\alpha}\,1\right) = \frac{d}{dt}\left[\frac{1}{\alpha}\left(1 - \epsilon^{-\alpha t}\right)\right] \tag{17}$$

In like manner

$$\frac{1}{p+\alpha}1 = \frac{1}{p}\left(\frac{p}{p+\alpha}1\right) = \int_0^t \epsilon^{-\alpha t}dt \tag{18}$$

The time derivative or integral obviously is taken of the equivalent time function for the operational expression. It should be understood that the juxtaposition of 2 operational functions does not mean the product of their respective time functions. An operation is implied, and the entire quantity must so be treated.

Although these 2 examples are given for special and the simplest of circuits, the time function equivalents of the corresponding operational expressions are perfectly general and may be used on all other circuits that yield the same operational forms. There is only one time function that is related to a given operational expression.

To illustrate the value of what has just been presented, consider the operational equivalent of sin ωt (refer to equation 10):

$$\sin \omega t = \frac{1}{2j}(\epsilon^{j\omega t} - \epsilon^{-j\omega t}) = \frac{1}{2j}\left(\frac{p}{p-j\omega} - \frac{p}{p+j\omega}\right)1$$

$$= \frac{p\omega}{p^2+\omega^2}1 \tag{19}$$

Similarly

$$\cos \omega t = \frac{p^2}{p^2+\omega^2}1 \tag{20}$$

Both relations are of importance in operational circuit analysis.

Operational Division

The second manner of evaluating operational forms is that of long division, which for equations 3 and 6 gives the binomial expansions for those forms. To illustrate, when applied to equation 6 there results

$$\begin{aligned}\frac{p}{p+\alpha}1 &= p(p+\alpha)^{-1}1\\ &= p(p^{-1} - p^{-2}\alpha + p^{-3}\alpha^2 - p^{-4}\alpha^3 + \ldots\ldots)1\\ &= \left(1 - \frac{\alpha}{p} + \frac{\alpha^2}{p^2} - \frac{\alpha^3}{p^3} + \ldots\ldots\right)1\\ &= \left(1 - \alpha t + \frac{\alpha^2 t^2}{2!} - \frac{\alpha^3 t^3}{3!} + \ldots\ldots\right)\\ &= \epsilon^{-\alpha t}\end{aligned} \tag{21}$$

The fourth step is obtained from the third by application of $\frac{1}{p^n}1 = \frac{t^n}{n!}$, and the resulting series is recognized as the expansion of $\epsilon^{-\alpha t}$. The same method of expansion holds for $\frac{1}{p+\alpha}1$.

The solutions thus obtained are complete; they include the transient and the steady state variations of the currents. In the method of operational division, or where p appears in the denominator as it does in the foregoing expressions, it is the added restriction of making the reciprocal of the operator p the definite integral from zero time to time t that has the effect of including the constants of integration in the solution. Other methods of solution, one of which has been illustrated in the preceding section, give the correct result without recourse to integration.

More complicated operational expressions may be treated similarly through some convenient form of expansion of the operator into a power series, often by formal division of the numerator by the denominator of the operational fraction. The objection to operational expansions of this kind, however, is that they lead to infinite series which at times are extremely difficult, if not impossible, to recognize and sum. Furthermore, they may be of no, or very limited, value for numerical computations, though they are sometimes very useful in obtaining approximate results.

One point should be presented before passing on. The process of "algebrizing" the operational equation will give 2 series, depending upon the manner of expansion. The binomial theorem, for example, always can be written in 2 ways $(p+\alpha)^{-1}$ or $(\alpha + p)^{-1}$. In the first instance p appears in the denominators of the consequent terms, and in the second instance in the numerators. Where p occurs in descending powers, as it does in equation 21, the time function may be evident in its relation to the correct problem solution. With p appearing in whole powers in the numerators, the time function being 1, a series of zeros results and correspondence with the true solution is not observed. In the example just given it has been necessary to expand in inverse powers of p as shown.

Series expansions of operators may lead to a convergent series, or to a divergent or asymptotic solution. One is satisfactory for numerical computation for small values of time, the other for large values of time. Failure, however, may occur with either series, the algebrizing process breaking down. In brief, Heaviside's method of series expansion of the operator will not always give correct results automatically; caution, therefore, must be exercised in obtaining such forms of solution. One should investigate the correctness of the methods employed and the completeness of his results.

The Expansion Theorem

With but little discussion, Heaviside gave, in volume 2 of Electromagnetic Theory, and volume 2 of Electrical Papers, his expansion theorem. The theorem is a formal means by which the solutions of operational equations may be found directly. It is applicable to most problems, including a great many on transmission lines and heat flow where the constants are distributed rather than lumped. When the theorem does apply it is probably the most convenient method to use.

No derivation of the expansion theorem is given here, merely the statement of it:

$$i = E\left[\frac{1}{Z(0)} + \sum_{p_1}^{p_n} \frac{\epsilon^{p_k t}}{p_k Z'(p_k)}\right]1 \tag{22}$$

In brief, $Z(0)$ is the operational impedance function in which p and its powers have been replaced by zero; $p_1, p_2, \ldots p_n$ are the n roots of the equation $Z(p) = 0$; and $Z'(p_k)$ is $d/dp\ [Z(p)]$, after which the par-

ticular root p_k, for the kth term under consideration, is substituted for the general root p.

To show the steps in the use of the theorem, consider the R-L circuit of figure 2a. Here,

$$Z(p) = Lp + R = 0 \tag{23}$$

and only one root, $p = p_1 = -R/L$, exists; $Z(0) = R$ and $Z'(p) = L$, whence $p_1Z'(p_1) = -R$. The solution for the current is

$$i = E\left[\frac{1}{R} - \frac{1}{R}\,\epsilon^{-(R/L)t}\right] \tag{24}$$

The circuit of figure 2c is solved more conveniently by the expansion theorem than by other means, although when written out completely in symbolic form the algebraic expressions are somewhat cumbersome to manipulate. With circuit data: $E = 100$ volts; $r = 100$ ohms; $R = 150$ ohms; $L = 0.1$ henry; and $C = 80$ microfarads, the solution for the current is

$$i = 0.40 + 0.6075\epsilon^{-22t} - 0.0075\epsilon^{-140t} \tag{25}$$

which the reader may verify.

It may be seen that the term $Z(0)$ leads to the steady state current in the examples shown, the exponentials yielding the transient components. With an alternating voltage impressed on the circuits, the term $1/Z(0)$ disappears, and the steady state solutions come from the exponentials, those particular ones having imaginary indices $\pm j\omega t$ which lead to $\sin \omega t$ or $\cos \omega t$, the form of the applied voltage.

The expansion theorem often is easily handled, and, when such is the case, leads to solutions that readily can be evaluated numerically. The greatest difficulty encountered in its use enters in determining the roots of $Z(p) = 0$, particularly when $Z(p)$ is of degree in p higher than the fourth. This same difficulty, however, is met in factoring all algebraic equations and is not peculiar in any way to the expansion theorem. One of the restrictions on the expansion theorem is that in its development zero and repeated roots are excluded. This restriction is not one of much consequence because physical problems tend only to approach such conditions (as expressed in this mathematical manner), and that but very seldom.

Partial Fraction Expansion

Partial fraction expansion, the basic principle underlying the expansion theorem, is the operation of decomposing a given fraction into a group of simpler fractions. These partial fractions have denominators that are factors of the denominator of the given fraction, and hence the latter is converted into a sum of expressions each one of which can be treated individually and more conveniently. The given fraction usually is reduced to a proper fraction before being decomposed, unless the degree of the numerator is already less than that of the denominator. It is assumed that the reader will recall the method of partial fraction expansion.

This method applied to equation 8, which was derived for the circuit of figure 2d, gives for the voltage,

$$\begin{aligned} e &= \frac{i}{C}\,\frac{p}{p^2 + \alpha^2}\,1 \\ &= \frac{i}{C}\left[\frac{1}{2(p + j\alpha)} + \frac{1}{2(p - j\alpha)}\right]1 \\ &= \frac{i}{C}\left[\frac{1}{2j\alpha}(1 - \epsilon^{-j\alpha t}) - \frac{1}{2j\alpha}(1 - \epsilon^{j\alpha t})\right] = \frac{i}{C\alpha}\,\frac{\epsilon^{j\alpha t} - \epsilon^{-j\alpha t}}{2j} \\ &= i\sqrt{\frac{L}{C}}\sin\frac{t}{\sqrt{LC}} \end{aligned} \tag{26}$$

Observe also, that

$$e = i\sqrt{\frac{L}{C}}\,\frac{p\alpha}{p^2 + \alpha^2}\,1 = i\sqrt{\frac{L}{C}}\sin\frac{t}{\sqrt{LC}}$$

an application of the relation given by equation 19. This problem can be attacked equally as well by use of the expansion theorem.

Solving equation 11, for the circuit of figure 2e, the method of partial fraction expansion gives for the voltage

$$\begin{aligned} e &= I\sqrt{\frac{L}{C}}\left(\frac{\alpha\omega}{\omega^2 - \alpha^2}\,\frac{p^2}{p^2 + \alpha^2} - \frac{\alpha\omega}{\omega^2 - \alpha^2}\,\frac{p^2}{p^2 + \omega^2}\right)1 \\ &= \frac{IL\omega}{\omega^2LC - 1}\left(\cos\frac{t}{\sqrt{LC}} - \cos\omega t\right) \end{aligned} \tag{27}$$

Heaviside's Shifting Theorem

To show the manner in which an exponential time function is removed from the operand of an operational equation, Heaviside's shifting theorem is employed. The theorem, not proved here, allows an exponential, such as $\epsilon^{-\beta t}$, to be shifted from the operand by the substitution of $(p - \beta)$ for all p's in the rest of the operational equation. That is,

$$\frac{p}{p + \alpha}\,\epsilon^{-\beta t}\,1 = \epsilon^{-\beta t}\,\frac{p - \beta}{p + \alpha - \beta}\,1 \tag{28}$$

The exponential time function now becomes a multiplying factor only.

Equation 28 is a second form of the operational equation representing the circuit of figure 2f, whence, by partial fraction expansion of the operand, or by use of the expansion theorem

$$i = \frac{E}{1 - RC\beta}\left[\frac{1}{R}\,\epsilon^{-t/(RC)} - C\beta\epsilon^{-\beta t}\right] \tag{29}$$

Space does not permit further discussion of methods of solving operational equations, but the methods presented, though in brief, should give some idea of the operational attack on physical problems.

Fractional Powers of p

Because questions frequently are asked about the significance of fractional differentiation and integration, a word should be given before closing on that phase of operational calculus. In his investigations on telegraph cables, Heaviside obtained series solutions for many problems in which the operational equations contained the operator to half powers. Both ascending and descending series were found, and it was necessary to interpret these half-power operators.

The appearance of terms such as $p^{3/2}1$, $p^{1/2}1$, $p^{-1/2}1$, etc., called particularly for interpretation of $p^{1/2}1$. By comparing his operational mathematics with classical heat flow problems having known solutions, Heaviside determined that

$$p^{1/2}1 = \frac{1}{\sqrt{\pi t}} \tag{30}$$

Other half powers of p then became simply the derivatives or integrals of $1/\sqrt{\pi t}$, for example

$$p^{-1/2}1 = \frac{1}{p}p^{1/2}1 = \frac{2}{\sqrt{\pi}}t^{1/2}$$

$$p^{3/2}1 = \frac{d^2}{dt^2}\frac{1}{\sqrt{\pi}}t^{-1/2} = \frac{1}{\frac{2}{1}\cdot\frac{2}{3}\cdot\sqrt{\pi}}t^{-1/2}$$

Again may be noted the experimental manner by which the time function equivalent to an operational form had been obtained.

Whether the terminologies "fractional differentiation" or "fractional integration" have meaning depends perhaps upon the reader's viewpoint. The entire interpretation of the fractional power operator is based upon equation 30, after which the operations are in integral powers of p. In this sense, these terminologies have lost the significance that might be carried over to the operational calculus from the ordinary calculus.

Tables of Operational Equivalents

From what few problems have been discussed thus far in this article, the time function equivalents of several operational forms have been determined. The solution of a larger group of problems obviously would increase the number of related expressions. Further, by use of the described methods of solution it is possible to devise operational forms and to seek their time function equivalents without the necessity of having specific physical problems in view.

The advantage of equivalent expressions is that once they are obtained they need not again be derived, but the time function may be written immediately whenever its corresponding operational form is met, regardless of the problem giving rise to it. Tables of operational expressions with their related time function equivalents are given in the textbooks mentioned. In addition to these, attention also is called to the extensive table of Fourier transforms presented by Campbell and Foster.[36] Since the operational calculus readily can be interpreted in terms of the Fourier integral, as in the work of Bromwich and March, this table properly may be regarded as belonging to the class of operational equivalents. As stated by Bush, "Most of them (Fourier transforms) become immediately available as operational formulas by noting that the operand is $p1$ in our notation." One approaching the operational calculus can obtain familiarity with many of its fundamentals by deriving for himself operational formulas he will find in these several tables.

Quite frequently one finds equivalent expressions in which the unit function accompanies both members, e. g., $\frac{p}{p+\alpha}1 = \epsilon^{-\alpha t}1$. Whether or not one cares to retain the unit function with both members is perhaps optional. Unit function has exactly the same physical significance for both terms, and in the sense of being a signpost serves only to call attention to the nature of the impressed force, and to the fact that the ultimate solution may be computed using values of time beginning with $t = 0$. For that reason its retention is fully justifiable. One may argue, though, that, once having operated upon unit function to obtain the corresponding time function, unit function perhaps should disappear. One also may question the mathematical correctness of the statement "operating upon unit function." As the writer views the ideas underlying the operational method, $\frac{p}{p+\alpha} = {}^{-\alpha t}$ whether or not the unit function is exhibited explicitly in either term. We always are left with a far greater physical significance of the unit function than with one that is mathematical.

As stated at the outset, this article has been directed toward the reader who has had little acquaintance with the Heaviside operational calculus but who has desired to have some of its fundamentals presented to him. It has been the aim primarily to discuss the physical ideas underlying the material given. The treatment has been specific, with the view that in definitely applying the operational method to particular circuits its elements may be grasped more readily.

The scope of the operational method is fairly large. In the great majority of circuits cause and effect are directly proportional to each other, and the coefficients of the terms involving differentials or derivatives in the problem statements are constant. As a consequence, the differential equations representing such a system are said to be linear with constant coefficients. To be precise, these statements are not strictly true, but for all practical purposes they are assumed to hold. The coefficients are the system parameters R, L, C, etc., (either singly or grouped) which usually are called the circuit constants.

It is to the linear circuit with constant parameters that the operational method may be applied. It is not restricted, however, only to that type of problem described by the ordinary differential equation; it includes also certain circuits that may be represented by partial differential equations, e. g., the transmission line, and some problems in heat flow. As yet the operational calculus has not been applied satisfactorily from an engineering point of view to systems that are nonlinear or that have variable "circuit constants."

Many phases of operational circuit analysis and its related features, of course, have not been touched upon. Listing several of such subjects of consideration, there are: circuits the past history of which must be taken into account, changes of circuit, coupled circuits, net-works and systems of equations, the theorem of superposition, the infinite integral equation, transmission lines and cables, heat flow, series solutions, transfer operators, traveling waves.

These topics are beyond the scope of this article and must be left to the reader to follow. It has been the hope, however, that in the treatment given here he will be led to a better understanding of the operational method of approach to the solution of engineering problems.

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Multielement Operation of the Cathode Ray Oscillograph

With the aid of specially designed auxiliary devices, the cathode ray oscillograph may be operated as a multielement instrument, in circuits that permit of the repeated application of the wave to be observed. The number of waves that may be traced with apparent simulataneity on the oscillograph screen is limited only by the complexity of the control circuit and the crowding of the various curves on the relatively small screen.

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THE cathode ray oscillograph has undergone a very rapid development during the past few years, largely because of its promise as a receiver in television apparatus. Laboratory workers have benefited from this development, but its rapidity perhaps has resulted in an as yet incomplete realization of its potentialities.

For the observation and measurement of quick transients in electric circuits perhaps the only important disadvantage of the cathode ray oscillograph, in comparison with the bifilar type, is that it is designed to trace only a single curve. To overcome this disadvantage, there have been developed in the electrical engineering department at the Massachusetts Institute of Technology devices for making possible the operation of the instrument as a multielement oscillograph, in circuits that allow the repeated application of the waves to be measured. The waves may be either steady-state or transient.

Figure 1 shows the simple apparatus required, in addition to the standard oscillograph and sweep circuit, for handling 2 transients, and figure 2 a similar device developed to handle up to 4 transients simultaneously. In the apparatus of figure 1 a small synchronous motor drives 3 insulating disks bearing copper insets on portions of their peripheries. The function of the device in brief is to act as a commutator and to switch to the measuring plates of the oscillograph the various voltage waves to be traced. At the same time the device must trip the sweep circuit at the proper time so that the curves will remain stationary on the oscillograph screen.

Figure 3 indicates the layout of the 3 disks that

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Fig. 1. Synchronous-motor-driven commutating disks, with brush assembly

Fig. 2. Synchronous-motor-driven commutating disks, with change gears, designed to handle as many as 4 circuits simultaneously

form part of the device. For recording 2 voltage curves, such as, for example, on a transmission line transient, disks 2 and 3 only need be used and the circuit connected as indicated in figure 4. As disk 2 rotates, the conducting insets, traveling counterclockwise, pass the 3 brushes marked 3, 4, and 5. The wire to the sweep-circuit trip contact is connected to the supply when the inset reaches brush 4 and 20 degrees later, when brush 5 is reached, the line to the sending end of the transmission line is energized. These contacts remain closed for almost a half revolution, and then after a brief open period are reclosed by the passage of the other metal inset. Turning on the same shaft, disk 3 contains only a single metal inset; 2 pairs of brushes, diametrically opposite as shown, bear on this disk. One pair of the opposite brushes is connected together to a common deflecting plate of the oscillograph. The other 2 brushes are connected to the 2 points at which the voltage variation curves are to be traced.

In operation, 2 transients are thrown on the line for each revolution of the disks. During alternate transients the voltage of one point is recorded, and during the other transients the voltage of the second point is recorded. These alternate curves are traced in such rapid succession that to the eye they both appear to be present continuously on the screen. The persistence of the willemite fluorescence contributes to this illusion.

Figure 5 shows a series of oscillograms taken with the aid of this device, representing the d-c transients on a 100-mile laboratory smooth transmission line. The line was open at the receiving end, and a constant direct voltage was applied intermittently at the sending end. Provision was made for draining the residual charge from the line between applications of voltage. On each oscillogram is traced the sending-end voltage, which jumps suddenly from zero to a constant value. The other curve is the voltage at another point along the line. Not only are the shapes and sizes of the various voltage waves and reflections clearly indicated, but the time required for the wave to reach the several positions on the line is indicated by the horizontal distance between the application of sending-end voltage and the initial arrival of the wave at the several points.

Figure 6 shows a series of oscillograms taken on the same line, but with alternating voltage impressed. The voltage was thrown on at different parts of the cycle in the various oscillograms. The driving motor of the commutator disks is of the synchronous type, which is necessary in order to hold steady the a-c transients. A nonsynchronous drive would

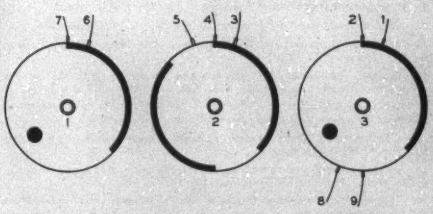


Fig. 3. Commutating disks and brushes for 2 element operation

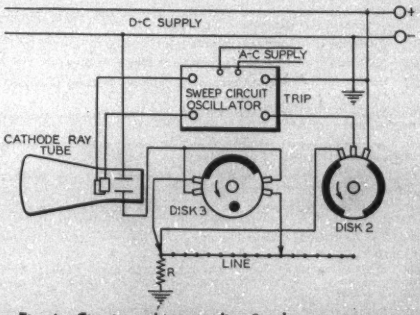


Fig. 4. Circuit used in recording 2 voltage transients simultaneously

result in the voltage being thrown on at different points of the cycle even though the locking feature of the oscillograph sweep circuit might keep it synchronized with the wave to be measured.

The device is not limited to voltage measurements but may be applied equally well to measurements of current. If one voltage and one current curve are to be traced, then all 3 disks must be used along with

the circuit shown in figure 7. It will be assumed that the oscillograph is equipped with magnetic coils for current operation. These must be connected in series with the section of the line in which the current is to be measured, but this connection is to be established only on alternate applications of the

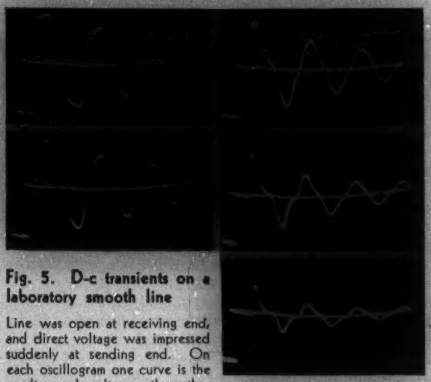


Fig. 5. D-c transients on a laboratory smooth line

Line was open at receiving end, and direct voltage was impressed suddenly at sending end. On each oscillogram one curve is the sending-end voltage; the other curve is voltage: (a) at receiving end; (b) $^1/_8$ of way back from receiving end; (c) $^2/_8$ of way back from receiving end; (d) $^3/_8$ of way back from receiving end; and (e) $^4/_8$ of way back from receiving end

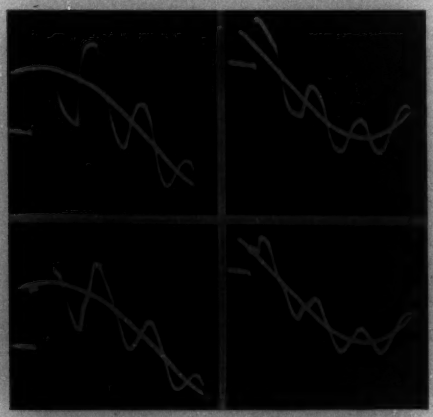


Fig. 6. A-c transients on a laboratory smooth line

Line was open at receiving end, and alternating voltage was impressed suddenly at sending end. On each oscillogram one curve is the sending-end voltage; the other curve is voltage at: (a) receiving end; (b) center of line; (c) receiving end; and (d) center of line. In (a) and (b) the voltage was impressed near its positive peak; in (c) and (d) just before passing through zero

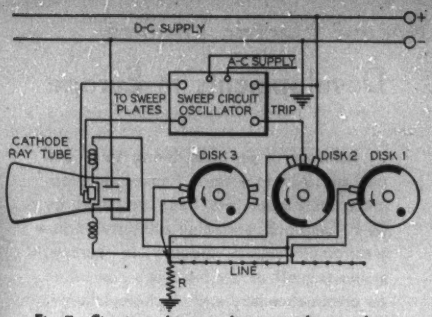
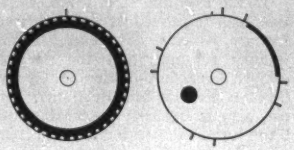


Fig. 7. Circuit used in recording one voltage and one current transient simultaneously

transient. This is accomplished by short-circuiting the coils on alternate transients by means of disk 1 on which bear a single pair of brushes.

There is no definite limit to the number of curves that may be traced with apparent simultaneity on the oscillograph screen. The practical limitation is only the complexity of the control circuit and the crowding of the various curves on the relatively small screen. If 4 voltage curves are to be traced, one of

Fig. 8. Timing disk and 4-wave switching disk



the disks should be of the design shown at the right in figure 8. The sweep trip and initiating voltages are thrown on 4 times per shaft revolution. During each quarter revolution the oscillograph plates are connected to 1 of the 4 points whose potential variations are to be recorded. If the voltages to be recorded are not all connected to a common neutral, then an additional disk is needed for the second lead from each voltage. If there be a common neutral, the lead from this neutral may be connected permanently to one of the deflection plates of the oscillograph. The left-hand disk of figure 8 is for the purpose of providing a convenient timing wave in the form of a series of rectangular steps.

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Recent Electric Furnace Developments in Europe

A summary of progress during 1934 and part of 1935 in electric furnace developments in Europe has been prepared by D. F. Campbell, a leading authority on the electrometallurgical industry in Europe, at the request of the Institute's committee on electrochemistry and electrometallurgy. The summary is presented herewith for the information of the Institute's membership.

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ELECTRIC furnace progress in Europe during the 12 months preceding April 1935, has been characterized by steady development and improvement of types of equipment that had previously reached a stage of industrial application.

In the iron and steel trade, metallurgical practice has been improved in the high frequency induction furnace, which is now being used on a large scale for quality refining, and the preparation of highly alloyed steels, in the principal steelworks of England, Sweden, France, and Belgium. Furnaces in general use vary in capacity from laboratory sizes to 5 and 6 ton furnaces operated for high frequency generators of 1,250 kw. The generators are now generally of the inductor type, the wound rotor method of constructing these machines having been discarded, except in Germany. English, French, and Swedish constructors are manufacturing motor-generator sets having over-all efficiencies of about 88 per cent for 1,250 kw sets, and 86 per cent for 400 kw sets, which shows a marked improvement on the older type of machines built formerly.

The largest high frequency melting shop is that in the steelworks of the Etabs. Jacob Holtzer, in France, where there are 2 sets of 650 kw, and 3 sets of 150 kw, with a number of furnaces of various sizes.

An Unusual Installation for Quality Refining

The most interesting installation is probably that of Samuel Fox and Co. Ltd., near Sheffield, England. Important metallurgical advances have been made in quality refining in this installation, the following description of which may be of interest.

Furnaces of 2 and 5 tons are arranged for melting cold scrap, or molten metal by a duplex process.

The motor-generator is placed in a separate substation 80 feet from the furnaces, the condenser plant being situated under the furnace platform. The alternator consists of 2 625-kw stators, with a common rotor. Each stator consists of 2 separate halves, and provision is made to prevent interaction between the magnetic circuit of one stator and the excitation winding of the other stator. It is thus possible to control the voltage of each of the circuits independently and operate 2 furnaces simultaneously. When desired, the stators can be connected in series so that 1,250 kw can be applied to one furnace.

The furnaces can be completely automatically, semiautomatically, or hand controlled, at will.

A number of protective devices have been incorporated in the equipment. Relays are provided to cut off the current if the water supply to the coils fails, and colored lamps indicate any failure of the water cooling supply to the machine bearings, or any undue heating of the equipment.

The furnace bodies are arranged to be normally flush with the platform, and the provision of a special charging cylinder permits very rapid charging. In a full day's run, the current was only switched off for an average of 6 minutes per heat, which includes the time required for pouring and recharging the 2 ton furnace.

In a recently published article, Doctor Swinden, chief metallurgist of United Steel Companies Ltd., of which Samuel Fox and Co. Ltd. is a member, states that in this plant sulphur can be removed more rapidly than in normal arc furnace practice, owing to the intense movement of the metal. This movement also provides an opportunity for microscopic particles to coalesce and rise in the liquid steel. In this way, the nonmetallic inclusions formed from the products of deoxidation can to a large extent be removed. Tests made on air-hardening nickel-chromium steel, nickel-chromium-molybdenum case-hardening steel, low-carbon chromium-molybdenum steels, and many others, show the very high quality of steel made by quality refining. Perfectly sound stainless steel, with only 0.05 per cent carbon, is being cast, and it is found that this steel withstands weld decay tests under conditions many times as severe as those stipulated in the government specifications.

High Frequency Generators

The output of high frequency generators used for steelmaking in Europe is now between 30,000 and 35,000 kw.

Larger furnaces have involved the use of higher voltages, owing to the large kilovolt-ampere rating of the inductor coils, and 2,500 volts has now become within the limits of standard practice. For small furnaces up to $^1/_2$ ton, frequencies of 500 cycles per second have been found to give conditions unsuitable for the best steelmaking practice, and higher frequencies are now specified for these small units.

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For furnaces of 5 tons, periodicities of 800 to 1,000 cycles per second have been selected.

Induction Furnaces

Interesting attempts have been made to build induction furnaces with controlled movement of metal and slag. Extensive work was done at Hanau by Doctor Rohn, who has been responsible for great advances in the vacuum melting of metals and the working of heat resisting alloys of the nickel-chrome-molybdenum, etc., type. The induction furnace on which he has been working is a normal frequency, 3 or 6 phase, hemispherical furnace giving an intense and controlled movement of the metal and slag, which opens interesting possibilities in metallurgical practice. Electrical power input is limited by constructional difficulties, and the speed of melting and heat control is accordingly strictly limited, and has retarded the commercial development of this interesting design of furnace, and, until these limitations are overcome, its commercial value cannot be considered established.

In Sweden interesting work is being done with dual frequency furnace construction, in which normal frequency induction coils are used to control the movement of metal, while normal high frequency induction coils are used to maintain the heat and energy input that is required for rapid operation. It is expected that metallurgical reactions may be controlled better by this means, but the additional cost and the complication of the electrical apparatus are serious factors. The problem of maintaining the refractory linings for a sufficient period will, however, probably prove the determining factor in the success or failure of these new types of ironless induction furnaces with intense electrically-controlled movement of the charge.

Arc Furnace

Arc furnaces continue to find wide application, and many are now being built. The removable roof for rapid charging is being generally adopted, and greatly speeds up the charging time. There are no other substantial advances, and little improvement has been made in recent years in power consumption. Furnaces of large capacity, of about 30 tons, are used for refining liquid metal, but the difficulty of skimming these furnaces clean of slag makes the smaller units of about 10 tons generally preferred for the manufacture of the highest grades of steel from cold stock, and larger units are generally considered of little advantage for this class of work.

In the nonferrous trades, the Ajax-Wyatt, or furnaces of similar design, have become standard practice for melting in brass mills, and large units of 2,500 pounds and 360 kva capacity have been developed, and give marked economy in labor and power, and some metallurgical advantages, owing to the mixer effect of the larger unit, when melting miscellaneous scrap. These furnaces are of the Ajax-Wyatt type, and are operated by 2 phase current obtained from standard 3 phase systems by a Scott connection on the furnaces. It is noteworthy that this important improvement and economy does not seem to have been adopted in the United States.

Resistance Furnaces

A rocking resistance furnace has recently been introduced in France for the melting of bronzes and cast iron in small quantities for the manufacture of piston rings and similar special products. The construction of the furnace is generally similar to that used for the well-known horizontal rocking arc furnace, but, instead of heating by an arc, a graphite resistor is used and this is loaded sufficiently to heat the resistor to the required temperature. In furnaces of 1,000 pounds capacity, for example, the resistors of Acheson graphite are operated at 2,000 amperes per square inch. Special patented features are the terminals, arranged to prevent excessive loss of heat, and an arrangement whereby the power factor is maintained at a high value, even in the case of large furnaces.

This system of heating was first used for the manufacture of silica tubes, but it is now finding application in bronze foundries, where the Ajax-Wyatt furnace is unsuitable, owing to the continual changing of analysis of product and the small tonnages required. It is considered better than the horizontal arc furnace for certain applications, as there is no excessive heat to damage or volatilize the metals heated, and it is being installed by specialized iron foundries for small castings.

The use of resistance furnaces is developing rapidly, especially for the heat treatment of aluminium alloys within narrow limits at low temperature, for the bright annealing of copper in controlled atmospheres by a dry process which gives a perfect finish without the risk of water stain, and in the many other metallurgical processes to which this equipment has been previously applied. The greatest progress in Europe during the past year has been made in the finer control of atmosphere in electric furnaces for heat treatment.

Heat Resisting Alloys

Progress in the manufacture of heat resisting alloys for high temperatures, and to resist sulphur, has resulted in the production of metals which can be worked continuously at 2,350 to 2,400 degrees Fahrenheit. These are chrome-iron-aluminium-cobalt alloys, without nickel. The use of alloys of this type is increasing, both for high temperature work, and also for domestic applications, where the low intrinsic value of the metals contained makes its use competitive with the standard 80/20 nickel-chrome alloys.

In Europe, the metallurgical works of Great Britain and Sweden have worked generally to capacity, and considerable technical progress has been made. In France, industry, other than government contracts, has been very depressed, and little money has been available for technical developments. In Belgium, where nearly 80 per cent of metallurgical industry works for export, trade has been bad owing to import restrictions and currency questions, while

in Germany research work has had a serious setback, owing to the disturbance of works staff and the depression in many industries during the last year. The ironless induction furnace undoubtedly presents the greatest possibility of further development, and the experience now being obtained in Great Britain, Sweden, and Germany should result in a wider application of this interesting method of electric heating.

Electrical Brush Wear

An investigation of the effects of polarity and current density on the rate of wear of electrical brushes is reported in this paper, following a brief review of previous experimental work in this field. For carbon and copper impregnated carbon brushes the rate of wear of the positive brush is considerably less than that of the negative brush, while for metallic brushes the situation is reversed. The rate of wear of metallic brushes was found to be much greater than that of carbon brushes, under conditions of these tests. While no complete explanation of brush wear can be derived from the results, the rate of wear seems to be related intimately to the conduction of current across the contact.

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A CAREFUL SURVEY of the literature on electrical brushes reveals little qualitative information concerning electrical brush wear. Practically all the investigations reported are concerned with the effects of various operating conditions upon contact potential drops.

Hunter-Brown[1] obtained 2 curves of electrical brush wear versus current density, which indicate that the negative brush (motor notation) wears at a greater rate than the positive brush, and that the rate of wear is approximately proportional to the current density. However, the points obtained are too few to justify a definite conclusion.

J. S. Dean[2] made an extensive survey of the life of carbon brushes in d-c railway service. In this type of service the actual end wear of the brush is small compared with all the other factors that bring about deterioration of brushes. He found that high grade graphitized brushes on commutating pole motors with undercut mica, when subjected to end wear alone, would have a probable life of 200,000 car-miles. With modern medium grade carbon brushes on non-commutating pole motors with flush mica, the probable life due to end wear is 20,000 car-miles. Dean concludes that burning action is responsible for most of the end wear. He gives 2 extensive tables of the factors causing brush wear in railway service. These tables indicate that if good contact is maintained between the brush and commutator at all times, the rate of brush wear will be low.

Under conditions of very low humidity the rate of wear of metallic brushes on high speed converter rings often becomes excessive. Bracken[3] states that whole sets of brushes sometimes are worn out in from 30 minutes to $1^1/_2$ hours. This effect never has appeared on low-speed 25-cycle machines. He finds that rapid wear is likely to start when the absolute humidity drops below 1.25 grains per cubic foot.

A series of tests was conducted by Baker[4] to determine the effect of a hydrogen atmosphere upon electrical brush wear and commutation. In these tests a d-c machine was operated both in air and in an atmosphere of hydrogen with varying qualities of commutation. Two runs were made to determine the effect of humidity in a hydrogen atmosphere with poor commutation. The following conclusions were drawn from the results of the tests:

1. A well designed commutator machine will operate satisfactorily and give good brush life in hydrogen.
2. If a brush must spark in hydrogen, the brush life may be increased many times by maintaining the relative humidity below 10 per cent.
3. Carbon and graphite brushes cannot be operated upon a tool steel ring in hydrogen. Particles of cementite (Fe_3C) are formed which immediately begin to score the ring and the brush face.

Perrier[5] found that the rate of brush wear is increased with the oxidation, sulfuration, or chlorination of the ring surface.

The foregoing items constitute most of the investigations of electrical brush wear that have been reported. The scarcity of quantitative data indicated a real need for further investigation of electrical brush wear. Information on brush wear should be of value to the brush manufacturers and to designing and operating engineers. It also should aid in extending or checking the present inadequate theories of the sliding contact. It is for the purpose of obtaining additional information of this character that

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1. For all numbered references, see list at end of paper.

the investigation reported in this paper was undertaken.

Apparatus Used in Tests

Details of the mechanical arrangement of the apparatus used in the tests reported in this paper are shown clearly in figure 1. The rings were carried on a $1^{15}/_{16}$ inch shaft which rotated in self-aligning ball bearings. The rings were attached to the shaft by means of tapered sleeves with a sheet of 0.005 inch vulcanized fiber between the sleeve and the shaft for insulation. This arrangement held the rings securely to the shaft and gave sufficient insulation for all purposes of the tests. After completely assembling the rings, bearings, and bearing housings the complete unit was removed from the bearing hangers and mounted upon a lathe bed. The surfaces of the rings then were turned with the shaft rotating in its own bearings. By this method the eccentricity of the rings could be kept below 0.0005 inch. The translation of the brush caused by the eccentricity was measured with a dial micrometer attached to the vertical rod on the brush holder.

Rings. Hard drawn electrolytic copper bar was rolled and brazed to form the slip rings. A special low temperature brazing metal was applied to a V notch in the joint on the inside of the ring, which joint barely was visible on the outer surface of the rings. These copper rings were pressed upon cast aluminum disks. The surfaces of the rings were polished carefully with commutator dressing stones and burnished with a beechwood stick. They were repolished in the same manner at intervals throughout the period of the tests.

Brush Holders. The brush boxes consisted of 4 pieces of $^1/_2$ inch brass soldered and pinned together. Considerable care was taken with the internal dimensions to assure proper clearances between the brushes and the box; the boxes were one inch long. Details of the pressure arm mechanism are shown in figure 1. As the brushes wore away, the pressure arm was kept perpendicular to the brush by lowering the fulcrum. The brush pressures were adjusted with the aid of a balance and a pair of headphones, a click in the headphones indicating that the pressure arm had been lifted clear of the hammer plate. The reading of the balance always was corrected for the weight of the brush. The springs were continuously adjustable so that the brush pressure could be adjusted to any desired value.

Fig. 1. Brush holder and ring mechanism

Fig. 2. View showing air conditioning equipment

Temperature and Humidity Control. The humidity control equipment is shown in figure 2. The box temperature was held constant by means of a thermostatic control. To maintain constant humidity air from the room was drawn into the blower at the lower left and was blown past a series of water spray nozzles in the tunnel, then through baffle plates to remove entrained moisture, next past a heater where the temperature was raised sufficiently to prevent condensation in the tunnel, and finally through a group of air nozzles into the box. The water was forced through the spray nozzles by the centrifugal pump at the lower right and flowed back into the supply tank. Humidity control consisted of maintaining the water temperature at the dew point corresponding to the relative humidity and air temperature desired.[6] The relative humidity was measured with a wet and dry bulb hygrometer.

Method of Measuring Wear. An attempt first was made to determine the wear by weighing the brushes. This method, however, was found to be impractical because of the variation of the absorbed moisture. The micrometer arrangement shown in figure 3 then was developed, which gave excellent results. The bed plate was of invar and had an effective expansion of less than 0.00002 inch for the maximum change in room temperature. To measure the length of a brush, it was placed in the V block as shown; the micrometer head then was screwed in until the hammer plate of the brush made contact with the insulated point, as indicated by a click in the headphones.

Method of Measuring Contact Drop. The positive and negative contact potential drops were measured by means of the auxiliary copper leaf brushes shown in figure 1, which were lowered to the ring whenever measurements were to be taken. They rode on

the middle of the ring between the positive and negative brush paths. Auxiliary potential leads were soldered to the hammer plate rivet to eliminate all possible *IR* drops from the measurements, and the readings were corrected for the drop through the brush material.

Brushes and Brush Circuit. The brushes were $^1/_2$ inch square and 2 inches long. The hammer plates and shunts were attached with spun tubular rivets. Some of the physical constants and the types of material of the brushes are given in table I.

All brushes were connected in series, and the group was connected to a 110-volt d-c generator through a variable resistance. A low voltage generator was used originally, but it was impossible to hold the current constant because of the change in contact potential drop at the brushes.

Test Procedure

The brushes always were "run in" carefully before any measurements were taken. They first were sanded as nearly as possible to the curvature of the ring and then were run at approximately normal current density until the entire brush face made contact with the ring. Much less time was required and a better surface was obtained when the brushes were "run in" with current.

When a satisfactory brush surface had been obtained, the ring was repolished and the brush measured. The brush then was operated at a given current density for a sufficient time to give a measurable wear after which it was measured again. Readings were taken at each of several current densities. The rings were not polished during the time the metallic brush wear data were being taken. The positive and negative brushes were run on separate paths. Data for 4 different grades of brushes were obtained simultaneously upon the 4 rings.

Before proceeding with the current density tests a series of tests was made to ascertain whether the values chosen for brush pressure, speed, and humidity were critical as regards rate of wear. These tests indicated that any changes that were likely to occur in pressure, speed, or humidity would not have any appreciable effect upon the rate of wear.

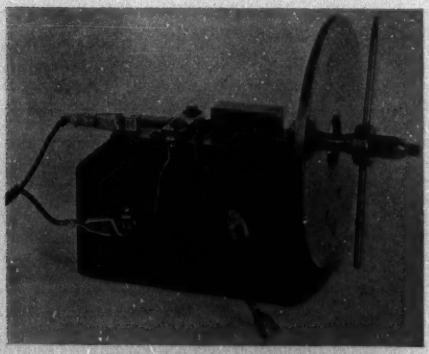

Fig. 3. Special micrometer for measuring brushes. Cord at left connects to headphones

Table I—Physical Characteristics of the Brush Materials

Brush	Resistance, Ohms per Inch Cube	Hardness (Scleroscope)	Transverse Strength, Lb. per Sq In.	Normal Current Density, Amp per Sq In.	Type of Material
A	0.0020	65	3,600	55	Electrographitic lampblack
B	0.00225	54	2,960	60	Electrographitic lampblack
C	0.00106	40	3,500	45	Carbon graphite
D	0.00142	40	3,500	45	Carbon graphite
F	0.00000242	5	9,700	150	Heavy metal graphite
G	0.000010	16	4,000	100	Metal graphite
H	0.0000064	20	4,900	115	Metal graphite
I	0.000214	35	6,000	85	Copper impregnated carbon

In the following discussion the brush in which the conventional current flow is from brush to ring is considered positive.

Carbon Brush Wear

The data on carbon brush wear and contact drop versus current density are presented in figures 4 to 7. Each of the experimental points of contact potential drop shown in the figures represents the average of from 12 to 15 readings taken at intervals throughout the tests at a given current density; thus each point represents the mean value of contact drop for a week of continuous operation. There can be no doubt that the contact drop did decrease with increased current density. It must be remembered that contact drop is affected by other factors as well as by current density.

A curve of contact potential drop versus current density obtained by increasing the current to its maximum value in a few minutes almost always will show an increase of contact drop with increased current; also any sudden increase in current always will result in an increased contact drop. If this were not true it would be impossible to operate brushes in parallel. For these instances of comparatively rapid change in current other factors affecting brush contact drop are constant and the drop is determined by the current density. When the current density is maintained at a given value for a week, the brush surface, ring surface, and ring temperature assume a condition more or less characteristic of that current density. It is not understood very clearly just how the surface conditions affect the contact drop, but increased ring temperature brings about a decided decrease.[7] Thus the decreased contact drop is the indirect effect of the increased current, which, unfortunately, cannot be indicated on a 2 dimension diagram.

Metallic Brush Wear

The data on metallic brush wear and contact drop versus current density are presented in figures 8 to 11. The rate of wear of metallic brushes is so much greater than for carbon brushes that a measurable

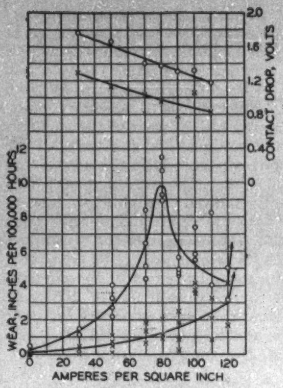

Fig. 4. Brush A

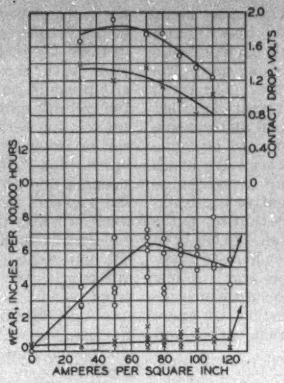

Fig. 5. Brush B

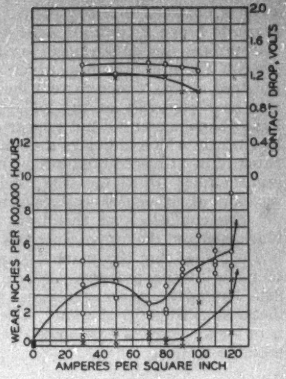

Fig. 6. Brush C

Figs. 4 to 7. Rate of wear of carbon brushes

Ambient temperature, 45 degrees centigrade
Relative humidity, 50 per cent
Brush circuit potential, 80 volts
Ring speed, 3,500 feet per minute
Brush pressure, 48 ounces per square inch
o—negative brush x—positive brush

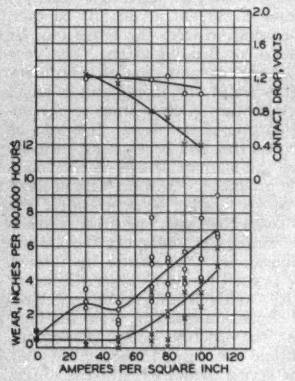

Fig. 7. Brush D

Figs. 8 to 11. Rate of wear of metallic brushes

Ambient temperature, 45 degrees centigrade
Relative humidity, 50 per cent
Brush circuit potential, 90 volts
Ring speed, 3,760 feet per minute
Brush pressure, 48 ounces per square inch
o—negative brush x—positive brush

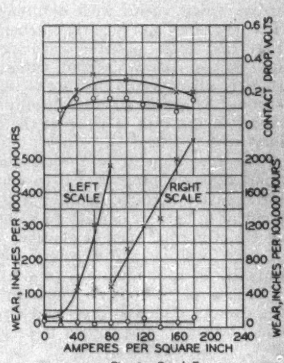

Fig. 8. Brush F

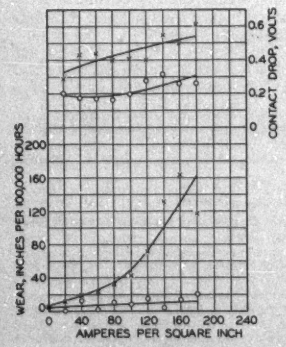

Fig. 9. Brush G

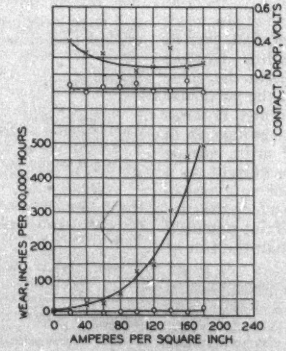

Fig. 10. Brush H

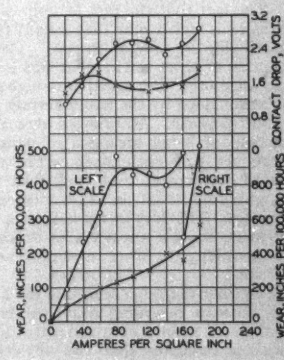

Fig. 11. Brush I

wear is obtained in a few hours. The heavy metal graphite brush *F* contains some lead. Shortly after the run was started the positive ring path assumed a grayish white appearance, which became more pronounced at the higher current densities. The brush also sparked badly at the higher current densities. This phenomenon did not appear at all at the negative brush, which indicates that there must be something akin to electrolytic action between the brush and the ring. Brush material *I* did not operate satisfactorily at either the positive or negative brush under the conditions of this test. Both ring paths blackened and the rate of wear was high. It has been learned since that this material cannot be used satisfactorily at the pressure used in this test. A few runs have been made at a higher pressure which indicate normal rates of wear. The curves are given here for purposes of comparison between carbon and metallic brushes.

Summary of Results

The rate of wear of positive carbon brushes is low and is independent of current density below a critical value which varies with different brush materials. The rate of wear of negative carbon brushes is greater than that of the positive and is proportional to current density below a certain value; above this value there is a decrease in the rate of wear with increasing current density, followed usually by a sudden increase in the rate of wear as the current density is increased to excessive values.

The rate of wear of positive metallic brushes is approximately proportional to current density, but for negative metallic brushes it is practically independent of current density to values considerably in excess of normal current density. The rate of wear of both positive and negative copper impregnated brushes is approximately proportional to current.

In general, there is no consistent relation between the contact potential drop and rate of wear of electrical brushes. The copper impregnated brush, however, is an exception; in all the tests made on it the configurations of the contact drop curve and the corresponding rate of wear curve were similar.

The fact that the rate of wear of positive metallic brushes is higher than that usually found in practice is ascribable to several causes: The normal current density of all of the brushes was exceeded. In some instances the ring speed was higher than the value recommended by the manufacturer for the particular grade of brush. All brushes were connected in series instead of being arranged in parallel groups as in practice; thus each brush carried the entire current continuously and could not shift the current to a neighboring brush during a moment of unfavorable contact. This last factor is known to affect the rate of wear, because a test with a brush circuit potential to 10 volts gave lower rates of wear than the test at 90 volts.

A rather thorough search of the literature revealed no theories regarding electrical brush wear. The variety of results obtained with different grades of brushes indicates that the physical characteristics of the brush materials have a decided effect upon the rates of wear. Some of the physical properties of the brush materials used in these tests are given in table I. In any attempt to correlate the rate of wear with these physical properties, the carbon group would have to be considered separately from the metallic group. There seems to be some consistent relation between the rate of wear of the negative carbon brush and the hardness and resistivity of the brush materials, but no correlation between the strength and rate of wear. The metallic brush with the greatest strength showed the greatest rate of wear, whereas the opposite result might have been expected. Apparently the strength of the brush does not materially affect its rate of wear. To form definite conclusions concerning the effect of the physical properties upon the rate of wear it will be necessary to obtain data for many different grades of brushes. Even so, it will be difficult to draw definite conclusions because of the many factors that vary simultaneously.

The pronounced polarity effect and the complex nature of the curves for the negative carbon brushes indicate that the rate of wear is connected intimately with the conduction of current across the contact. Material might be removed from the brush face by abrasion, combustion, or disintegration. The very low rates of wear at zero current show that ordinary abrasion does not account for more than a small portion of the total wear. Combustion might account for a small portion of the wear. It would be instructive to mount a ring and brush in an enclosed space and measure the amount of carbon monoxide and carbon dioxide produced. The quantity of these gases could not be very large, because one of the difficult problems connected with operating a brush in a closed space consists of removing the carbon dust from the atmosphere. Apparently the flow of current across the contact produces a disintegration of the brush surface. This disintegration might result from thermal expansion resulting from the high current density at the discrete points of contact between the brush and the ring. However, it is not apparent how this action would explain the difference between the rates of wear of positive and negative brushes. It is evident that much more quantitative data, involving other factors of brush wear will have to be obtained before the final and complete explanation of brush wear is found.

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Current Harmonics in Nonlinear Resistance Circuits

A semigraphical method of solving for harmonics in the input current to a network containing any number of linear and nonlinear resistances in any combination, when a sinusoidal voltage is applied across the network, is presented herewith. The treatment is restricted to nonlinear resistances in which the d-c volt-ampere characteristic is the same regardless of the direction of current. While the method has the errors inherent in any graphical solution, the results indicate good accuracy with little labor.

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METHODS of solving for alternating currents and voltages in various parts of a network containing only linear elements are well known, and calculations for such a circuit usually can be made without great difficulty. The problem of the circuit containing one or more elements that depend for their magnitude on the current flowing through them, is entirely another matter. Here mathematical expressions that characterize the nonlinear element or elements must be employed, which may cause the solution to become highly involved. Sometimes suitable mathematical expressions cannot be found and recourse then must be made to experimental means, or to approximations which may be quite unsatisfactory.

It is the purpose of this study to develop a semigraphical method of solving for the harmonics contained in the input current of a 2-terminal resistance network when a sinusoidal voltage is applied across its terminals. The network may contain resistances of the linear and nonlinear types in any number or combination. The nonlinear resistances, however, will be restricted to those having the same d-c volt-ampere characteristic regardless of the direction of current through them. The material known commercially as "thyrite" has a characteristic of this type.[1,2] A volt-ampere curve of a 2-terminal network containing a number of linear and nonlinear elements, subject to the foregoing restriction, will be identical in the first and third quadrants except for the signs of the current and voltage.

If a sinusoidal voltage wave be applied at the terminals of such a circuit, the current wave in general will not be a sine wave but will contain various harmonics. From inspection of the volt-ampere curve certain conclusions may be drawn regarding the nature of these harmonics. The current wave will pass through zero when the instantaneous voltage is zero. The positive half of the current wave will be symmetrical around the 90 degree ordinate, and the negative half symmetrical around the 270 degree ordinate. Furthermore, the positive and negative halves will be identical except for the signs of the ordinates. Such a wave may be represented by a Fourier series containing only sine terms of odd harmonics.[3]

The Basic Circuit

The circuit upon which the theory is based consists of a linear and a nonlinear resistance in series, with a sine wave voltage impressed across the terminals. The problem is to find the amplitudes of the current harmonics.

Let the curve OA, in figure 1 represent the volt-ampere curve of the nonlinear element. The linear resistance will have the magnitude R. For the instantaneous value of current OF, the voltage drop across the nonlinear resistance is FC. Adding the distance CD, which is the current multiplied by R to scale, gives the total instantaneous impressed voltage, FD or OB. If the line BC be drawn as shown, the tangent of the angle Φ is equal to R.

Similarly, for another value of current OF', the impressed voltage is OB'. The tangent of Φ' is also R; therefore Φ and Φ' are equal. Thus to find the current corresponding to any value of instantaneous voltage, it is necessary only to lay off the voltage on the vertical axis and from this point draw a line parallel to BC or $B'C'$. The intersection of this line and the curve OA marks a point which, if porjected to the current axis, determines the current. If the instantaneous voltage be a function of time, such as $E \sin \omega t$, then in a like manner any number of values of instantaneous current can be determined and plotted against time. This procedure actually is followed to obtain current waves for analysis by

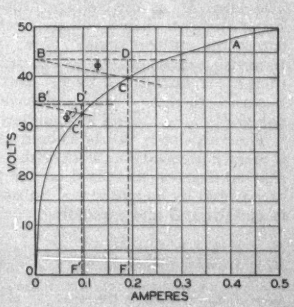

Fig. 1. Volt-ampere relations in a circuit containing a linear and nonlinear resistance in series

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1. For all numbered references see list at end of paper.

means of the harmonic analyzer. The results of these analyses are used for comparison in the numerical examples. To avoid the labor of plotting an accurate current wave and then performing an analysis the following method was developed.

If a sinusoidal voltage, $E \sin \omega t$, be impressed across the 2 elements in series, the current can be expressed in the form

$$i = \Sigma I_m \sin m\omega t \tag{1}$$

where

$$m = 1, 3, 5, 7 \ldots\ldots\ldots$$

Equating the voltage drops,

$$E \sin \omega t = R\Sigma I_m \sin m\omega t + \Sigma A_m \sin m\omega t \tag{2}$$

where

E = maximum value of the impressed voltage
I_m = maximum value of the mth current harmonic
A_m = maximum value of the mth harmonic voltage across the nonlinear resistance
R = value of the linear resistance

At a time $\omega t = \theta_1$, equation 2 becomes

$$E \sin \theta_1 = R\Sigma I_m \sin m\theta_1 + \Sigma A_m \sin m\theta_1 \tag{3}$$

Similarly, when $\omega t = \theta_2$

$$E \sin \theta_2 = R\Sigma I_m \sin m\theta_2 + \Sigma A_m \sin m\theta_2 \tag{4}$$

Thus a set of equations can be written for the angle $\omega t = \theta_n$, where $n = 1,2,3,4,\ldots\ldots$ Now if θ_2 be set equal to $2\theta_1$, θ_3 equal to $3\theta_1$, and in general θ_n equal to $n\theta_1$, the set of equations with some rearrangement becomes

$$\begin{aligned} E \sin \theta_1 - R\Sigma I_m \sin m\theta_1 &= \Sigma A_m \sin m\theta_1 \\ E \sin 2\theta_1 - R\Sigma I_m \sin 2m\theta_1 &= \Sigma A_m \sin 2m\theta_1 \\ &\ldots\ldots\ldots\ldots \\ E \sin n\theta_1 - R\Sigma I_m \sin nm\theta_1 &= \Sigma A_m \sin nm\theta_1 \end{aligned} \tag{5}$$

The general term $\Sigma I_m \sin nm\theta_1$ is the instantaneous value of current in the circuit corresponding to the instantaneous value of impressed voltage, $E \sin n\theta_1$. The numerical value of the left hand member of any equation in group 5 is equal to the instantaneous voltage across the nonlinear resistance at a time when ωt is equal to $n\theta_1$. In general let

$$M_n = E \sin n\theta_1 - R\Sigma I_m \sin nm\theta_1 \tag{6}$$

The term M_n is the voltage drop across the nonlinear element when a voltage $E \sin n\theta_1$ is impressed across the entire circuit. Thus, in figure 1, if the terminal voltage, $E \sin 4\theta_1$, be represented by OB, then M_4 is represented by FC, and if OB' represents $E \sin 3\theta_1$ then $F'C'$ is the value of M_3. The other values of M_n are found in a similarly from the curve.

The value of θ_1 will be chosen as 15 degrees. As it is only necessary to work with $^1/_4$ cycle, it follows that 90 degrees, measured on the fundamental, will be covered by 6 equations. Substituting equation 6 in equations 5 and expanding,

$$\begin{aligned} M_1 &= A_1 \sin \theta_1 + A_3 \sin 3\theta_1 + \ldots\ldots A_{11} \sin 11\theta_1 \\ M_2 &= A_1 \sin 2\theta_1 + A_3 \sin 6\theta_1 + \ldots\ldots A_{11} \sin 22\theta_1 \\ &\ldots\ldots\ldots\ldots \\ M_6 &= A_1 \sin 6\theta_1 + A_3 \sin 18\theta_1 + \ldots\ldots A_{11} \sin 66\theta_1 \end{aligned} \tag{7}$$

In these equations the 6 amplitudes, $A_1 \ldots\ldots A_{11}$, are the only terms that are unknown. Solving for A_1 by means of determinants,

$$A_1 = \frac{\begin{vmatrix} M_1 \sin 3\theta_1 \ldots\ldots\ldots\ldots & \sin 11\theta_1 \\ M_2 \sin 6\theta_1 \ldots\ldots\ldots\ldots & \sin 22\theta_1 \\ M_3 \sin 9\theta_1 \ldots\ldots\ldots\ldots & \sin 33\theta_1 \\ \ldots\ldots\ldots\ldots & \\ \ldots\ldots\ldots\ldots & \\ M_6 \sin 18\theta_1 \ldots\ldots\ldots\ldots & \sin 66\theta_1 \end{vmatrix}}{\begin{vmatrix} \sin \theta_1 \sin 3\theta_1 \ldots\ldots\ldots\ldots & \sin 11\theta_1 \\ \sin 2\theta_1 \sin 6\theta_1 \ldots\ldots\ldots\ldots & \sin 22\theta_1 \\ \sin 3\theta_1 \sin 9\theta_1 \ldots\ldots\ldots\ldots & \sin 33\theta_1 \\ \ldots\ldots\ldots\ldots & \\ \ldots\ldots\ldots\ldots & \\ \sin 6\theta_1 \sin 18\theta_1 \ldots\ldots\ldots\ldots & \sin 66\theta_1 \end{vmatrix}}$$

Let the denominator of this expression be denoted by D; on expanding,

$$A_1 = M_1 \frac{\begin{vmatrix} \sin 6\theta_1 \ldots\ldots \sin 22\theta_1 \\ \sin 9\theta_1 \ldots\ldots \sin 33\theta_1 \\ \ldots\ldots\ldots \\ \ldots\ldots\ldots \\ \sin 18\theta_1 \ldots\ldots \sin 66\theta_1 \end{vmatrix}}{D} - M_2 \frac{\begin{vmatrix} \sin 3\theta_1 \ldots\ldots \sin 11\theta_1 \\ \sin 9\theta_1 \ldots\ldots \sin 33\theta_1 \\ \ldots\ldots\ldots \\ \ldots\ldots\ldots \\ \sin 18\theta_1 \ldots\ldots \sin 66\theta_1 \end{vmatrix}}{D}$$

In the foregoing expansion only the first 2 terms are shown. The remaining terms are similar in form. Since the angle θ_1 has been chosen as 15 degrees the determinants are constants and the multipliers of M_n will be denoted by K with suitable subscripts. The solution for the A terms then can be written

$$\begin{aligned} A_1 &= K_{11}M_1 + K_{12}M_2 + K_{13}M_3 + \ldots\ldots + K_{16}M_6 \\ A_3 &= K_{31}M_1 + K_{32}M_2 + K_{33}M_3 + \ldots\ldots + K_{36}M_6 \\ &\ldots\ldots\ldots\ldots \\ A_{11} &= K_{61}M_1 + K_{62}M_2 + K_{63}M_3 + \ldots\ldots + K_{66}M_6 \end{aligned} \tag{8}$$

From these equations the amplitudes can be calculated by making use of the 6 scaled values from the curve and the coefficients. These coefficients are given in table I.

If equation 2 be expanded and terms of like frequency equated, the following equations can be written:

$$E = A_1 + RI_1; \quad 0 = A_3 + RI_3; \quad \ldots\ldots \quad 0 = A_{11} + RI_{11} \tag{9}$$

Since a sinusoidal voltage wave is impressed, the amplitudes of the higher harmonics are zero.

Solving equations 9 for the current amplitudes,

$$I_1 = \frac{E - A_1}{R}; \quad I_3 = \frac{-A_3}{R}; \quad \ldots\ldots \quad I_{11} = \frac{-A_{11}}{R} \tag{10}$$

Example. Let a voltage $e = 50 \sin \omega t$ be impressed across the nonlinear resistance, as represented in figure 1, in series with a linear resistance of 20 ohms.

Table I—Numerical Values of the Coefficients in Equations 8

n	K_{1n}	K_{2n}	K_{3n}	K_{4n}	K_{5n}	K_{6n}
1	0.0863	0.1667	0.2357	0.2887	0.3220	0.1667
2	0.2357	0.3333	0.2357	0.0000	−0.2357	−0.1667
3	0.3220	0.1667	−0.2357	−0.2887	0.0863	0.1667
4	0.3220	−0.1667	−0.2357	0.2887	0.0863	−0.1667
5	0.2357	−0.3333	0.2357	0.0000	−0.2357	0.1667
6	0.0863	−0.1667	0.2357	−0.2887	0.3220	−0.1667

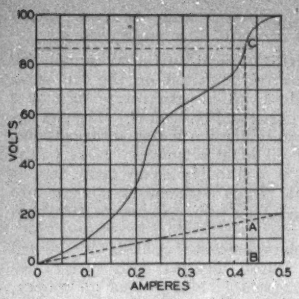

Fig. 2. Volt-ampere curve illustrating general application of method

From the curve the following voltages are found:

$M_1 = 12.8 \qquad M_3 = 33.3 \qquad M_5 = 43.2$
$M_2 = 24.3 \qquad M_4 = 39.6 \qquad M_6 = 44.2$

The amplitude of the first harmonic voltage across the nonlinear resistance is calculated from equation 8:

$$A_1 = 12.8K_{11} + 24.3K_{12} + 33.3K_{13} + 39.6K_{14} + 43.2K_{15} + 44.2K_{16}$$

Taking the values of the coefficients from table I and performing the operations indicated,

$$A_1 = 45.71$$

From equation 10

$$I_1 = \frac{50 - 45.71}{20} = 0.2195$$

In the same manner

$$A_3 = 12.8K_{31} + 24.3K_{32} + 33.3K_{33} + 39.6K_{34} + 43.2K_{35} + 44.2K_{36} = 1.42$$

$$I_3 = -\frac{1.42}{20} = -0.0710$$

Higher harmonics are found to be negligible. The current then may be expressed as follows:

$$i = 0.2195 \sin \omega t - 0.0710 \sin 3\omega t$$

The corresponding solution obtained by means of the harmonic analyzer gives the following series:

$$i = 0.2184 \sin \omega t - 0.0726 \sin 3\omega t$$

General Application of Method

The method outlined can be applied easily to more general circuits. While the restriction on the type of nonlinear resistances used in the circuit still must hold, there may be any number of linear and nonlinear resistances, connected in any manner, between the 2 input terminals. Since any resistance in the circuit will pass the same current irrespective of the polarity of a given voltage across it, the network as a whole will behave in a similar manner.

Let the volt-ampere curve OC in figure 2 represent the relation between the terminal voltage and input current of a complex network as found by experimental means. The curve supplies sufficient information for computing the current harmonics resulting from a sinusoidal impressed voltage, 100 $\sin \omega t$. The problem here consists of finding a linear resistance and a nonlinear resistance that, when connected in series, will be equivalent to the complex network. In other words, each of the 2 circuits will have the same volt-ampere curve. If the equivalent circuit is used for computing the current harmonics, the problem is identical to that described in the preceding section, and the same procedure may be followed.

A great many equivalent circuits are possible. Let the line OA in figure 2 be drawn at any convenient angle Φ. This line may be considered the volt-ampere curve of an imaginary linear resistance R, which is equal to the tangent of Φ. For a current OB, the vertical distance AC from the straight line to the curve represents the voltage drop across the nonlinear resistance. Thus if BC is some definite value of voltage, $E \sin 5\theta_1$ for example, then AC is the value of M_5. Other values of M_n may be found in a similar manner and the solution carried out as before.

Curve OC in figure 2 is an arbitrary one designed to introduce some of the higher harmonics in order to check the accuracy of the method. The expression for the current is found to be

$$i = 0.491 \sin \omega t + 0.014 \sin 3\omega t + 0.018 \sin 5\omega t + 0.015 \sin 7\omega t + 0.027 \sin 9\omega t$$

The corresponding solution obtained by means of the harmonic analyzer gives

$$i = 0.488 \sin \omega t + 0.0168 \sin 3\omega t + 0.0132 \sin 5\omega t + 0.0118 \sin 7\omega t + 0.0288 \sin 9\omega t$$

Accuracy of Method

While the method shown has the errors inherent in any graphical solution and also those resulting from the use of a limited number of points, the results indicate a reasonable accuracy with little labor. If greater accuracy be desired, θ_1 may be chosen smaller than 15 degrees, say 9 or 7.5 degrees, thereby including more points. In this event, however, the table of coefficients would have to be recomputed.

The amount of work involved in plotting a current wave against time and analyzing it is considerable, and if the values are obtained from the volt-ampere curve similar errors are involved. Experimentally, the curve may be obtained with an oscillograph and then analyzed. This method may be more accurate, but time and labor are large factors.

It should be noted that the application of the coefficients shown in table I is perfectly general. They refer to no particular curves or circuits. All nonlinear resistances, however, must have volt-ampere curves that are symmetrical in the first and third quadrants.

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The A-C Electrolytic Capacitor

The electrolytic capacitor for alternating current is coming into increased use, having recently been introduced for the starting of small single phase motors. Little is known of the film upon which its operation depends, but the general construction and characteristics of the capacitor are reviewed in this paper. The need for the development of testing procedure that will lead to an improved product is pointed out.

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THE general principle of the electrolytic capacitor is not new. It was investigated in the laboratory nearly a century ago, but its practical development awaited a commercial demand which first presented itself in the a-c radio receiver and later in the single phase motor.

The principle of the electrolytic capacitor lies in the insulating film which may be formed by chemical or electrochemical means on the surface of various metals of which aluminum is the most commonly used. This film with a thickness of the order of the wave length of light, has both high insulating value and high dielectric constant, so from these qualities it approaches an ideal dielectric. It does, however, have certain limitations. In spite of its high insulating value it permits an appreciable leakage current to flow as compared with other high grade dielectrics. Moreover, the film must be operated in the presence of a suitable electrolyte. Attempts to place the film in direct contact with another metallic conductor, or to place 2 filmed surfaces together, result in prompt puncture of the film when voltage is applied. Hence in practice it is necessary to use some spacing material between the filmed surface and the other electrode, or—in a-c capacitors—between the 2 filmed surfaces. The spacers commonly employed commercially in dry capacitors are gauze and paper, both specially selected for physical properties and chemical purity.

A paper recommended for publication by the A.I.E.E. committee on electrochemistry and electrometallurgy, and scheduled for discussion at the A.I.E.E. Great Lakes District meeting, West Lafayette, Ind., October 24–25, 1935. Manuscript submitted July 29, 1935; released for publication August 29, 1935.

Formation of Film

The film is usually formed on the aluminum foil by impressing positive potential on the foil while passing it through a suitable electrolyte such as a water solution of borax and boric acid. The electrolyte is in a metal container which acts as the cathode. About the film itself little is known. Next to the aluminum surface it is probably a very dense deposit of aluminum oxide which degenerates upward into a spongy amorphous structure, perhaps an hydroxide of the metal.

The a-c electrolytic capacitor consists of 2 filmed aluminum strips placed together with spacers between, the entire assembly being rolled up concentrically. Suitable electrolyte is introduced either during or after the rolling. The film possesses the unique property of permitting charge, negative electrons, to flow only in the direction from metal to electrolyte. Hence by placing 2 filmed electrodes in series conduction current cannot flow through the 2 in either direction, because the permeable direction from metal to electrolyte for one film becomes the impermeable direction from electrolyte to metal for the other film. Thus a true a-c capacitor is formed since there is no flow of conduction current through it (neglecting a small leakage current).

At any given instant the charging current of the capacitor consists of the capacitance current of one filmed electrode only. The other filmed electrode acts merely as a conductor and could momentarily be replaced by an unfilmed electrode without in any way affecting the instantaneous performance of the capacitor as a whole. With the reversal of direction of current flow on the next half cycle, these functions of the 2 electrodes are reversed or interchanged.

Voltage Relations in A-C Electrolytic Capacitors

Since negative electrons flow freely through the film in the direction metal-electrolyte but not in the direction electrolyte-metal a very interesting condition of potential develops.[1] Starting with a completely discharged capacitor when all parts are at the same potential, an alternating voltage is applied to the electrodes. At the instant of application negative electrons flow into the negative electrode. The film being permeable to negative charges in the metal-electrolyte direction these negative charges pass freely through it into the electrolyte through which they are conducted ionically to the surface of the other electrode. There they are stopped by the film which is impermeable in the electrolyte-metal direction. This group of negative charges thus comprises the total charge Q of the capacitor. They constitute a bound charge at the surface of the positive film so long as the capacitor voltage is unchanged.

As the alterating voltage wave falls to zero, the charge is no longer bound to the surface of the film since both electrodes are now at the same potential. The charge in the electrolyte, being free, tends to dissipate itself in the external circuit. It is restrained from doing so, however, by the impermeability of

1. For numbered reference see end of paper.

both films in the electrolyte-metal direction. Thus, the electrolyte permanently retains the entire charge acquired during the first half cycle of voltage. (This entire discussion neglects the leakage current of the film which will eventually discharge the electrolyte.)

Since, as has been shown, the electrolyte retains its full charge at the zero point of the voltage wave it is obvious that an equal and opposite charge must appear on one or both electrodes. However, the potential difference between the 2 electrodes being zero, this charge must be equally distributed between them. The important point is that its total magnitude is the same as when the capacitor was fully charged.

As the impressed voltage on the second electrode now reaches its maximum negative value no additional electrons flow from the negative electrode into the electrolyte, because the latter already possesses a complete charge for the particular maximum value of voltage. At the same time all the negative charge in the electrolyte has accumulated at the surface of the opposite electrode, which has now acquired a full positive charge.

Thus it is seen that on alternating current the charge of the capacitor is pumped by the generator alternately from one electrode to the other and simultaneously the charge in the electrolyte which equals the charge Q of the capacitor is flowing back and

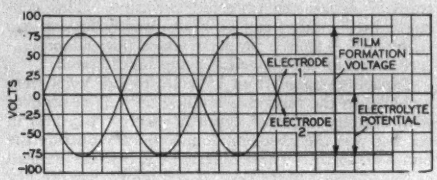


Fig. 1. Ideal voltage-time relationships in a-c electrolytic capacitor with 110-volt 60-cycle sine wave

forth through the electrolyte from one electrode to the other. The curves shown in figure 1 illustrate graphically this action. It may be observed that the electrolyte potential slides down along the first voltage wave to the latter's maximum negative value where it remains, and that neither electrode ever becomes negative as regards the electrolyte. This is a theoretical discussion only, and is not based upon actual voltage measurements which will vary somewhat from the curves. A grasp of the principle involved, however, is necessary to a clear conception of the various phenomena encountered in electrolytic capacitors.

Power Losses in Electrolytic Capacitors

Since as has been shown the entire charging current of the capacitor flows from plate to plate through the electrolyte at each reversal of potential, it would be expected that this flow would result in a power loss I^2R where R is the ohmic resistance of the electrolyte.

The current density in the electrodes or foil varies with its distance from the terminal, being the full charging current of the capacitor at the terminals and zero at the opposite end. By integrating the expression

$$P_E = 2\int_0^l \frac{4\pi^2 f^2 C_0^2 V^2 W R_0 (10^{-18}) X^2 dx}{t}$$

we can determine the power loss due to conduction in the foil, where

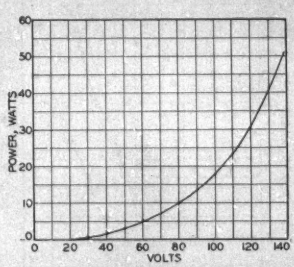
P_E = total losses in watts in both electrodes
F = frequency of voltage in cycles per second
C_0 = capacitance in microfarads per square inch of one electrode
V = root mean square value of impressed potential in volts
W = width of electrode in inches
R_0 = resistivity of electrode material in microhms per inch cube
l = length of a single electrode in inches
t = thickness of electrode in inches

For foil electrodes 0.002 inch thick, 3 inches wide, 153.3 inches long and possessing a capacitance of $^1/_4$ microfarad per square inch, these losses prove to be about 0.4 watt when 110 volt, 60 cycle potential is impressed across the capacitor terminals.

By a simple computation based upon an electrolyte resistivity of 1,000 ohms per centimeter cube, it is found when the foregoing potential is impressed that the power loss in the electrolyte of this capacitor is approximately 0.1 watt. This is based upon an electrolyte thickness of 0.004 inch, as would exist when 2 0.002-inch paper spacers are employed.

The sum of the total electrode and electrolyte losses is thus 0.5 watt. Assuming a film leakage at

Fig. 2. Variation of power loss with 60 cycle voltage in a 110-microfarad 110-volt paper-spacer capacitor at 25 degrees centigrade



110 volts of 9 milliamperes, which is a fairly high average value, one additional watt loss is allocated. Thus all the accountable losses aggregate less than 2 watts.

Other Losses

Actual tests show that the losses so computed comprise less than 10 per cent of the entire losses in the capacitor. The nature of the additional losses is not definitely known though their existence has long been recognized. The authors, however, discovered that these losses increased with the voltage applied to the capacitor more rapidly than a square law would predict. Also, there seemed to be a definite rule governing this increase. It was first ob-

served that doubling the voltage increased the losses in the capacitor about 5 times. These figures are all based on voltages not exceeding the formation voltage of the foil.

Comprehensive tests on foils formed at various voltages were conducted. Characteristic data are plotted on rectangular co-ordinate and logarithmic paper, respectively, in figures 2 and 3. The capacitance ratings given in the figures are actual values. In all these capacitors the effective area of each anode per microfarad is 9.2 square inches for 220 volt rating, 4.6 square inches for 110 volt, and 3.2 square inches for 75 volt.

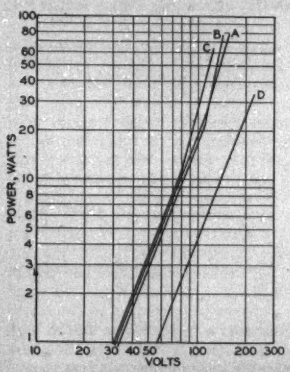
The foil in the 75 volt units is formed at 115 volts direct current, while the 110 volt and 220 volt units employ 165 and 330 volt formation, respectively. It will be noticed that the curves on logarithmic paper are straight lines, which indicate an equation with a definite exponent. Computation shows this exponent to be between 2.42 and 2.5 for various samples tested.

The expression for the losses in a capacitor at any voltage may then be written as

$$P = KE^{2.5}$$

where K is a constant for the particular capacitor depending upon its capacitance, power factor, and temperature.

Curves are shown for 3 different capacitors, A, B, and C in figure 3, all of which are parallel, indicating the same exponent. The horizontal displacement of



A. Paper spacer, standard electrolyte, 110 volts, and 110 microfarads

B. Gauze spacer, special electrolyte, 110 volts, and 119 microfarads

C. Paper spacer, standard electrolyte, 75 volts, and 124 microfarads

D. Gauze spacer, standard electrolyte, 220 volts, and 55 microfarads

Fig. 3. Variation of power loss with 60 cycle voltage in a-c electrolytic capacitors at room temperature

the several curves represents varying values of the constant K. These 3 curves are all at room temperature, about 25 degrees centigrade.

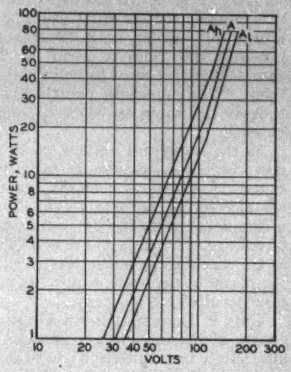
It was realized, however, that at different temperatures the exponent of the equation might change, or the curve might even depart from a straight line in which case the equation would be inapplicable. That K would change with temperature was a foregone conclusion. To cover these possibilities, the same capacitor that gave curve A, figure 3, was again tested at 60 degrees centigrade and at −18 degrees centigrade, and the respective curves are shown as A_h and A_l, in figure 4. To all intents and purposes these 3 curves are absolutely parallel. The exponent becomes 2.49 in every case within the limits of

Fig. 4. Variation of power loss with 60 cycle voltage in a 110-microfarad 110-volt paper-spacer capacitor at different temperatures

Curve A at 25 degrees centigrade

Curve A_l at −18 degrees centigrade

Curve A_h at 59 degrees centigrade



error of the graphical method employed. The constant K shows the expected variation. This constant, incidentally, can be read directly for various temperatures from a properly scaled power-temperature curve of the capacitor being investigated.

Capacitors rated from 75 volts to 220 volts were included in the foregoing studies, as well as samples with entirely different types of electrolytes, and in no case was the exponent found to vary outside the limits set forth. These different electrolytes were all of the so-called paste type as commonly used in dry electrolytics and employed an ammonium borate base but the solvents differed, resulting in a range of resistivity of from 200 to 1,000 ohms per centimeter cube.

As soon as the formation voltage of the foil is exceeded the curve takes a steeper slope upward showing that the losses increase more rapidly than the above exponent indicates. Whether this portion of the curve continues as a straight line is not known. Capacitors are not customarily operated above their formation voltage so it was not deemed of practical value to investigate this area too extensively. It is interesting to note, however, that in curves A and C, figure 3, the portions above the formation voltages are parallel. These 2 capacitors employ electrolyte of the same basic composition. Curve B assumes a definitely different slope above its formation voltage. This capacitor was built with an electrolyte in which another solvent was substituted for the ethylene glycol used in A and C. This solvent is not in the polyhydric alcohol group as is glycol. The resistivity of electrolyte B is far lower than that of A and C.

It is worthy of note that in this investigation of power loss at different voltages capacitors were built with radically different electrolytes; both

Table I—Temperature Distribution in Capacitors

Time, Hours	Temperature, Degrees Centigrade								
	With Gauze Spacer				With Paper Spacer				
	A	B	C	Can	A	B	C	Can	Room
0.0	34	33.5	34	.....	34	33	32	.....	35
0.5	42	40	41	.....	42	41.5	40	.....	34.8
1.0	46.5	45	43.5	.....	47.5	46	45	.....	36.8
1.5	48	47	47	.....	50	47	49	.....	35
2.0	53	52	50	39	53	52	49.5	41	35.4
18.0	60.5	59	57	42	62.5	59	57	45	31

Thermocouple *A* was in the inner turn of the capacitor winding, *B* in the middle of the winding, and *C* in the outer turn.

gauze and paper spacers were employed; electrodes formed over a wide range of voltages were used and all these units were tested at an extreme range of temperatures. Yet, in spite of varying all these factors the exponent of the equation remained fixed. It seems an unescapable conclusion, therefore, that this exponent is an inherent function of the electrolytic film itself and arises from the molecular structure and functioning of the latter.

Temperature Gradients in Electrolytic Capacitors

The life of an electrolytic capacitor is dependent definitely upon its internal operating temperature. This fact is recognized generally and is illustrated forcefully by the following experiment. A standard paper spacer electrolytic tested at room temperature with a certain number of line voltage applications per hour lasted for about 1,500 hours. Tested similarly in a 60 degree centigrade oven it lasted about 120 hours—approximately $^1/_{10}$ as long.

The importance of this internal temperature on the life of the capacitor has led to a study of the relative temperatures on gauze as compared with the more recent paper spacer capacitors. The argument has gained wide credence in the industry that since the paper type of a given capacitance occupies a smaller can than the gauze type it must, due to the smaller radiating area, run hotter inside. Obviously this is fallacious since radiating area is only one factor. Others equally important are thermal conductivity of the materials and the length of the conducting path. The latter is necessarily shorter in the smaller can. Conductivity of paper, however, may be less than of gauze.

Capacitors of both gauze and paper and of identical capacitances were built with thermocouples embedded in the inner and outer turns of the winding, and a third half way between them. Table I shows the actual temperatures as measured with the above arrangement. The capacitors were excited with rated alternating voltage for 3 seconds out of each 20 seconds until thermal equilibrium was attained. The greater part of the temperature rise occurs in the first 2 hours. The interesting point, however, is that the temperatures at the various points in the paper and gauze capacitors are practically identical; the slight discrepancy might easily be due to the difference between individual capacitors. The difference in can temperatures is to be expected since the same number of watts is being radiated from surfaces of different areas.

Capacitance-Temperature Studies

In certain applications capacitors are subjected to extreme temperature ranges. Used as a motor starter outdoors the capacitor should operate down to −40 degrees Fahrenheit, while in the summer on a similar installation the unit might be raised by the motor heat to as high as 125 or 150 degrees Fahrenheit. While the average electrolytic has behaved fairly well at the higher temperatures, its capacitance falls off very rapidly at low temperatures of about 0 degrees Fahrenheit and below.

The authors have attempted to develop a capacitor which would have a much flatter capacitance-temperature curve. The curve of figure 5 shows the results. Over a range of 125 degrees centigrade the reduction in capacity down to minus 50 degrees Fahrenheit was less than 25 per cent. This is only a fraction of the usual reduction in capacitance heretofore found in this type of capacitor. It is rather surprising to note that the points in figure 5 practically fall on a straight line, the maximum deviation being less than 4 per cent. The curves of similar temperature range previously published have approached hyperbolic shape. It is possible of course that these capacitors will exhibit a similar curve if the temperature is sufficiently reduced but the range explored more than covers the practical working range.

Based on the straight line function of figure 5, the change in capacitance per degree centigrade from room temperature is 0.23 per cent or roughly 0.2 per cent. Then the following capacitance formula may be written:

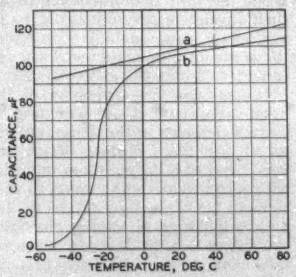


Fig. 5. Variation of capacitance with temperature

a. Improved electrolytic capacitor

b. Typical electrolytic capacitor

$$C_t = C_T\,[1 + 0.0023(t - T)]$$

where

T = temperature at which the capacitance is measured
t = temperature at which the capacitance is desired
C_T and C_t are the capacitances at these respective temperatures

These tests were conducted at 2 widely separated times by different technicians, and 6 individual

capacitors were tested. As a final check the capacitors were placed overnight in a commercial cold storage room at −18 degrees centigrade. Results of all these tests coincided very closely.

Life Studies of Electrolytics

The average user probably lacks a complete realization of the vast variations in life of electrolytics resulting from almost uncontrollably small changes in materials or technique of design and manufacture.

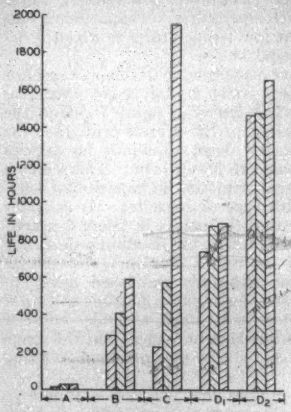


Fig. 6. Comparison of accelerated life tests of several makes of commercial electrolytic capacitors for motor starting service

All capacitors have paper spacers and are rated 110 volts and 100 microfarads

Even the best manufacturers in the industry find their ingenuity severely taxed to design capacitors so that they may be built with uniform life and then to control the manufacturing processes closely enough to secure this essential end.

It has been the experience of the authors based upon rather careful and searching investigation that correct elements in the design are vital to a uniformity of long life. If these design factors are lacking it is impossible to maintain materials and processes within sufficiently close limits to prevent wide variations in life of the final product. Obviously there is little advantage in having one third of a group of capacitors last 10 years in service if another third fails in one year. It is much better that they all run about the same length of time even though it may be less than this maximum.

For the purpose of illustrating these points a graphic presentation of life studies of various makes of commercial electrolytic capacitors is made in figure 6. Three capacitors of each of various leading makes were tested. All these capacitors employ practically identical materials in their fabrication. It may be argued that 3 capacitors are not enough to give an accurate picture; however, the authors believe this is not true in this case where it is the uniformity rather than the average length of life which is of primary importance. The life of make *A* was of such fleeting duration as to require no comments. Make *B* shows no particular merit either as to uniformity or length of life. Make *C* is highly interesting in that it contained one unit which displayed a materially longer life than any other of the 15 capacitors charted; yet another unit of this make failed earlier than any unit shown excepting make *A*.

This emphasizes the point of the preceding discussion as to the necessity of designing uniformity into the capacitors. Based upon his design this manufacturer finds it impossible to control his manufacture adequately to secure uniformity. If he could duplicate uniformly the best of these 3 capacitors the product would be outstanding.

Make *D* consists of 2 groups which differ slightly from each other in technique of manufacture. Although one group has a life about twice the other they are both good from this standpoint. They are, however, noteworthy from the angle of uniformity, since all units in each group failed within less than 10 per cent of the same time.

Standard Testing Procedure Needed

In spite of the value to the industry of some of the laws developed in this paper, the authors fully realize the insignificance of this contribution compared with the vast amount of fundamental investigation which remains to be done before engineers can profess any real knowledge of the subject of electrolytic capacitors.

While a product satisfactory for certain applications is available there are many potential uses which the manufacturer cannot satisfy today. Continuous a-c duty is one of the most common. It is hoped that before long the work being done by various manufacturers may realize this particular result.

Even on the question of accelerated life testing of the finished capacitor for a single type of application there is wide disagreement, which imposes hardships on both manufacturer and customer. The development of a satisfactory standard method of test would be a boon. It is the clear duty of the manufacturers to aim at such an objective.

Several large users of a-c electrolytic capacitors have voluntarily expressed their readiness to adopt any accelerated life test which might be agreed upon by the capacitor manufacturers. Unfortunately, the authors do not feel prepared at this time to suggest any such standard. While they have employed at various times and for various purposes several testing procedures, no one of these seems to possess every desirable feature of all of them.

One test commonly employed is the imposition of about 115 volts at 60 cycles for 3 seconds out of each 20 seconds. A variation of this test for use on motor starter capacitors is the introduction in series with the capacitor of an impedance duplicating that of the motor on which the capacitors are to be used. Other tests consist of one or 2 excitations per minute of one second duration each, either with or without impedance in series. Finally, the capacitor may be tested by actually using it to start a motor loaded or unloaded. In this case from one to 10 starts a minute may be employed. The disadvantage of the slower tests is that they require too long an elapsed

period to test the units to failure, and thereby obtain the desired answer.

It is the hope of the authors in presenting this paper that by giving to the profession the results of their research a better understanding of the underlying problems may be brought about. It is upon a fuller grasp of these basic facts that the fullest development of electrolytic capacitors for the entire range of present and future industrial applications must depend.

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A Static Thermionic Tube Frequency Changer

By
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ASSOCIATE A.I.E.E.

R. C. GRIFFITH
Membership Application Pending

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A 300 kva, synchronous type, 60–25 $^5/_7$ cycle static frequency changer, which was designed to be changed to a rectifier after the 25 cycle motor load has been replaced by 60 cycle motors, is described in this paper. The problems involved in the design of the control circuits are discussed in some detail, and the performance is described.

THE versatility of thermionic tubes in various types of service is illustrated by the static frequency changer described in this paper. An industrial plant in New Jersey (New York Shipbuilding Corp., Camden) generates its own power for a load consisting principally of 60 cycle and d-c motors and it was desired to replace by more efficient equipment an engine driven generator supplying power to a few hundred horsepower of 25 cycle motors. It was anticipated that during the next few years these motors would be replaced gradually by 60 cycle motors and there would be no further need for the new 25 cycle generating equipment. During certain periods of the week the demand for d-c power is considerably less than the capacity of the smallest generating unit in the plant so that an efficient source of a few hundred kilowatts of d-c power would return an appreciable saving. A static frequency changer was finally chosen which uses 12 grid-controlled mercury vapor tubes and delivers 300 kva at 220 volts, 2 phase, 25 $^5/_7$ cycles, from a 2,300-volt 3-phase 60-cycle source. When 25 cycle power is no longer required, the 60 cycle transformer windings will be reconnected for a lower secondary voltage, a portion of the control equipment will be disconnected, and the apparatus will be available as a rectifier with an output of 300 kw at 250 volts.

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POWER CIRCUIT

The frequency changer comprises 2 single phase conversion circuits whose outputs are displaced 90 electrical degrees. A network was chosen which affords maximum apparatus economy consistent with subsequent conversion to a rectifier circuit. Figure 1 shows the elements of one 3 phase to single phase power circuit. Assuming a resistance load, if groups A and B are fired alternately the output voltage will alternate and will have a frequency dependent upon the number of tubes fired consecutively

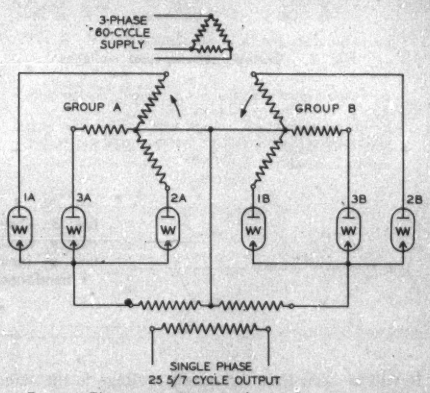


Fig. 1. Elementary diagram of a 3 phase to single phase frequency changer

in each group. In the present case 3 tubes are fired consecutively for each half cycle, resulting in the output voltage and current shown by figure 2*a*.

Next consider the case in which the load is purely reactive and, for s mplicity, assume there are sufficient filters in the output circuit to permit only the fundamental current to flow, as shown by figure 2*b*. Tube 2*A* fires when its phase voltage is a maximum, conducts for 60 degrees (referred to the input frequency) and transfers the current to tube 3*A*. With a resistance load, tube 3*A* would conduct for 150 degrees after which tube 3*B* would fire. In this case, however, the current is a maximum at this time, and group *B* cannot conduct until the current in group *A* has become zero. The potential of phase 3*A* opposes the flow of current after the 150 degree point and gradually reduces the current, but at the end of another 150 degrees the current is still not zero, so the current is transferred to tube 1*A* which reduces the current to zero in 60 degrees.

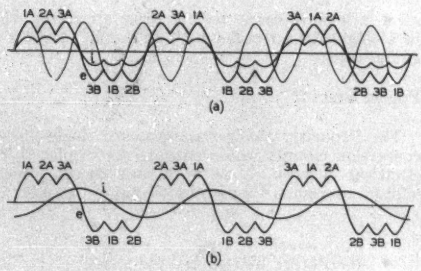


Fig. 2. Output currents and voltages

a—Output current and voltage of a frequency changer with a resistance load

b—Output current and voltage with reactive load and sufficient filter to prevent all but the fundamental current from flowing

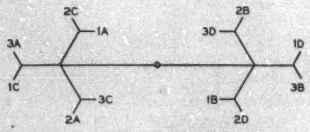


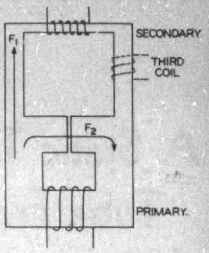
Fig. 3. Secondary windings of input transformer

It will be seen that the output voltage is the same whether tube 1*A* or tube 1*B* is conducting, so as soon as tube 1*A* ceases to conduct tube 1*B* is fired.

Current is transferred from tube 3*A* to tube 1*A*, in the above discussion, by phase commutation. Current must be transferred from 3*A* to 1*A* early enough for 3*A* to deionize before the anode again becomes positive. This time will increase with the load.

For any intermediate power factor and with current waves having higher harmonics the current transfer between groups *A* and *B* will occur in a similar manner: (*a*) the load current must be zero at the time of transfer; (*b*) the current always transfers to an anode 180 degrees out of phase with the last conducting anode; (*c*) when the power factor is very low a transfer of current by the method used in the phase commutated inverter is necessary.

Fig. 4. An impulse transformer



The actual windings of the input transformer secondary are shown by figure 3, where *C* and *D* refer to the second converter circuit.

Control Circuit

Four parts are necessary for the control circuit: (1) grid excitation for the tubes when supplying power; (2) grid excitation when regenerating; (3) a means for firing only 3 consecutive tubes in each group; (4) a means to prevent firing any tube in one group until the current has become zero in the other group. Of the several methods which have been proposed, a circuit using "impulse transformers" has been selected.

In this paper the term "impulse transformer" refers to a transformer which, when excited by a sinusoidal primary voltage, has a sharply peaked, nonsinusoidal secondary voltage. Figure 4 is a sketch of a simple impulse transformer with one secondary winding. The primary flux passes through 2 parallel paths, F_1 and F_2, when the density is low, and as the reluctance of F_1 is less than the reluctance of F_2 a relatively large secondary voltage is induced. After F_1 has saturated, however, most of the flux

Table I—Harmonic Composition of Output Voltage and Current

Quantity	Order of Harmonic 1	3	5	7	9
No load voltage	1.000	0.308	0.156	0.112	0.041
Voltage, 15% load 0.60 p. f.	1.000	0.275	0.166	0.108	0.060
Voltage, 100% load 0.76 p. f.	1.000	0.193	0.125	0.108	
Output current, 15% load 0.60 p. f.	1.000	1.223	0.464	0.169	0.096
Output current, 100% load 0.76 p. f.	1.000	0.521	0.266	0.142	

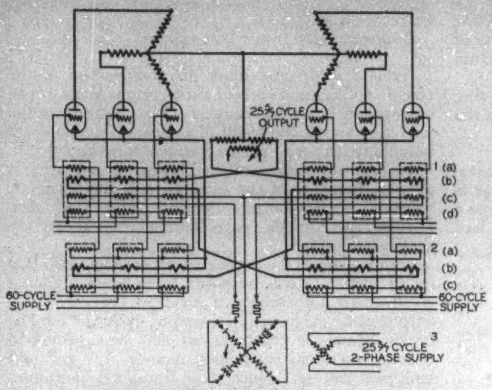


Fig. 5. Schematic diagram of power and control circuits

1*a*—Power control impulse transformer secondary
1*b*—Hold-off coil
1*c*—Frequency control coil
1*d*—Primary coil
2*a*—Regenerative control impulse transformer secondary
2*b*—Phase advancing coil
2*c*—Primary coil
3—Output frequency control circuit

passes through F_2 and the rate of change of flux through F_1 is small. If a constant direct current is passed through another coil wound on F_1, the time at which the peak of voltage occurs will be different because the core density will be zero at a different time; by varying the magnitude and direction of this direct current the time at which the peak occurs can be changed ±90 degrees.

If the number of ampere turns in the third coil is slightly greater than the number of primary ampere turns, no secondary voltage will be induced because the core will be saturated continually. Now assume that the current in this third coil varies in some regular manner. The flux through F_1 will be the sum of the fluxes induced by the primary and the third coil, and a peak of secondary voltage will occur when the resultant flux does not saturate F_1.

As it is necessary to supply excitation to each tube at 2 different times, 2 impulse transformers are necessary for each tube. The one supplying excitation for power control has a primary coil, a secondary coil, a frequency control coil, and a hold-off coil, the latter 2 surrounding F_1. The frequency control coil receives pulses of direct current at the required output frequency; the hold-off coil is in series with the output transformer primary winding associated with the group of tubes opposite to the group in which the tube under consideration is placed. The impulse transformer supplying excitation for regeneration has a primary coil, a secondary coil, and a phase advancing coil, the latter surrounding F_1. The phase advancing coil is in series with the half of the output transformer primary associated with the tube under consideration. Figure 5 is a schematic diagram of

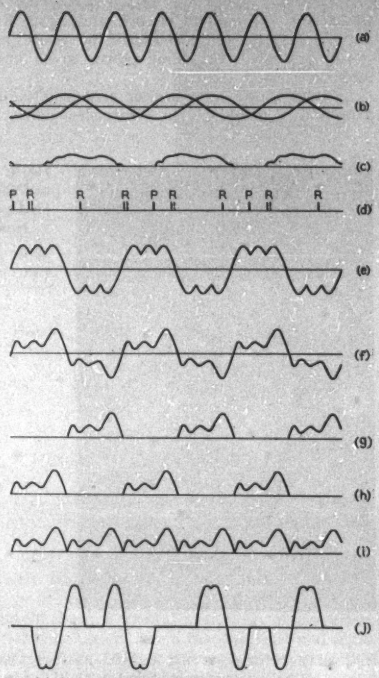


Fig. 6. Voltages and currents when supplying power to an induction motor

a—Phase voltage associated with tube 1*A*
b—Output frequency control voltage
c—Output frequency control current
d—Grid excitation. *P* is the power excitation and *R* is the regenerative excitation. The dotted lines show the position of regenerative excitation when unaffected by phase advancing currents
e—Output voltage
f—Output current to an induction motor load
g—Current in hold-off coil
h—Current in phase advancing coils
i—Current in common neutrals of groups *A* and *B*
j—Anode-cathode voltage of tube 1*A*

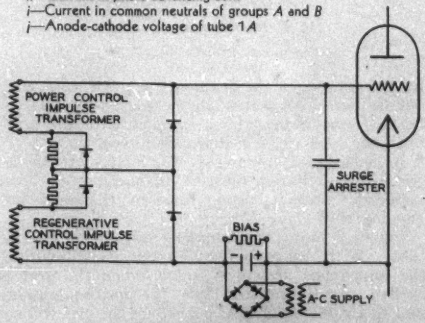


Fig. 7. Grid circuit used in the frequency changer

the power and control circuit, and figure 6 shows various voltages and currents in the several parts of the circuit when supplying power to an induction motor.

A small synchronous motor generator set having a frequency ratio of 7 to 3 furnishes power to the frequency control circuit which, in turn, supplies alternate pulses of direct current to the frequency control coils of groups A and B. By proper timing, just 3 consecutive tubes are fired in each group. With a unity power factor load the flux induced by the current in the hold-off coils adds to that induced by the current in the frequency control coils without further effect, but when the load is reactive the hold-off current maintains F_1 in a saturated state until the load current approaches zero.

Fig. 8. Current and voltage in induction motor load

Upper oscillogram—100 per cent load, 0.76 power factor

Lower oscillogram—15 per cent load, 0.60 power factor

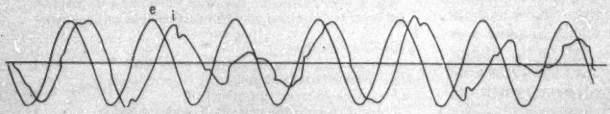


Fig. 9. Input current and voltage

As mentioned previously, the phase of the regenerative excitation must be advanced as the load increases. This is accomplished by the phase advancing coils.

Figure 7 shows the complete grid circuit for one tube. With this copper oxide rectifier combination, the impedance presented is low when the grid is excited, and the resistor limits the positive ion current to a value which does not reduce the bias voltage appreciably.

Output Voltage and Current, and Input Current

Table I shows the harmonic composition of the output voltage and current with various loads. The decrease in harmonic content of the current as the load increases is the result of a constant transformer inductance in series with a variable load impedance. Since the regulation of the harmonic voltages is greater than that of the fundamental, the harmonic voltages in the output decrease with load also. Oscillograms for the cases enumerated above are shown by figure 8.

Figure 9 shows the input current with an induction motor load. It will be noted from figure 2 that a given anode fires during a specified portion of the output cycle only once in 3 output cycles or 7 input cycles, hence the input current may be expected to contain fractional harmonics, namely, 1/7 and odd multiples thereof. Since these fractional harmonics increase the generator losses, their magnitude must be limited when the frequency changer output is a considerable portion of the generator rating. Reduction of harmonic input currents may be effected by the use of sufficient anodes and different anode potentials to secure an output voltage wave with small harmonic content. Resonant filters in the input transformer primary circuit may be used to reduce the harmonics in the generator windings.

Regulation

Regulation is due principally to 2 factors: (1) commutation from one anode to another, with a loss in voltage proportional to the load; and (2) reactance of the output transformer. In addition, there is some regulation due to resistance in the circuit and reactance of the control windings on the grid transformers. The measured regulation in terms of root mean square voltage was 14 per cent from no load to full load. Since the harmonic voltages are more prominent at no load, the regulation of the fundamental component of voltage is less, the difference being 2 per cent.

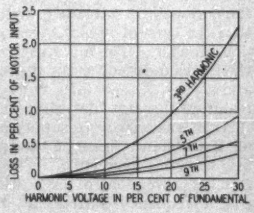


Fig. 10. Increase in losses of typical 2 phase induction motor due to harmonics in supply voltage

Efficiency

A frequency changer of this type has the following circuit losses: (1) input transformer loss; (2) output transformer loss; (3) arc loss in tubes; and (4)

cathode heater and control circuit losses. The utility factors of the input and output transformer are 0.62 and 0.83, respectively. The total transformer loss is 8.6 per cent at full load and 0.7 power factor. The arc loss is 2.5 per cent. The loss in cathode heaters and a suitable control circuit totals 2.5 per cent. The apparent full load efficiency and the no load loss compare favorably with the values for a rotating set.

It should be noted that the output is not entirely useful. Figure 10 shows the additional losses in a typical 2 phase induction motor resulting from harmonics in the voltage wave. From table I, it can be shown that the harmonics in the no load voltage wave increase the losses in the motor by 2.8 per cent, while at full load on the frequency changer the losses are increased by 1.2 per cent. These losses should properly be charged to the frequency changer, decreasing its full load efficiency from 86.4 to 85.2 per cent.

In general, the harmonic voltages in the output may be reduced to any desired value if a sufficient number of anodes and transformer windings is available, and resonant shunt filters may be used in the output circuit to eliminate specific harmonics. In particular, by doubling the number of tubes, the third harmonic may be eliminated by making the potential of the center peak in figure 2, 1.88 times as great as the potential of the adjacent peaks.

Figure 11 shows the assembly of tubes and control transformers. Figure 12 shows a control panel containing control switches and means for insuring the proper heating time for the cathodes before voltage is applied to the anodes. During nonoperating periods, the cathodes are heated at reduced voltage

Fig. 11. Assembly of tubes and control transformers

to prevent mercury condensation on the anode or cathode. The control power switch is closed to apply full voltage to the cathodes, and after the proper heating period an indication is given for manual closing of the main power switch which energizes the input power transformer. A manually operated control switch is used to change transformer

Fig. 12. A control panel

taps under load, through a pair of contactors, to deliver the desired output voltage.

Figure 13 shows a typical load chart of operation. During the changes between the day shift and night shift, the voltage taps are changed to compensate for the regulation of the set. Normal operation is at or slightly under rated load. Starting peaks or operating peaks during the day have been observed up to nearly 200 per cent load.

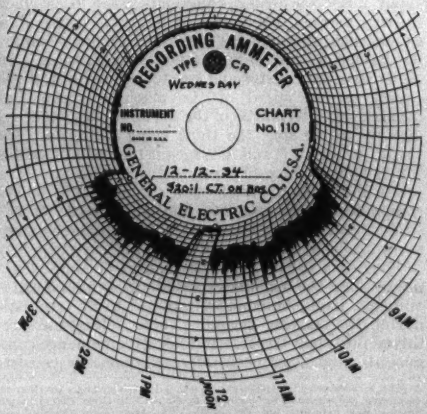


Fig. 13. Typical load chart during operation of the converter. Rated load = 2.1

Split Phase Starting of 3 Phase Motors

When 3 phase induction motors are to be operated from single phase lines, split phase starting is frequently used. The optimum values of external resistance and reactance for split phase starting may be determined by the method of symmetrical components. In the present paper, equations for determining these values for each of the 2 commonly used split phase starting schemes are derived. The result of calculations based upon this method are shown to compare favorably with experimental data.

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THE determination of the "best" values of external resistance and reactance to produce starting torque when standard 3 phase induction motors are operated from single phase sources of supply is a problem to which the method of symmetrical components is admirably adaptable. Two "split phase" schemes, commonly used to produce starting torque, are shown in figure 1, where R is an external resistor and X an external inductive reactor having as low a power factor as possible. In either case the resistor and reactor are cut out of the circuit as the speed of the machine approaches normal, and 2 terminals of the machine are connected directly to the line, the third being left open. By "best" values of R and X is meant that pair of values which will produce maximum starting torque for a given line voltage; or, if such values should be accompanied by an excessive line current, the "best" values would then be those which produce maximum torque at an arbitrarily fixed line current.

The use of the method of symmetrical components implies that the machine is considered to have 3 phase voltages, badly unbalanced, applied to its terminals during the starting period. These voltages are resolved into their positive and negative sequence components, and since each set of components consists of balanced 3 phase voltages, the standard expressions for torque and current under balanced conditions may be employed. The resultant torque and current may then be deduced. Finally, the conditions for maximum torque for each method are determined. The validity of the expressions for R and X so obtained has been amply verified by experiment, some of the experimental checks being shown in this paper.

The conclusions reached as the result of the study discussed in this paper may be summarized as follows. A comparison of the 2 methods shown in figure 1 for producing starting torque on single phase circuits reveals the fact that the torques obtainable by method 2 are larger than those of method 1, but that these greater torques are obtained at the expense of larger currents. The maximum torque obtainable by method 1 is in the neighborhood of 18 per cent of the 3 phase starting torque for the same voltage between lines, while the corresponding current in the line is in the neighborhood of 87 per cent of the 3 phase starting current. The torque obtainable by method 2 depends, as pointed out before, upon how much line current is permissible; but ranges, in general, from about 37 per cent of 3 phase starting torque at a line current of 200 per cent of 3 phase starting current to about 20 per cent at 110 per cent of 3 phase starting current. It is significant that the torque per ampere of line current is approximately the same for both methods. In choosing between the 2 methods for a particular case the deciding factor would be the upper limit on the starting current. If a line current of 110 per cent or more of 3 phase starting current at rated voltage is permissible, method 2 is preferable because of its higher starting torque. If the permissible starting current lies between about 75 per cent and 100 per cent of 3 phase starting current, method 1 is preferable, and can be used without a compensator. If the starting current must be kept below 75 per cent, a compensator must be used in conjunction with either method and there is little to choose between them, except that the "best" values of R and X are more directly obtained in method 1 than in method 2.

Theoretical Analysis

In deriving the expressions for R and X the following symbols are employed:

R = external resistance
X = external reactance, assumed to have zero power factor

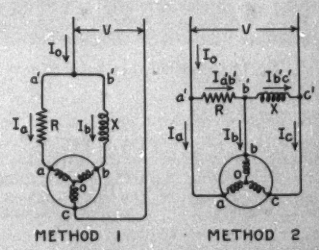

Fig. 1. Split phase connection

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z = impedance per phase of motor at standstill, motor assumed star connected
r = resistance per phase of motor at standstill
x = reactance per phase of motor at standstill
V = voltage of single phase source
I_b = single phase line current
a = 120 degree forward rotating operator ($a = -0.5 + j\,0.866$),
a^2 = 240 degree forward rotating operator ($a^2 = -0.5 - j\,0.866$),
T = torque in synchronous watts
Vector quantities are indicated by bold faced symbols, as $\boldsymbol{V}$, $\boldsymbol{I}$, and $\boldsymbol{z}$
Positive phase sequence quantities are indicated by $\check{\boldsymbol{V}}$, $\check{\boldsymbol{I}}$, and $\check{T}$
Negative phase sequence quantities are indicated by $\hat{\boldsymbol{V}}$, $\hat{\boldsymbol{I}}$, and $\hat{T}$

Method 1

The vector diagram for method 1 is shown in figure 2, in which the motor impressed voltages, $\boldsymbol{V}_{ab}$, $\boldsymbol{V}_{bc}$, and $\boldsymbol{V}_{ca}$, considered as voltages of a 3 phase system,

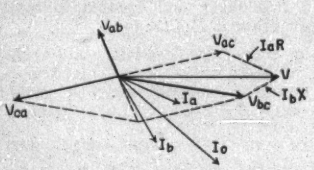

Fig. 2. Vector diagram for method 1

are shown in heavy lines. The expressions for these voltages, in terms of V, R, and X, are

$$\boldsymbol{V}_{bc} = \boldsymbol{V} - j\boldsymbol{I}_b X$$
$$\boldsymbol{V}_{ca} = -(\boldsymbol{V} - \boldsymbol{I}_a R) = \boldsymbol{I}_a R - \boldsymbol{V}$$
$$\boldsymbol{V}_{ab} = -(\boldsymbol{V}_{bc} + \boldsymbol{V}_{ca}) = -\boldsymbol{I}_a R + j\boldsymbol{I}_b X$$

The positive phase sequence component of $\boldsymbol{V}_{ab}$ is:

$$\check{\boldsymbol{V}}_{ab} = \frac{1}{3}\left[\boldsymbol{V}_{ab} + a\boldsymbol{V}_{bc} + a^2\boldsymbol{V}_{ca}\right]$$
$$= \frac{1}{3}\left[\boldsymbol{I}_a R(a^2 - 1) + j\boldsymbol{I}_b X(1 - a) + \boldsymbol{V}(a - a^2)\right] \quad (1)$$

Similarly, the negative phase sequence component is:

$$\hat{\boldsymbol{V}}_{ab} = \frac{1}{3}\left[\boldsymbol{I}_a R(a - 1) + j\boldsymbol{I}_b X(1 - a^2) + \boldsymbol{V}(a^2 - a)\right] \quad (2)$$

The zero phase sequence component is zero.

It is now convenient to make use of 2 important propositions in the theory of symmetrical components. The first relates the line-to-neutral voltage of each sequence to the corresponding line-to-line voltage. Defining the positive phase sequence to be the one in which b lags a, and $\boldsymbol{V}_{ao}$ to be the line-to-neutral voltage of phase a, these relations are:

$$\check{\boldsymbol{V}}_{ab} = \sqrt{3}\,\check{\boldsymbol{V}}_{ao}\angle 30^\circ = (1 - a^2)\,\check{\boldsymbol{V}}_{ao} \quad (3)$$

$$\hat{\boldsymbol{V}}_{ab} = \sqrt{3}\,\hat{\boldsymbol{V}}_{ao}\angle -30^\circ = (1 - a)\,\hat{\boldsymbol{V}}_{ao} \quad (4)$$

The second proposition states that when the 3 impedances of a star-connected load are balanced, the positive phase sequence voltage to neutral is simply equal to the product of the impedance per phase and the positive phase sequence current, and does not involve any cross products with the negative phase sequence current as it would if the impedances were unbalanced. Consequently:

$$\check{\boldsymbol{I}}_a = \check{\boldsymbol{V}}_{ao}/\boldsymbol{z} \quad (5)$$

$$\hat{\boldsymbol{I}}_a = \hat{\boldsymbol{V}}_{ao}/\boldsymbol{z} \quad (6)$$

Also

$$\boldsymbol{I}_a = \check{\boldsymbol{I}}_a + \hat{\boldsymbol{I}}_a \quad (7)$$

$$\boldsymbol{I}_b = \check{\boldsymbol{I}}_b + \hat{\boldsymbol{I}}_b = a^2\check{\boldsymbol{I}}_a + a\hat{\boldsymbol{I}}_a \quad (8)$$

Substituting equations 3 to 8 in equations 1 and 2

$$\check{\boldsymbol{V}}_{ao}\left[1 - a^2 + \frac{R(1 - a^2)}{3\boldsymbol{z}} - j\frac{a^2X(1 - a)}{3\boldsymbol{z}}\right] +$$
$$\hat{\boldsymbol{V}}_{ao}\left[\frac{R(1 - a^2)}{3\boldsymbol{z}} - j\frac{aX(1 - a)}{3\boldsymbol{z}}\right] = \frac{1}{3}V(a - a^2) \quad (9)$$

$$\hat{\boldsymbol{V}}_{ao}\left[\frac{R(1 - a)}{3\boldsymbol{z}} - j\frac{a^2X(1 - a^2)}{3\boldsymbol{z}}\right] +$$
$$\check{\boldsymbol{V}}_{ao}\left[1 - a + \frac{R(1 - a)}{3\boldsymbol{z}} - j\frac{aX(1 - a^2)}{3\boldsymbol{z}}\right] = \frac{1}{3}V(a^2 - a) \quad (10)$$

These 2 equations may now be solved simultaneously for $\check{\boldsymbol{V}}_{ao}$ and $\hat{\boldsymbol{V}}_{ao}$, yielding

$$\check{\boldsymbol{V}}_{ao} = \frac{V}{\sqrt{3}}\left[\frac{aX + jR - \sqrt{3}\,a^2\boldsymbol{z}}{3\boldsymbol{z} + 2R + j2X + jRX/\boldsymbol{z}}\right] \quad (11)$$

$$\hat{\boldsymbol{V}}_{ao} = \frac{V}{\sqrt{3}}\left[\frac{-a^2X - jR - \sqrt{3}\,a\boldsymbol{z}}{3\boldsymbol{z} + 2R + j2X + jRX/\boldsymbol{z}}\right] \quad (12)$$

The torque of a 3 phase induction motor under unbalanced 3 phase voltages is the difference between the torque corresponding to the positive phase sequence voltage and that corresponding to the negative phase sequence voltage.[1] Each component of torque, therefore, may be found by substituting equations 11 and 12 in the ordinary expression for the starting torque of an induction motor; *viz.*, $T = 3V_1^2r_2/z^2$, where r_2 is the rotor resistance (referred to the stator) and V_1 is the line-to-neutral voltage, and T is the torque in synchronous watts. The expression for the resultant torque under unbalanced voltages is

$$T = \check{T} - \hat{T} = 3\left[(\check{V}_{ao})^2 - (_{ao}\hat{V})^2\right]\frac{r_2}{z^2} \quad (13)$$

Since all quantities in the expression for torque are scalar quantities, it is necessary to find the scalar values of the positive phase sequence and negative phase sequence voltages. The scalar values of the numerators of equations 11 and 12 are shown in equations 14 and 15, respectively:

$$V[(0.866r - 1.5x - 0.5X)^2 + (1.5r + 0.866x + R + 0.866X)^2]^{1/2} \quad (14)$$

$$V[(0.866r + 1.5x + 0.5X)^2 + (-1.5r + 0.866x - R + 0.866X)^2]^{1/2} \quad (15)$$

The scalar value of the denominator in each case is:

$$\sqrt{3}\left[\left(3r + 2R + RX\frac{x}{z^2}\right)^2 + \left(3x + 2X + RX\frac{r}{z^2}\right)^2\right]^{1/2} \quad (16)$$

Substituting and simplifying equation 13 becomes:

$$T = \left(\frac{V^2r_2}{z^2}\right)\frac{2\sqrt{3}\,(Rx + Xr + RX)}{\left(3r + 2R + RX\frac{x}{z^2}\right)^2 + \left(3x + 2X + RX\frac{r}{z^2}\right)^2} \quad (17)$$

1. See reference 1 at end of paper.

Table I—Calculated and Experimental Values of R and X for Typical Machines

Machine Number	Type	Rating H.P.	Rating Volts	Constants r	Constants x	Constants z	Method	Calculated Data R	Calculated Data X	Experimental Data R	Experimental Data X
1	High reactance	7.5	110	0.137	0.297	0.327	1	0.46	0.152	0.50	0.15
2	Single squirrel cage	3	110	0.584	0.628	0.858	1	0.94	0.713	0.88	0.713
3	Double squirrel cage	7.5	110	0.193	0.286	0.345	1	0.428	0.245	0.50	0.28
4	Single squirrel cage	5	220	0.86	1.51	1.74	1	2.32	1.00	2.40	0.75
5	Wound rotor	15	110	0.074	0.164	0.183	1	0.40	0.064	0.40	0.00
1	(See above)						2(C = 1.5)	0.48	0.48	0.42	0.42
2	(See above)						2(C = 1.5)	1.31	1.31	1.28	1.28
4	(See above)						2(C = 1.5)	2.59	2.59	2.52	2.52
4							2(C = 1.15)	5.13	5.13	5.10	5.10

$$C = \frac{\text{Single phase starting current}}{\text{3-phase starting current}}$$

All constants in ohms

The value of z occurring in equation 17 is the scalar value. Since the first term of equation 17 expresses the torque under balanced conditions for a between-line voltage equal to V, the remainder of the equation is the ratio of the split phase starting torque to the starting torque under normal 3 phase operation.

The line current I_0 is readily found as follows:

$$I_o = I_a + I_b = (\bar{I}_a + \bar{I}_a) + (a^2\bar{I}_a + a\bar{I}_a)$$
$$= (1 + a^2)\bar{I}_a + (1 + a)\bar{I}_a = -a\bar{I}_a - a^2\bar{I}_a \qquad (18)$$

Substituting equations 5 and 6 into 18, the vector expression for $\bar{I}_0$ is

$$\bar{I}_o = V\left(\frac{R + 2z + jX}{3z^2 + 2Rz + 2jXz + jRX}\right) \qquad (19)$$

and the corresponding scalar expression is

$$I_o = \frac{V}{\sqrt{3}z}\left[\frac{3(R + 2r)^2 + 3(X + 2x)^2}{\left(3r + 2R + RX\frac{x}{z^2}\right)^2 + \left(3x + 2X + RX\frac{r}{z^2}\right)^2}\right]^{1/2} \qquad (20)$$

The value of z in equation 20 is the scalar value. Since the first term expresses the line current for a balanced 3 phase voltage of V volts the remainder is the ratio between the single phase line current and the 3-phase starting current.

It is of interest to examine the manner in which the torque (equation 17) of a given machine varies as the external resistance and reactance are varied. For any fixed value of X the torque is relatively small when R is zero, but rises as R is increased, passes through a maximum value, then drops off approaching zero as R becomes very large. Such a curve is shown in curve A of figure 3, the data having been obtained experimentally on a 5-horsepower squirrel-cage ball-bearing induction motor. A different value of X yields another curve similar in shape to that of curve A, but having either a higher or a lower peak value depending on whether this second value of X is closer to, or farther away from the "best" value. A similar characteristic obtains when X is varied and R is kept constant, a typical curve being shown in curve B of figure 3. If a 3 dimensional diagram is built plotting torque as ordinates against R and X as mutually perpendicular abscissas, a sheet will result having a hump at the intersection of the best value of R with the best value of X. Such a diagram is shown in figure 4, for the machine described above.

In order to predetermine the best values of R and X, the partial derivative of equation 17 with respect to R is first taken and equated to zero. There results a quadratic in R of the form

$$AR^2 + BR + C = 0 \qquad (21)$$

where

$$A = (x + X)(4z^2 + 4Xx + X^2)$$
$$B = 2rX(4z^2 + 4Xx + X^2)$$
$$C = 4Xr^2(3z^2 + 3Xx + X^2) - z^2(x + X)(9z^2 + 12Xx + 4X^2)$$

For any arbitrarily chosen value of X, the above equation yields the corresponding best value of R, i. e., that value corresponding to the peak of curve A in figure 3. The first choice of X, of course, would in general not be that which corresponds to the hump in figure 4, but this value could be found by assigning a few different values to X, solving for the corresponding value of R from equation 21 and then substituting the pairs of values of R and X so found into equation 17 until the optimum torque is found. A much shorter procedure, however, is to obtain a second equation similar to 21 by taking the partial derivative of 17 with respect to X and equating to zero. This is

$$DX^2 + EX + F = 0 \qquad (22)$$

where

$$D = (r + R)(4z^2 + 4Rr + R^2)$$
$$E = 2xR(4z^2 + 4Rr + R^2)$$
$$F = 4Rx^2(3z^2 + 3Rr + R^2) - z^2(r + R)(9z^2 + 12Rr + 4R^2)$$

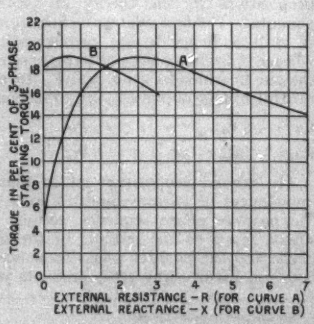

Fig. 3. Torque characteristics of method 1

Data pertains to machine 4, table I

Curve A: Reactance held constant at 1.0 ohm

Curve B: Resistance held constant at 2.0 ohms

R and X in ohms

Equations 21 and 22 are now used as follows. Any arbitrarily chosen value of X (preferably of the same order of magnitude as x) is substituted in equation 21 and the corresponding value of R found. This value of R is then used in equation 22 and a new value of X found, which is again substituted in equation 21. This process is continued until the values of R and X repeat themselves, which means that they are approaching the values corresponding to the hump of figure 4. Due to the symmetry of the equations and to the rapid convergence of R and X on their best values, a surprisingly small amount of labor is required in this process. Usually, only 4 or 5 of the above substitutions are necessary. For example, using the constants of machine 4, table I, and assuming $X = 1.5$ ohms as a first trial (suggested by the value $x = 1.51$), substitution into equation 21 yields a positive value of R of 2.27 ohms. Substituting this value of R, in turn, into equation 22 results in $X = 1.03$ ohms. Results of succeeding substitutions are $R = 2.305$, $X = 1.01$, $R = 2.32$, $X = 1.00$. Evidently the values of R and X have practically converged on their best values. The latter pair are therefore assumed to be the best values.

METHOD 2

An inspection of the circuit diagram of method 2, in figure 1, suggests the following relations:

$$\left.\begin{aligned} &I_0 = I_a + I_{a'b'} = I_{b'c'} - I_c \\ &\text{But } I_{a'b'} = \frac{V_{ab}}{R}\text{, and } I_{b'c'} = \frac{V_{bc}}{jX} \end{aligned}\right\} \quad (23)$$

Expressing V_{ab} and V_{bc} in terms of the symmetrical components of the line-to-neutral voltage V_{ao}:

$$V_{ab} = \check{V}_{ab} + \hat{V}_{ab} = (1 - a^2)\check{V}_{ao} + (1 - a)\hat{V}_{ao}$$
$$V_{bc} = a^2\check{V}_{ab} + a\hat{V}_{ab} = a^2(1 - a^2)\check{V}_{ao} + a(1 - a)\hat{V}_{ao}$$
$$= -j\sqrt{3}\,\check{V}_{ao} + j\sqrt{3}\,\hat{V}_{ao}$$

Upon substituting these relations, together with those expressed in equations 5 to 8 into equation 23 there results:

$$\left(\frac{1 + a}{z} + \frac{1 - a^2}{R} + \frac{\sqrt{3}}{X}\right)\check{V}_{ao} + \left(\frac{1 + a^2}{z} + \frac{1 - a}{R} - \frac{\sqrt{3}}{X}\right)\hat{V}_{ao} = 0 \quad (24)$$

Also, from figure 1,

$$V = -V_{ca} = -a\check{V}_{ab} - a^2\hat{V}_{ab} = -a(1 - a^2)\check{V}_{ao} - a^2(1 - a)\hat{V}_{ao}$$
$$= (1 - a)\check{V}_{ao} + (1 - a^2)\hat{V}_{ao} \quad (25)$$

Equations 24 and 25 may now be solved simultaneously for $\check{V}_{ao}$ and $\hat{V}_{ao}$, yielding

$$\check{V}_{ao} = \left(\frac{V}{\sqrt{3}}\right)\frac{\sqrt{3}\,zR - (1 - a)zX - (1 + a^2)RX}{3zR + j2RX + j3zX} \quad (26)$$

$$\hat{V}_{ao} = \left(\frac{V}{\sqrt{3}}\right)\frac{\sqrt{3}\,zR + (1 - a^2)zX + (1 + a)RX}{3zR + j2RX + j3zX} \quad (27)$$

As in the case of method 1, the next step is to find the scalar values of the above 2 equations and substitute them into equation 13 for torque. Passing over all intermediate steps the torque equation is

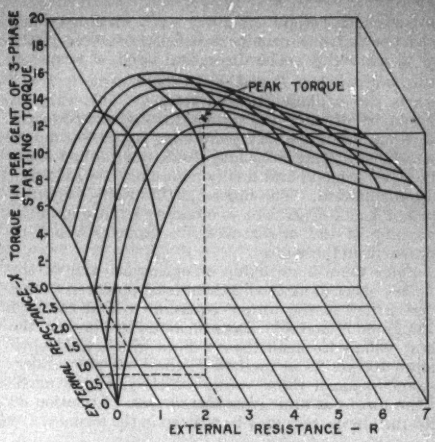

Fig. 4. Isometric graph of torque characteristics of method 1

Data pertain to machine 4, table I
R and X in ohms

$$T = \left(\frac{V^2 r_2}{z^2}\right)\frac{2\sqrt{3}\,RX(z^2 + Rr + Xx)}{(3Rr - 3Xx)^2 + (3Rx + 2RX + 3Xr)^2} \quad (28)$$

The value of z in the above equation is its scalar value. As in the corresponding equation for torque in method 1, the second term of equation 28 is the ratio of the split phase starting torque to the 3 phase starting torque.

The line current for method 2 is found from $I_0 = I_a + I_{a'b'}$ (see figure 1); I_a and $I_{a'b'}$ are expressed in terms of $\check{V}_{ao}$ and $\hat{V}_{ao}$ in equations 5 and 23, and $\check{V}_{ao}$ and $\hat{V}_{ao}$ are further expressed in terms of V in equations 26 and 27. The resulting vector expression for I_o is:

$$I_o = V\left(\frac{2zR + 3z^2 + j2zX + jRX}{3z^2R + j2zRX + j3z^2X}\right) \quad (29)$$

And the corresponding scalar expression is

$$I_o = \frac{V}{\sqrt{3}z}\left[\frac{3(2rR - 2xX + 3r^2 - 3x^2)^2 + 3(2xR + 2rX + RX + 6rx)^2}{(3rR - 3xX)^2 + (3xR + 2RX + 3rX)^2}\right]^{1/2} \quad (30)$$

As in the case of equation 20, the expression under the radical of equation 30 is the ratio of the single phase line current to the 3 phase starting current.

The manner in which the torque varies as either R or X alone is varied is much the same as is shown in figure 3. If torque, however, is plotted in a 3 dimensional diagram, the sheet so formed differs from that of figure 4 in that there is no hump at any positive values of R and X. The torque continues to increase as R and X are both reduced, and attains its greatest value (for positive values of R and X) as R and X approach zero. The torque sheet has a diagonal ridge which increases in height as it ap-

proaches the origin. Figure 5 is a 3 dimensional chart of the same machine as in figure 4 but connected as in method 2. The theoretical value of torque at the origin (when R and X are both zero) is $1/\sqrt{3}$ times the 3 phase starting torque. This value is found by dividing the numerator and denominator of equation 28 by RX, retaining only those terms which have appreciable magnitude when R and X are both very small, and finally assuming $R = X$ as an approximation. The current at the origin of figure 5, where R and X are zero, is infinitely large, and in the vicinity of the origin excessive current would be drawn from the source.

Since there is no hump or optimum value of the torque sheet in method 2 there is no object in taking derivatives of the torque equation to find the best values of R and X. Instead of understanding the best values to mean those values which yield optimum torque as in method 1, they are now understood to mean those values which yield the maximum torque at some *given line current*. Equation 30 for the line current may be written in the form

$$C^2 = 3\frac{(2rR-2xX+3r^2-3x^2)^2+(2xR+2rX+RX+6rx)^2}{(3rR-3xX)^2+(3xR+2RX+3rX)^2} \qquad (31)$$

in which C = ratio of single phase starting current to 3 phase starting current. Then if it were permissible, for example, to draw a starting current from the single phase source equal to 1.5 times the 3 phase starting current of the motor, the value 1.5 would be assigned to C and the procedure would be to assign a few arbitrary values to X in equation 31, solve for the corresponding values of R, and then substitute the pairs of values so found into equation 28. The best values of R and X would then be those corresponding to the largest value of torque.

A shorter but less exact method than that outlined above is to let $R = X$ in equation 31. The results of several tests and computations indicate that over a wide range of ratios of r to x the torque for any given line current when R is equal to X is within about 10 per cent of the maximum torque at the same current. Equation 31 may now be rearranged as a bi-quadratic in R (or X) of the form:

$$JR^4 + KR^3 + LR^2 + MR + N = 0 \quad .$$

where

$$J = 3 - 4C^2$$
$$K = 12(1 - C^2)(r + x)$$
$$L = 6z^2(4 - 3C^2) + 36\,rx$$
$$M = 36z^2(r + x)$$
$$N = 27r^4 + 27x^4 + 54r^2x^2$$

This bi-quadratic may be solved directly for R by one of the standard methods that can be found in any handbook of mathematics. Horner's method was used to obtain the data in table I.

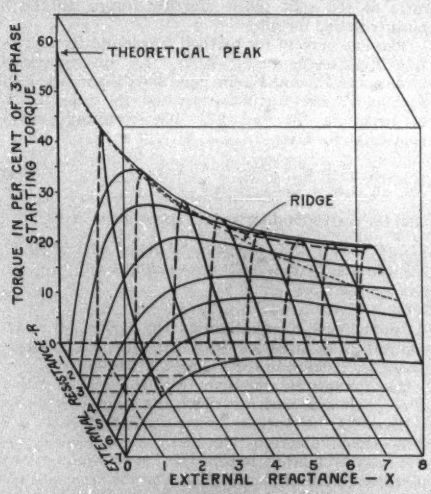

Fig. 5. Isometric graph of torque characteristics of method 2

Data pertain to machine 4, table I
R and X in ohms

Experimental Checks

The validity of the methods described above for computing the best values of R and X has been verified by experimental tests on a number of different induction motors. Most of the machines tested were ball bearing machines with skewed rotor slots, thus minimizing the possibilities of errors due to bearing friction and slot grabbing. The reactor used for X consisted of a rectangular laminated iron core with 2 $^1/_{32}$-inch air gaps. The winding was tapped in several places and heavy copper was used in order to minimize the resistance. Table I compares computed and experimental results.

Wound Rotor Machines

When wound rotor induction motors are used in conjunction with external resistors in the rotor circuits, the values of r, x, and z, when used in the above equations, should include the effect of the external resistance. In other words, if the constants of the machine are determined from the blocked rotor test, the same resistance should be connected in the rotor circuits during the test as will be used when the machine is started. A little consideration will show that the same value of rotor resistance that produces maximum starting torque under normal 3 phase conditions will also produce maximum starting torque when started split phase. Experimental results support this consideration.

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3. Calculation of the Starting Torque of Single-Phase Induction Motors With Split-Phase Starting Devices, I. E. Hanssen. A.I.E.E. Trans., v. 27, 1908, p. 373–5.

A New Watt-Hour Meter

To meet the demand for sustained accuracy in watt-hour meters and for adaptability to service requirements, the meter described in this paper has been produced. It offers simplicity and interchangeability, light weight, high accuracy over a wide range of load, and convenience of adjustment, and features an improved overload compensator, a new form of full load adjustment, and a new form of combined open-potential-coil indicator and balance adjustment for polyphase meters.

By
STANLEY GREEN
MEMBER A.I.E.E.

Duncan Elec. Mfg. Co.,
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NEW watt-hour meter design has been necessitated by changing standards, which require a new line of meter elements designed especially to take advantage of an improved form of heavy load compensation. The space available for the element is determined closely by service installation requirements; at the same time new weather resistant nonferrous meter bases require an element substantially immune to stray field errors. The meter described in this paper secures this immunity by the use of a single potential pole and 2 current poles, which are constructed as a separable unit. Current windings are form wound and are interchangeable on a single lamination form for all ratings. The potential electromagnet has an unusually small mean length of turn with a minimum watts loss in the element, giving also a reduction in low power factor temperature errors and contributing to a light weight electromagnet without sacrifice in any performance detail.

Analysis of modern operating requirements resulted in the choice of a nominal full load torque of 46 millimeter-grams, and watt-hour constants in multiples of $^1/_2$ watt-hour per disk revolution. An improved overload compensator is used which gives substantially perfect registration at all loads between 5 and 300 per cent of nominal meter ratings, together with a 2 magnet damping unit of high coercive force and a new form of full load adjustment. Elements are used without change for polyphase meters, in which a new form of electromagnetic open-potential-coil indicator combines indication and balance adjustment in a single device. Accessibility for disassembly of all component parts is attained from the front in both single and multiple element meters.

The principal improvement embodied in the new meter, which is not brought out by the consideration of a single rating or size, lies in the adaptability of the new element to an entire line of meters with uniform performance and a maximum of simplicity and interchangeability both in manufacture and in use. Lighter weight, better accuracy, lower loss, and more convenience of adjustment are also among the advances. To those unfamiliar with the difficulties in design of the many models and types which have constituted the steps of meter progress in the past, these details may seem unworthy of mention. To this the answer is that simplifications are not obvious until after they are made, and even then serve only as steps to further improvement.

General

In the last decade, important changes in watt-hour meters have received attention in the technical press and in manufacturers' literature but mostly from the standpoint of performance and application. The user's point of view has been uppermost. Manufacturing and design features have received less attention, probably on the theory that the user is the one to be satisfied and that he is not particularly interested in *how* the manufacturer produces the product as long as the price and performance are satisfactory. This assumption is undesirable because among the users of watt-hour meters in the public utilities there is a large proportion of engineers who by training and interest are capable of appreciating design problems. Indeed, it is from this group that the manufacturer receives the current of constructive criticism which crystallizes into actual improvements.

Demands for better performance and adaptability to changing service requirements have been such that the meter of today is scarcely comparable with its forerunner of 10 years ago, and these have been met with little if any real increase in cost to the user. An outline of the causes of some of these improvements and of the design limitations involved should be interesting to the operator or user of meters, and, in addition, if it gives him any better understanding of the problems of the designer, should serve to stir up still further that responsive flow of constructive suggestion which has been the taproot of progress in the past.

For reasons of standardization, and to keep stocks of repair parts at a minimum, users of meters always have been loath to see frequent changes in types. In contrast to the extreme of annual models as indulged in by some industries, the meter manufacturer always has introduced a particular type with caution and deliberation, with the full realization that this type would be the fundamental "platform" upon which production would be based for a term of years, until the pressure of new requirements, better materials and processes, and accumulated improvements

A paper recommended for publication by the A.I.E.E. committee on instruments and measurements, and scheduled for discussion at the A.I.E.E. Great Lakes District meeting, West Lafayette, Ind., October 24–25, 1935. Manuscript submitted May 6, 1935; released for publication August 26, 1935.

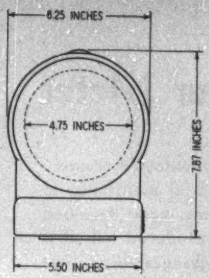
made it absolutely necessary to begin again with a clean slate.

The company with which the writer is associated recently made one of these infrequent but complete changes of model. A discussion of the salient features of its design and the reasons therefore may serve a useful purpose in indicating general design trend. Design of a line of meters cannot be accomplished by logical processes alone because it consists of interpreting the desires of the users, as well as drawing lessons from past experience, both in operation and manufacture. The resultant product is different from what might be produced if there were no restricting past practice or confining current opinion. Much of the process therefore will reflect the designer's opinion and interpretation of facts reported to him. Notwithstanding this, it should be possible to set down in a fairly orderly and logical form some of these factors and how they have affected the present form of the watt-hour meter, regardless of whether they be facts, theories, or plain preferences. To shorten the paper, it has been necessary to assume, on the part of the reader, a reasonably thorough knowledge of watt-hour meters and their performance and to dispense with such explanation or description of phenomena as is found in texts.[1]

Determination of Size

Figure 1 shows the over-all space relations for the ordinary bottom-connected single-phase meter. The case diameter is approximately 6.25 inches, and the width of the terminal chamber is 5.50 inches. Terminal chamber width has really evolved from practical experience in getting the proper number of wires of sufficient current-carrying capacity through the meter with the necessary insulation between them. Four principal wires are required and they may be called upon to carry 150 amperes continuously. The operating voltage between them may be a nominal 230 volts. A few years ago, at the request of the meter committee of the National Electric Light Association, the approximate terminal chamber width shown was standardized upon by all American manufacturers, and it is safe to say that it is not excessive, both insulation and copper being utilized to their maximum safe capacities under the above conditions. The user is benefited little in economy of wall space by reducing the enclosure diameter below the width of the terminal chamber; consequently a glass cover outside diameter of approximately 5.75 inches has also recently been standardized upon by all American manufacturers. The terminal chamber evolution has been a long process of trial and error in which the operating experience with meters in millions of installations has played a part. It is inextricably bound up with the standardization and operating practices of the utilities and to this extent is almost entirely out of the control of the designer except from the very long range point of view. At least for a term of years, it can be assumed that it has been determined for him by past co-operative efforts. The fact that it has been determined, however, does provide the fundamental factor of his design—the space available for the meter element.

1. For all numbered references see list at end of paper.



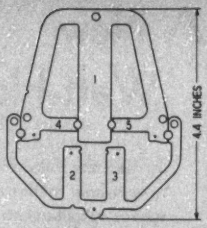


Fig. 2 (above). Outline of electromagnet lamination

Fig. 1 (left). Outline dimensions of typical terminal chamber type of single-phase meter

For economy of materials, a smaller meter diameter could be used, irrespective of the terminal chamber, but past practice has indicated that this is not desirable. Meters of smaller size have been tried and abandoned in favor of new types of approximately the present size. One plausible explanation of this is that there is a limit to the material economies obtained by size reduction where they are overshadowed by the extra manufacturing cost introduced by the crowding of parts and closer tolerances required to build a fine measuring instrument into the smaller space.

In the more recently developed socket type meter, shown in figure 14, it has been found that the socket diameter is largely determined by the required current carrying capacity and necessary spacing for contact clips and circuit wires. This diameter closely approximates the size already established by the former bottom-connected practice. The same fundamental size-fixing factors, therefore, apply to the socket form of meter.

Within the space of the meter cover shown in figure 1 is drawn a circle 4.75 inches in diameter. This is the approximate space which it is safe to utilize for the meter element itself. It will be noted that a fairly generous margin has been left between the element and the outside of the cover. This is to take care of such conditions as special registers requiring more room than usual, variations in cover dimensions and other tolerances, and finally for unforeseen future contingencies, because lack of space is the manufacturer's worst enemy.

Electromagnet Laminations

The shape of the lamination for the electromagnet is shown in figure 2. It is characterized by a single leg (1) for the potential pole and 2 legs (2 and 3) for current poles. A primary reason for this general structure is its resistance to the effects of stray a-c fields. Present practice is to make meter cases from die-cast aluminum or similar nonferrous alloy for weather resistance because of the increasing use of meters out of doors. The cast iron cases of older

meters acted as a rather effective shield against such stray fields, but with present bases the shielding effect is negligible.

The most damaging stray fields are those in which the magnetomotive force is in a direction to cross the gap and cut the disk. Consider the effect of such a stray field on the form of electromagnet shown in figure 2. The path of any flux as a result of this field would have to be through the current poles, across the gap, and through the potential pole. If the potential pole were unexcited by its normal magnetizing current I_m, the stray magnetomotive force would indeed cause flux to flow along such a path. However, with the coil connected across the potential of the circuit to be measured, the total flux through the pole is necessarily proportional to such potential. If any stray magnetomotive force causes a flux in the pole tending to change this proportionality, I_m immediately changes a compensating amount. Although this compensating action originates in the potential coil, its action is naturally effective to a considerable extent throughout the length of the path of the stray field flux, which also includes the length of the 2 current poles. Thus the accuracy of the meter is unaffected by the components of stray a-c fields which are in a direction perpendicular to the disk.

Finally, the yoke completely surrounding the outer ends of the poles and fastening them together in an integral structure acts to some extent as a shield against stray field, whatever its direction. The resultant electromagnet without any enclosing case of magnetic material can be classified as substantially immune to the effects of any stray fields which could be encountered in ordinary installation practices. It is interesting to note that all American makes of meters now embody the general scheme,

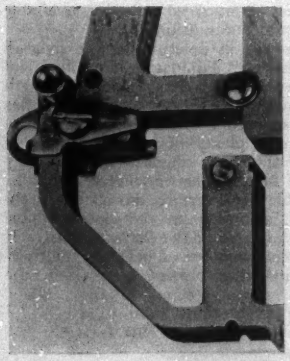


Fig. 3. Magnetic joint between separable current and potential electromagnet cores

which includes one single potential pole and 2 current poles, although the structural details to accomplish this in the various electromagnets naturally vary.

Another important advantage of the electromagnet form is that current and potential poles are held together in mutual relation in one integral structure without being clamped together for support upon some other part, such as a base, and thus are independent of the trueness and accuracy of this second member. Fortunately, it is not necessary to stamp the entire lamination in one piece to accomplish this. Such a structure would impose very great difficulties in applying the windings and especially the current coils, which are of various sizes of heavy wire. Instead, the potential and current parts are stamped separately and joined together. Figure 3 shows the details of this joint, which allows the parts to be detached conveniently at any time. The joint, nevertheless, is always effective in holding the parts in just as precise mutual position as though they were integral. This is important as it affects the length of the disk gap.

This detachability is advantageous to both manufacturer and user. For example, 6 current electromagnets cover the range of ordinary use for 5, 15, and 50 ampere meters in both 2 and 3 wire types. Only 2 potential electromagnets are necessary for the 115 volt and 230 volt ratings. Combinations of these produce any desired meter, thereby reducing parts stocks. Also, in the case of repairs, either the current or potential electromagnet can be replaced separately. The simplification mentioned has been merely for 2 voltage ratings and 3 current ratings in 2 and 3 wire at 60 cycles. If additional voltage, current, or frequency ratings are introduced, the advantages pyramid.

Electromagnet Windings

The starting requirement in the electromagnet design and one which has not always been met heretofore is to have a single form of electromagnet core of a fixed depth of stack which is capable of accommodating all ratings merely by putting on it windings of the proper number of turns. The ideal has nearly always been attained in transformer design where a relatively large number of turns may be employed on both primary and secondary; but for a meter element it is much more difficult, mainly because of the small number of turns which must be used on the current poles.

American practice requires that current windings be capable of carrying continuously 300 per cent of the nominal current rating on the basis of which nominal full load calibration is made. The extra 200 per cent is usually spoken of as "overload capacity," although it has really ceased to be that and modern meters may be momentarily loaded to far beyond the 300 per cent point. In the case of the 50 ampere rating, which is the largest present standard nominal rating, the current coils must be capable of carrying 150 amperes continuously. The ideal construction for such a coil is from relatively heavy copper bar or strap. It therefore is necessary in laying out the electromagnet to consider the entire range of current coils which may be used and preferably to start with the ones which present the greatest mechanical difficulty in applying them to the core.

Table I shows the current coil requirements throughout the necessary ratings. The figure of 12 turns per pole for the 5 ampere size is significant because of its divisibility by 2, 3, 4, and 6. Starting with this number, the required nominal ampere ratings are obtainable with identical cores and with identical torques through 15 amperes. The 25 and 50 ampere sizes are in reality 30 and 60 ampere elements calibrated at the nominal 25 and 50 ampere points. The so-called $^1/_2$ turn per pole in the table for the 50-ampere 3-wire coil is in reality one turn on each pole but with the turns in parallel so that the effect, at least, of a half turn is secured.

It is apparent that no number but 12 is suitable unless a full jump to 24 is made. Although possible, this would be very inconvenient and objectionable because the nominal 60 and actual 180 ampere turns per pole provided by the 12 turn base is already generously sufficient as compared to the potential coil ampere turns which it will be desired to use. Thus, it is a peculiarity of the design that for interchangeability and simplicity, the ampere turns per pole are definitely fixed at a nominal 60 with a base of 12 turns per pole for the 5 ampere size.

It is a simple matter to choose the proper copper cross section for the various coils on the basis of a 30 to 40 degree temperature rise. The lower rise applies to the coils of smaller capacities, while it is necessary to tolerate the higher rise in the case of the larger coils because of heat conveyed to the coil from the terminal chamber and line and load connections to the meter. Figures 4 and 5 show a 50-ampere 2-wire and a set of 50-ampere 3-wire coils which are chosen as the ones representing the most difficulties—mechanical, insulation, and space—for the line. It is to these that the electromagnet must really be "tailored" to provide ease of manufacture and reliability of insulation.

The distance between the 2 current poles is deliberately chosen so that these coils can be wound, insulated, and applied to the poles by simply dropping them in place. Similarly, the height of the current poles is made ample to take care of all possible contingencies for coil and insulation space, present or future. The roominess makes it possible to reverse coil sections from bottom to top on the respective poles for all 3 wire meter coils with the exception of the illustrated 50 ampere coil. This causes the annoying problem of coil balance on 3 wire meters to disappear. Even with the 50 ampere coil the space available makes perfect balance possible by proper shaping of the heavy leads. If space economies need be made, they should be at other points than here. Winding space and its convenient form are of paramount importance not only to the manufacturer but to the user, since restricted space is possibly the greatest contributor to difficult insulation problems and meager current carrying capacity.

Spacing apart the tips of the current poles so that they have no overhang and the coil slips on easily is a new feature and is accomplished at the expense of considerable torque reduction. However, the torque thus sacrificed is later restored by the overload compensator and indeed provides a basis for the working of this compensator. Consequently, an important structural advantage is secured with no loss and indeed with a performance gain, which will be understood fully when the overload compensation is discussed.

The current coil poles are made narrow to increase the clearance between coils and the yoke and to minimize the length of turns. Furthermore, a greater width than that shown adds almost nothing to the torque-producing ability of the element because the most effective portions of the current poles are near the tips of the potential pole. To really increase the torque, wider poles would require additional potential poles or counter poles above the disk. It is questionable whether the gain produced in this way would be worth the cost in space and the structural complications involved.

The potential pole is made as narrow as possible because over it must slip the potential coil, and it is necessary to keep down its mean length of turn. In the lamination shown in figure 2 this width is much less than usual for this style but is still sufficient for the outer tips of this pole to overlap the current pole faces by a slight amount. Thus the width of the potential pole is influenced by the initial choice of distance between current poles.

The primary cause of so-called class II temperature errors in watt-hour meters resides in the resistance of the potential coil, since this coil is of copper which has a large temperature coefficient. The most effective procedure, as well as the simplest, is to minimize this effect at its source, which means that the resistance drop I_mR of the potential coil must be kept low. To do this, the mean length of turn is kept short by using a coil of small diameter which hugs the narrow pole. The resistance of the coil is then further reduced by supplying a large winding cross section which, because of the small diameter, means a long coil. This requires a long potential pole. Here, again, is a place where false space economy should not be practiced and every available fraction of an inch has been utilized.

The 2 main factors in determining the over-all height of the completed lamination have been, of course, the height of the current poles and the length of the potential pole. In neither one of these has economy been exercised. Although in the single phase meter there is plenty of vertical room, the over-all height of the electromagnet enters directly into the height of 2 and 3 element meters and it is, therefore, desirable to keep it down. Notwithstanding all this, skimping on the essential pole dimensions is not justified in the electromagnet. It is possible to economize in over-all height in multiple-element meters in other places than within the

Table I—Current Coil Data

Ampere Rating		Turns per Pole	Turns per Coil Side	
Nominal	Actual		2 Wire	3 Wire
5	15	12	12	6
10	30	6	6	3
15	45	4	4	2
25	75	2	2	1
50	150	1	1	$^1/_2$

Fig. 4. A 50-ampere 2-wire current coil

Fig. 5. A 50-ampere 3-wire current coil

electromagnet itself and achieve the necessary results.

The 2 transverse arms (4 and 5) in figure 2 are the usual shunt paths for some of the potential coil flux. Compensation for the inherent small error in the meter caused by changes in voltage of the circuit to be measured is accomplished in the usual manner by having some portion of this path approach saturation as the voltage varies upward. The total amount of flux passing through the potential coil determines the number of turns necessary in this coil for a given impressed voltage. Also, the magnetizing current I_m in the coil varies inversely as the number of turns used. This total flux, and hence both turns and I_m, can be conveniently adjusted by fixing the relative permeance of these shunt paths. The width of the shunt paths, together with the length of the shunt-arm gaps, has, therefore, been chosen to give the desired number of potential-coil turns and desired magnitude of I_m in the finished meter. For the 115 volt coil, this is 0.06 ampere, a value somewhat below the average and one which has demonstrated itself to be acceptable to users of meters over a long period of time. For the 230 volt coil, I_m is, of course, one half this.

Temperature Errors

There are 2 classes of error caused by temperature variation. Class I temperature errors are those resulting from changes in magnitude of the various fluxes operating on the meter disk, and occur at all power factors of the measured circuit. Class II errors are caused by changes in the phase angle relationship of the various alternating fluxes as the temperature changes. Such errors are important only at low power factors in the measured circuit.

Kinnard and Faus[2] have fully analyzed the sources of error resulting from temperature changes and first developed a method of compensating for the so-called class I group by the use of a nickel-alloy shunt having a negative temperature coefficient of permeability on the permanent magnet damping unit. This has since become universal on all American makes of meters. In the present design, this shunt takes the form of a small clip having an approximate nickel content of 30 per cent. It can be seen plainly on the upper tips of the permanent magnets in figures 13 and 14. D. T. Canfield[3] has also presented a complete analysis of temperature errors for both class I and class II. The class II errors are existent only at power factors less than unity. The low resistance potential coil already described in the new design minimizes the class II errors at their source instead of resorting to compensation. This method of minimizing class II errors was also advocated by Kinnard and Faus. They are still further reduced by the use of a phasing and light load adjustment plate having a low temperature coefficient of resistance. Resultant performance of the meter with respect to temperature under unity power factor as well as inductive loads is given in the appendix.

Main Electromagnet Gap

The smaller the gap for the disk, the more effective the electromagnet. Both manufacturing and operating experience must be combined to determine a desirable minimum value. For a number of years gaps as low as 0.1 inch have been used by one company, but this value requires excessive manufacturing care. A value of 0.125 inch was chosen in the present design. This provides ample disk clearance, but more than this would be of doubtful value in that it is necessary in any event to use a gap of less than this amount for the damping magnets which are to fit on the same disk.

With all the main details of the electromagnet thus determined, it is merely routine to draw in the main outlines and yoke, bearing in mind that economy of material and a minimum number of rivets are desirable. The potential electromagnet yoke has been proportioned to give a flux path of uniform cross section. Ineffective excess iron has been eliminated. The resultant shape makes it easy to thread the laminations through the coil in the assembly operation.

Three main spacer and support rivets are used and go through the laminations in such positions that they are out of line with the main flux paths. These are almost equidistant and widely separated so that the 3 ends of the spacers determine precisely a plane which is parallel to the lamination plane.

Torque Requirements

The electromagnet is a motor and it is necessary to decide arbitrarily how much torque it is desired to produce from it. The lower the torque, the less copper and iron are needed in the complete meter. For many years the ratio of torque produced by the moving element in millimeter-grams to the weight of this element in grams has been regarded by manufacturers and users alike as a rough measure of the merit of a meter element. Current opinion for the past few years has sanctioned a ratio of 3 to 1 as good practice. This opinion is supported by service records over a period of years of many meters which have had a ratio of even less than this value. The ratio, however, has always been computed for a *nominal* full load condition and fails to take into consideration that modern meters are capable of 3 times this torque. Giving the overload torque full credit, a 9 to 1 ratio would exist.

Actually, users are not anxious to accept a reduction in this ratio because in the 5-ampere, 115-volt

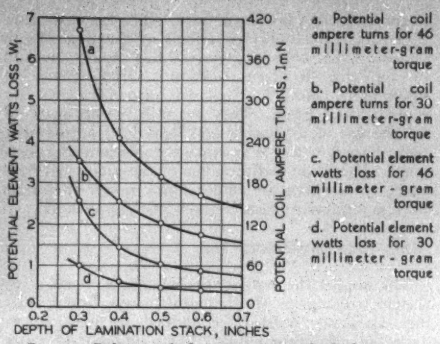


Fig. 6. Relation of electromagnet stack thickness to potential coil ampere turns and losses

meter it would mean less torque at exceedingly light loads. As an example, although a 5 ampere modern meter with a 3 to 1 ratio will measure accurately a 15 ampere load, it will start on only $^1/_3$ the watts of the old form of 15 ampere meter also having a 3 to 1 ratio but without overload capacity, or it will start on the same watts required by the old form of 5 ampere meter. Stated differently, the accuracy on overload was not obtained at the expense of accuracy at light loads.

Low starting watts and extreme light-load accuracy are wanted for 5 ampere meters on small installations so as to record energy flow because of clocks or bell-ringing transformers at times when no other loads are existent. On installations requiring 10 or 15 ampere meters, however, it becomes impractical to detect such a small power flow and, indeed, very unimportant from the standpoint of percentage of total energy measured. With the growth of loads in the future to take full advantage of the capacity of the 5 ampere meter, the problem of light-load accuracy will probably not loom so large. For the near future, however, it was important enough to warrant a maintenance of the 3 to 1 ratio.

Much work has been done in the past to make the weight of the moving element low because it must rest on the jewel bearing. It was possible to carry it over without change from the previous design. It consists of a light aluminum disk mounted on a short aluminum-alloy shaft. It is mounted on the extreme lower end of this shaft so as to give the complete element a low center of gravity and minimize the support, and thus the friction, contributed by the upper bearing. The moving element weighs 15 grams, and a value of 46 millimeter-grams was arbitrarily chosen as the nominal full load torque of the element.

Electromagnet Thickness

Cross section of iron was not considered as an important factor in shaping the lamination because within reasonable limits this can be made anything desired by changing the thickness of the lamination stack. The volume of iron in the completed electromagnet in order to produce the required torque is determined by considering performance with different depths of stack.

Figure 6 shows the relation of potential electromagnet loss, W_1, and potential-coil magnetizing ampere turns, I_mN, as the stack thickness is varied in a completed electromagnet. One set of the curves is drawn on the assumption that the desired 46 millimeter-grams torque is delivered at nominal

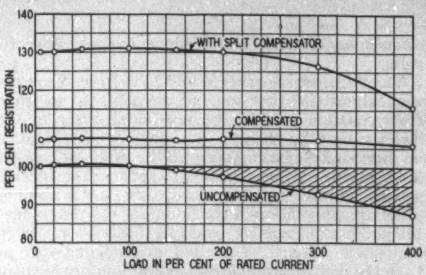


Fig. 7. Accuracy of element on heavy loads before and after compensation

current and voltage at all times regardless of stack thickness. The curves assume proper windings on the core and are easily secured by testing a few electromagnets with different amounts of laminations in each. The stack thickness chosen has been 0.6 inch, giving a watt loss of 0.9. Under these conditions, 162 magnetizing ampere turns are required in the potential coil, and with 2,700 turns, which are used on the 115 volt electromagnet, I_m becomes 0.06 ampere.

It is interesting to note that a substantial saving in stack thickness could be effected if the industry would be willing to accept a smaller torque, a higher loss, or a combination of the 2. . To illustrate this a second set of curves has been drawn on the basis of a required torque of 30 millimeter-grams, from which it can be seen that a stack depth of only 0.3 inch is required on the basis of a 1.0 watt loss. Similarly, a torque of 46 millimeter-grams could be had by raising the loss to 1.6 watts with a stack of only 0.375 inch.

Speed of Moving Element

Another arbitrary decision must be made, and this concerns the series of disk constants K_k which are to be used. This, also, is tied in closely with past experience and present standard practice. Three manufacturers have consistently used a constant of $^1/_3$ watt-hour per revolution in the 5-ampere 115-volt meter for a period of years. This corresponds to a nominal speed of 25 revolutions per minute at 500 watts load. There is little incentive to depart from this speed, and considerable resistance would

be encountered from users if it were tried. A lower speed would call for a higher torque, if the same power output of the moving element were maintained. This in turn would eventually require more material in both the electromagnet and damping magnets and hence would be a disadvantage in cost and weight. It would appear that some advantage would accrue in less bearing wear from the smaller number of revolutions because of a higher constant accompanying a lower nominal speed, but little actual evidence has accumulated in service to support this. At best, it could only be an improvement proportional to the reduction in the number of revolutions for a given kilowatt-hour consumption, while the demand for bearing improvement far exceeds the modest gain that could be obtained in this way. The subject of bearings merits a study in itself; and, although the jewel and pivot bearing is very old, being inherited from the clock art, there is a fair amount of evidence that improvements will be forthcoming which will be sufficient to fulfill operating requirements at established speeds. Such improvements could include better design, as well as the utilization of new materials which would either not require lubrication or which could be lubricated with greater permanency than present forms.

A further disadvantage of changing to a lower speed is that the meter element must be calibrated at light loads by counting revolutions against a standard. Since a minimum of one or two revolutions must be taken, this increases the time for testing. If stroboscopic testing is used, the difficulties are also increased as, even with the present speeds, this form of testing is difficult at 10 per cent load.

A main disadvantage of the high speed is that it causes the meter to have a markedly drooping characteristic in its registration curve at heavy loads. Until the advent of satisfactory means of overload compensation, this difficulty might have been entirely sufficient to require a lower speed, but, with the form of compensation to be described, it has been completely removed. The decision was therefore made to continue the established nominal speed of 25 revolutions per minute at 500 watts or multiples thereof.

Overload Compensation

The uncompensated element does not have a good registration curve. The lower curve of figure 7 shows this from 5 to 400 per cent nominal current load at unity power factor. The shaded area shows the amount of compensation necessary, which at 400 per cent load amounts to over 12 per cent. With a compensator, the curve can be straightened almost perfectly. The compensator consists of 3 laminations of steel (figure 9) held in the position shown in figure 8 on a brass slide which is driven into 2 notches in the inner faces of the current poles.

Imagine that the compensator is cut into halves by removing the magnetic material between the dotted lines in figure 9. The areas A and B of the compensator, being directly under the potential pole, will then act as extensions of the current pole faces because they are virtually connected with the respective poles through the gaps between the compensator and the pole pieces which extend along the perimeter of these poles.

It was formerly stated that the separation of the current pole tips to eliminate overhang reduced the torque available from them. The compensator in the bisected form completely restores that torque so that a registration curve taken on the meter, without recalibrating it, is as shown in the upper curve of figure 7. It is approximately parallel to the former curve and 30 per cent above it.

If the iron between the dotted lines in figure 9 is now restored, it is evident that areas A and B will tend to assume the same magnetic potential and can only differ in an amount equal to the magnetomotive force drop across the iron in the shunting portion of the compensator, which is roughly represented by the iron between the dotted lines.

At moderate loads the flux leaking on to areas A and B on each side of the compensator is so effectively shunted as to have little effect. On heavy loads, however, the iron between the dotted lines approaches saturation, and the areas A and B come into play as virtual extensions of the current pole pieces and hence increase the torque and thus pull up the drooping registration curve.

The middle curve, which is practically flat at 107 per cent registration, shows the actual effect of the addition of the complete unbisected compensator, assuming that the adjustments of the meter had remained unchanged. Actually, of course, calibration to 100 per cent registration is made with the compensator in place, which gives a flat curve at 100 per cent. In addition to its corrective effect, therefore, the compensator adds 7 per cent to the torque of the meter at all loads.

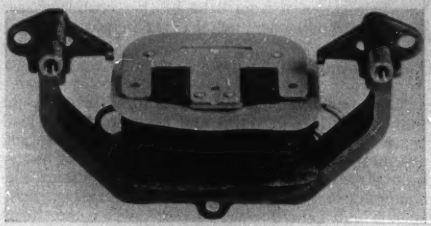


Fig. 8. Current core with overload compensator in place

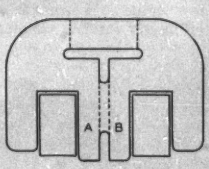


Fig. 9. Plan view of compensator

Industry requirements for the final registration curve are very exact, and the saturation curve of a plain single iron path of uniform cross section and

length is too sharp to match the required amount of compensation as indicated by the shaded area in figure 7. For this reason, the shape of plate shown has been developed, in which there are 2 shunting paths of different length, the longer one passing on the outer side of the T-shaped slot. The shorter path tends to saturate first, followed progressively by the longer one. Thus the knee of the curve is rounded off to match the compensation needed. Correction can be controlled with exactness by the shaping of the laminations and the slots therein. Production tests on many meters indicate that uniform compensation can be obtained by this method. One contributing factor is the extended gap between the compensator and the pole edges, which keeps a relatively constant reluctance despite any small displacements or changes in dimension of the parts in production.

The laminated structure of the compensator cuts down eddy currents in it which would tend to cause slight and nonuniform phase displacement of the current flux by reason of the fact that the current flux passing through the compensator is nonlinear with respect to the magnetomotive force on the current poles. For this reason, the compensator is as accurate on inductive loads as it is on unity power factor circuits. Table II gives the typical compensated registration curve data as determined accurately from a large number of meters of various voltage and current ratings. Note that the accuracy on inductive loads is almost identical with unity power factor accuracy, which means that throughout the wide range of from 3 to 400 per cent load, accuracy is independent of changes in power factor.

Performance Characteristics

The new meter element was arranged primarily to function with a powerful and accurate heavy load compensator such as that described. By taking advantage of what the compensator could do many indirect advantages were obtained. Without the compensator, it would not have been possible to use such a high value for the current pole ampere turns and still keep the potential coil ampere turns at a low value. Hence the compensator is responsible indirectly for the simple series of current pole turn values as well as the low losses in the potential electromagnet. In addition to straightening out the load curve it also contributes substantially to the torque of the element, even at moderate loads. All of the performance characteristics of a meter are interlocked in a substantial amount and there is scarcely one of them which is not affected favorably, at least in some degree, by the presence of the compensator.

A very few comparisons with the superseded design will serve to bring out some of the gains in the motor element. The complete weight of the old type electromagnet was 2.34 pounds and in the new it is 1.76, a reduction of 25 per cent. Even with the decreased weight the new element has 10 per cent higher torque. Potential-coil magnetizing currents are the same for both old and new elements but the new has 10 per cent lower watts loss in the potential coil. Current coil carrying capacities in the old meter were ample for 300 per cent load, and in the new meter these were increased slightly and the current coil insulation given a greater factor of safety.

Problems relating to the performance of meters under variations of power factors, voltage, frequency, and wave form are fully described in texts on meters such as that by Jansky[4] or Knowlton.[5] For a period of years this performance has been so excellent as to leave little to be desired. For reference, a brief tabulation of various standard performance data including such items is given in appendix I.

Table II—Compensated Registration Curve Data

Per Cent of Rated Full-Load Current	Per Cent Registration: At Unity Power Factor	Per Cent Registration: At 0.5 Lagging Power Factor
3	100.5	101.1
5	100.1	100.7
10	100.0	100.3
20	100.1	100.1
50	100.3	100.4
100	100.0	100.0
200	100.0	100.3
300	100.0	100.7
400	98.5	99.7

Above data based on the assumption of correct calibration at 10 per cent and 100 per cent load, and are average or typical performance, from which individual meters should not vary by more than 0.5 per cent

Fig. 10. Meter element without the register, showing the frame

Design of Frame

The electromagnet is supported on a cast frame at only 3 points by means of the spacer rivets passing through it. Immediately below each spacer rivet is a support lug having a hole in it through which a screw may be passed to fasten the electromagnet to any desired base. These 3 support lugs practically coincide in position with the 3 spacer rivets. Thus the 3 point support scheme is carried out in such a manner that warping or displacement of the base cannot possibly communicate any distortion to the meter itself.

Figure 10 shows a complete meter element minus the register so that a better view of the frame can be

obtained. With only 3 support screws through the lugs on the rear of the electromagnet, the element can be fastened to any type of base without affecting its adjustment or operation. These screws are accessible from the front without difficulty with the meter completely assembled. Similarly, the 3 screws holding the frame to the electromagnet are also easily accessible with the meter completely assembled.

The current coil ends on all ratings of electromagnets are terminated in such a position that the binding screw heads passing through them can be conveniently operated from the front of the frame, if desired, without removing it from the electromagnet. Thus the frame and the parts which it supports, when screwed onto the electromagnet, comprise a complete measuring element, irrespective of any support or positioning contributed by the base and, indeed, can be mounted in any type of base with equal convenience. This is important as trends in the last few years have indicated that the forms of enclosure for meters, including the bases, may be subject to considerable modifications in design.

The new construction is such that a meter, even in its installed condition, can have its entire element removed from its base, working from the front without disturbing any other part. Similarly, the frame alone and all the parts which are carried by the frame can be removed without disturbing the electromagnet in the base. In addition, any part carried by the frame can be removed and put back without disturbing either the frame or the electromagnet. Any of these things can be done with a screw-driver, operated from the front, and without changing the calibration of the meter.

From the standpoint of electrical characteristics, such matters of arrangement of parts may seem trivial, but they loom large to the operator who must take care of large numbers of different makes and types of meters. To the casual observer they may seem obvious and easy to accomplish, and only by comparison with the many models and types which have gone before can the advance in the form of simplicity be recognized. It is in these problems affecting simplicity and space engineering that suggestions and requirements from operating engineers from many sections of the country have counted heavily in influencing the final design.

The frame carries the moving element with its upper and lower bearings together with the damping magnet unit. These are readily visible in figure 10. Much care was used to secure proper strength in the frame because these elements must be supported in fixed and unchanging relation.

Construction of Damping Unit

All of the American meter producers now use a 2 magnet unit similar in general construction to that shown in figure 11. Such units have given successful performance in a great many meters over a long period of years so that there are a number of their design features which need not be discussed, as they are matters of routine. Among these are kind of steel, heat treatment, and forging.

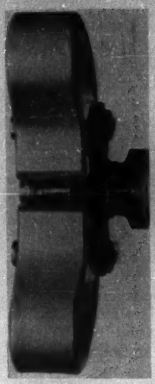


Fig. 11 (left). Damping unit with full load adjustment

Fig. 12 (right). Potential magnet with light load adjustment

The damping strength required is definitely fixed from the torque and the speed, which have already been discussed. The design problem consists in getting this from the unit with maximum economy and with an adequate factor of safety.

The first consideration is the length of gap, and here again the result of much operating experience comes into play. The smaller the gap, the more effective the magnet for a given weight of steel; but small gaps carry with them the disadvantage of very small tolerances and the very important operating factor that any magnetic dirt or filings in the meter will get stuck in a narrow gap and very probably scrape on the disk. Past successful operation has resulted in many meters with gaps as low as 0.078 inch, while some have operated with gaps as high as 0.125 inch. For the present design, a minimum of 0.090 inch was chosen.

The bearings and shaft are designed to bring the disk accurately in the center of this permanent magnet gap without necessity for vertical adjustment. This is checked by gauges at the proper stages of manufacture; and, when accomplished, the position of the disk in the electromagnet gap will also be correct with some margin to spare because the electromagnet gap is 0.125 inch in width.

The shape of the magnet is chosen to give it an adequate length for permanence and also to avoid sharp bends which are difficult to make and which tend to start cracks which are ruinous to a good magnet. The shape must also be worked out to provide as much room as possible above the magnets for the register mechanism, which must also include demand registers for some meters, and in demand registers space is always at a premium. In the present unit, the length of each magnet is approximately 65 times the minimum length of gap, and in past practice 50 times has been considered adequate. A thick magnet section has been avoided as the steel

near the surface responds most readily to heat treatment and is most efficient.

The 2 magnets are permanently fixed in a brass clamp which holds them at the most efficient damping radius from the center of the disk, and adjustment is secured by a soft iron bar below the disk which slides in and out to shunt a variable portion of their flux. This bar is chosen to shunt no more of the flux than is absolutely necessary to secure the proper range of adjustment so that all other available flux is actually effective for damping purposes, with the exception of that passing through a small nickel steel clip on the top poles of the magnets. In figure 11 the clip is not shown on the pole tips so that the view of the full load adjustment bar is not obstructed. This clip has a negative temperature coefficient of permeability and reduces the so-called class I temperature errors of the meter to a negligible value.

The merits of the design can be measured by fully magnetizing a unit and applying it to a meter. With the new design, under this condition, the damping effect is approximately twice that necessary, being sufficient to cause the meter to run at 50 per cent registration instead of the desired 100 per cent. The unit is, therefore, brought down to the desired strength by demagnetization before it is used. An alternating magnetomotive force is applied to each magnet for this purpose. The flux remaining in the magnet will subsequently be unaffected by any other accidental demagnetizing force having a lower value. In the new unit, the demagnetizing force for each magnet exceeds 250 ampere turns.

Mechanical and thermal abuse on meters in service is rarely serious. A far more likely cause of magnet weakening is electrical disturbance such as severe short circuits, or effects of lightning, which result in demagnetizing stray fields. The coercive force

Fig. 13 (left). Bottom-connected single-phase meter

Fig. 14 (right). Socket-type single-phase meter

or the amount of demagnetizing that a magnet unit is able to stand is, therefore, a most important indication of its stability and permanence. Because permanency is the very heart of value in a meter, the magnet unit should be proportioned not only efficiently but generously. Numerous laboratory and service tests were, therefore, run with respect

Fig. 15. Two-element meter without cover

Note similarity to single phase construction, and open-potential-coil indicators

to the new unit. Its resistivity to abnormal conditions was found to be closely proportional to the a-c demagnetization required. This factor was found to range from 50 per cent to 90 per cent higher than for similar successful designs which had preceded it, when measured under the same laboratory conditions.

Adjustments

A new feature of the full load adjustment on the damping unit is that the soft iron bar is pushed in and out on a screw arranged to be free from back lash so that small movements of the screw in either direction immediately produce corresponding changes in calibration. The screw requires no clamping to make the adjustment permanent so that the effect has been described as a "micro-set" adjustment. A departure from all previous designs is that the adjustment screw is operated by a screwdriver from the front of the meter. The entire magnet unit can, of course, be removed from the frame without affecting the adjustment or the resultant calibration.

The light load adjustment consists of the usual closed turn in the shape of a metal plate surrounding the lower end of the potential pole. It is shown in detail in figure 12. By means of a split nut and lever, it is made to operate in micro-set fashion from the front with a screw-driver. It is important to note that, since the light load adjustment operates by reason of its relative position with respect to the potential pole, the proper place for it to be mounted is actually on the potential electromagnet rather

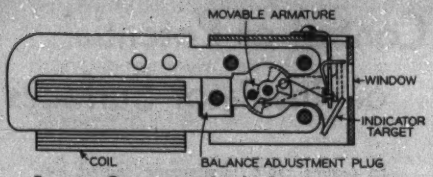


Fig. 16. Open-potential-coil indicator construction

than on some extraneous part, such as frame or base. This detail makes light load adjustment independent of accidental displacement of any other parts with respect to the potential pole.

Very little phasing is required to bring the potential flux of the pole in exact quadrature with the applied voltage. The light load plate more than supplies this, making it possible to accomplish the phasing adjustment differentially by a small coil of a few turns on each current pole. This coil is closed through an adjustable resistance. When adjusted to the correct value, it is soldered and the operation ordinarily is permanent and does not have to be repeated.

Enclosures

Figure 13 shows a completed single phase element in a front connected case, and figure 14 shows the same meter in a base for detachable mounting in a wiring socket. Discussion of various cases and their modifications comes outside the scope of this paper. Their importance with respect to the meter design results from the fact that the meter element must be easily adaptable to them. In this the new design fulfills requirements not only as to present cases, but will allow much flexibility in future requirements.

Polyphase Design

Once complete, it should be possible to apply the single-phase element interchangeably to multiple element designs. The same accessibility of parts from the front of the meter can also be obtained. In general, the multiple element unit should have the same performance as the single element. Only one detail need be added to the single units to make them adaptable, and this is some form of torque adjusting device which may be used to vary the torque output of the electromagnet uniformly at all loads so that balance of torques between elements can be secured when several electromagnets all operate on one moving element.

This should be some device which can easily be applied to any existing electromagnet without changing its form, because interchangeability between elements, as far as stocking for repair or manufacture is concerned, would be disturbed even by a modification as slight as the use of special length leads for the potential coil. In the new design, this balancing has been accomplished by inserting a small adjustable reactance in the potential circuit of each electromagnet. Since this is an entirely separate part, it fulfills the foregoing requirements.

There is an additional advantage in this method because another and separate function can be obtained from this device, since it can be used as an open-potential-coil indicator. Figure 15 shows a complete 2 element watt-hour meter with cover removed and the indicators in place; figure 16 shows the indicator construction.

An indicator of some form is necessary on polyphase meters because open potential coils are difficult to detect as the entire meter does not stop if only one element is affected. In the electromechanical indicator shown in figure 16, the magnetizing current I_m of the associated potential element passes through its coil. The impedance drop through this coil is only 8 per cent of the total applied potential, and hence there is little torque sacrificed. When the indicator is energized, the target is pulled up into a conspicuous position to show that the element is "ON". Similarly, the target will drop down to show "OFF" conspicuously if I_m is in any way interrupted. The indicator coil is as well insulated and of the same size wire as the potential coil which it protects and cannot burn out for any cause less severe than that which would cause failure of the main coil. A high degree of reliance can, therefore, be placed on the indication.

The permeance of the magnetic circuit through the indicator coil can be varied by changing the position of an iron balance plug in this circuit which changes the impedance drop through the coil to give the adjustment required. This adjustment also has been made micro-set by means of a screw passing through the plug. Operating the balance adjustment changes the torque of the meter element a uniform percentage under all conditions of load, and does not affect the phasing adjustment in an appreciable degree.

Appendix

The accompanying tables give miscellaneous performance characteristics of the new design for 60 cycle meters, both single phase and polyphase, in all voltage ratings and in all current capacities, including the 50 ampere rating. Average values are given for the typical meter. Small manufacturing variations and local conditions

Table III

Per Cent of Rated Voltage	Per Cent Registration at Full Load: Unity Power Factor	Per Cent Registration at Full Load: 0.5 Lagging Power Factor
85	100.1	100.1
100	100.0	100.0
115	99.7	99.6

of test and installation may cause the individual meter to vary slightly from the average performance, but never by a substantial amount. The effect of voltage variation on meter registration is shown in table III. The data in the table are based on the assumption of correct calibration at a reference voltage within the rated voltage limits as given on the nameplate of the meter, and were taken at full load. However, nearly identical performance with respect to variation in voltage is obtained at all other loads between

10 per cent and 300 per cent. Note that the readings with inductive load practically coincide with the readings at unity power factor loads.

The effect of frequency variation on registration is shown in table IV. For present day electric distribution circuits, these errors are negligible.

Variation in registration caused by temperature is shown in table V, for which correct calibration at 10 per cent load and 100 per cent load and correct power factor adjustment at 20 degrees centigrade are assumed. The variations shown are typical and average for all loads between 10 per cent and 300 per cent.

Table IV

Cycles	Per Cent Registration at Full Load: Unity Power Factor	Per Cent Registration at Full Load: 0.5 Lagging Power Factor
57	100.4	99.8
60	100.0	100.0
63	99.7	100.3

Table V

Temperature, Degrees: Fahrenheit	Temperature, Degrees: Centigrade	Per Cent Registration: At Unity Power Factor	Per Cent Registration: At 0.75 Power Factor	Per Cent Registration: At 0.5 Power Factor
−4	−20	99.9	100.15	102.3
14	−10	100.1	100.1	101.8
32	0	100.1	100.05	101.2
50	10	100.0	100.0	100.7
68	20	100.0	100.0	100.0
86	30	100.0	99.95	99.5
104	40	100.1	99.90	99.0
122	50	100.3	99.85	98.4

Temperature coefficient per degree centigrade at unity power factor = 0
Temperature coefficient per degree centigrade at 0.5 lagging power factor = 0.055 per cent
At approximately 0.75 lagging power factor, all temperature errors are substantially zero

MISCELLANEOUS DATA
(For 5 amperes, 115/120 volt, single phase meters)

Potential element exciting current at 115 volts	0.06 ampere
Potential element coil resistance	72 ohms
Potential element loss at 115 volts	0.9 watt
Power factor of potential coil	0.13
Electromagnet disk air gap	0.125 inch
Diameter of disk	3 1/2 inches
Thickness of disk	0.036 inch
Weight of moving element	15 grams
Full load torque (at 575 watts)	46 millimeter-grams
Ratio-torque to weight	3
Speed of disk at 500 watts	25 r.p.m.
Watt-hour constant	1/4
Resistance of current coil circuit	0.010 ohm
Current coil loss at 5 amperes	0.25 watt
Range of adjustment at light load	80 to 120 per cent
Range of adjustment at full load	85 to 120 per cent
Weight of service type	7.2 lbs.
Weight of plug-in type (without socket)	6.6 lbs.
Weight of socket for plug-in type	2.1 lbs.

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Control of Potential Over Insulator Surfaces

To reduce radio interference caused by corona from pin insulators, adherent conducting coatings or films usually are applied to the central portions of the heads of the insulators, and metal thimbles or conducting coatings in the pin holes. By extending the coating to cover the entire head and by using a coating of the proper resistivity, the voltage at which corona occurs can be raised considerably without materially lowering the flashover voltage. This paper calls attention to the principle of controlling the potential distribution over surfaces of insulators by utilizing the resistance drop in potential resulting from the flow of charging current in high resistance films.

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BRUSH DISCHARGES in the film of air that separates the porcelain surfaces of pin type insulators from the adjacent surfaces of the line and tie wires have been a troublesome source of radio interference on moderate-voltage power-transmission lines. Laboratory tests indicate that any commercial pin insulators, regardless of the manufacturer's voltage rating, may be expected to give rise to radio interference if operated at effective line voltages exceeding 8 kv to ground, unless the insulators be provided with caps or conducting coatings which eliminate the discharges from the line and tie wires to the insulator surfaces.

To eliminate these brush discharges it is the usual practice to apply an adherent conducting coating or film to the central portion of the head of the insulator extending about one inch out beyond the tie wire groove and to employ a metal thimble or a conducting coating in the pin hole. The prevailing practice is to have the resistance of these coatings so low that the entire coating assumes the potential of the line wire or of the pin with which it is in contact. This

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means that there is a tendency for a brush or corona discharge to occur at the edge of the coating, although the voltage between line and ground necessary to cause this corona usually is higher than the voltage necessary to cause corona on the uncoated insulator.

This paper points out that by extending the coating to cover the entire head, the voltage at which corona occurs can be raised greatly without materially lowering the flashover voltage of the insulator provided the following principle is utilized: The resistivity of the coating must be increased to the range of values at which the IR drop in potential from the line wire to the peripheral edge of the coating is as great as possible consistent with no material decrease in the flashover voltage of the insulator. The current that causes the drop in potential toward the periphery is the radially directed charging current that flows in the coating.

Briefly, the paper calls attention to the principle of controlling the potential distribution over surfaces of insulators by utilizing the resistance drop in potential resulting from the flow of charging currents in the high resistance films with which the surfaces are coated. It presents the current-voltage equations for several simple geometrical forms, and the results of experimental confirmations of the principle.

Potential Equations for High Resistance Films

Disk. If the head of a pin insulator be coated with a conducting film of known resistivity, the differential equations of the film relating current, potential, and distance cannot be solved because of the impossibility of expressing the capacitances of the successive circular zones of the film. A simple geometrical form, susceptible of solution, which to some extent resembles a coated insulator head, is illustrated in figure 1. It consists of an insulating disk of glass or porcelain, A, resting on a metal plate, B. On the upper surface of the disk is a thin

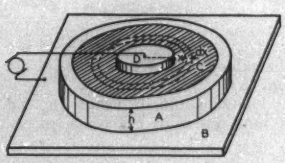


Fig. 1. Disk insulator model somewhat similar to a coated insulator head

circular conducting sheet or coating, C, of high (and uniform) resistivity. Concentric with this coating and resting on it is a circular metal electrode, D.

If a sinusoidal electromotive force be applied between the circular electrode D and the metal plate B, a conduction current from the electrode flows radially in the high resistance coating to charge the successive circular zones of the coating to the appropriate potentials. If for figure 1:

x represents the radial distance from the center of the coating to any circular zone of width dx

a and b represent, respectively, the radii of the metal electrode D, and the coating C

i represents the instantaneous value of the current in the outward direction in the zone of radius x

e represents the potential of the zone of radius x relative to the metal plate A

p represents the permittivity of the disk in coulomb-volt-centimeter units

r represents the resistance between opposite edges of a centimeter square of the high resistance coating

then the resistance of the zone of radius x is $rdx/2\pi x$, and its capacitance to the metal plate, a, is $2\pi xpdx/h$.

h = 1.3 centimeters
b = 15.0 centimeters
a = 5.0 centimeters
p = 6 × 8.85 × 10^{-14} in coulomb - volt - centimeter units
$\omega = 2\pi 60$

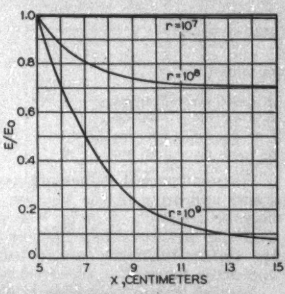


Fig. 2. Distribution of potential over high resistance coating of disk insulator shown in figure 1 for 3 coating resistivities (in ohms per centimeter square)

The capacitance from the upper surface of the zone to ground may be ignored, or it may be allowed for approximately, depending on the configuration of the ground surfaces.

Accordingly, the differential equations for the film are

$$\frac{\partial i}{\partial x} = -\frac{2\pi px}{h}\frac{\partial e}{\partial t} \tag{1}$$

$$\frac{\partial e}{\partial x} = -\frac{ri}{2\pi x} \tag{2}$$

Writing the expressions for the sinusoidal current and potential difference in the exponential forms,

$$\left.\begin{aligned} i &= I \exp j\omega t \\ e &= E \exp j\omega t \end{aligned}\right\} \tag{3}$$

in which ω represents $2\pi f$ and the amplitudes I and E are functions of x. Substituting these expressions in equations 1 and 2 the following equations result:

$$\frac{\partial I}{\partial x} = -j\frac{2\pi px\omega E}{h} \tag{4}$$

$$\frac{\partial E}{\partial x} = -\frac{rI}{2\pi x} \tag{5}$$

Eliminating I between these equations,

$$\frac{\partial^2 E}{\partial x^2} + \frac{1}{x}\frac{\partial E}{\partial x} - \frac{jr\omega p}{h}E = 0 \tag{6}$$

This is Fourier's equation; its solution written in terms of the "ber" and "ker" functions is[1]

$$E = E_1 (\text{ber } mx + j \text{ bei } mx) + E_2 (\text{ker } mx + j \text{ kei } mx) \tag{7}$$

in which

$$m = + \sqrt{\frac{rp\omega}{h}} \tag{8}$$

Evaluating the integration constants E_1 and E_2 to satisfy the boundary conditions, namely, $I = 0$ at $x = b$ and $E = E_0$ (the impressed voltage) at $x = a$, their values are found to be

$$E_1 = -\frac{AE_0}{BC - AD}$$

$$E_2 = \frac{BE_0}{BC - AD} \tag{9}$$

in which

$$\left.\begin{aligned} A &= \text{ker}' \, mb + j \, \text{kei}' \, mb \\ B &= \text{ber}' \, mb + j \, \text{bei}' \, mb \\ C &= \text{ker} \, ma + j \, \text{kei} \, ma \\ D &= \text{ber} \, ma + j \, \text{bei} \, ma \end{aligned}\right\} \tag{10}$$

When numerical values are assigned to the constants appearing in the solution, a series of curves may be constructed giving the potential variation over the high resistance film for different values of the surface resistivity r. Such a family of curves appears in figure 2.

Parallel Stream Line Flow of Charging Current in High Resistance Films. Instances arise in practice in which the presence of corona at the peripheries of capacitor plates is undesirable. In many such instances the potential gradients in the vicinity of the edges of a highly conducting plate can be reduced to values lower than the critical value for corona by applying a high resistance border strip as illustrated in figure 3. The charging current which flows through the dielectric between high resistance strips causes a resistance drop over the strips thus leading

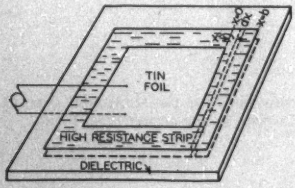


Fig. 3. Parallel plate capacitor

to lower potential gradients around the periphery of the modified capacitor plate than would obtain otherwise without the strips.

In performing puncture tests on metal sheathed cable, some expedient usually is employed to prevent abnormally high potential gradients at the edge of the sheath. The principle of obtaining controlled potential distribution by means of a resistance drop in a high resistance film may be used to considerable advantage in this practical instance. Figure 4 illustrates how the effect may be obtained with high resistance paint or tape applied over the cable dielectric beginning at the edge of the sheath.

The differential equations that approximately govern the flow of current and potential distribution over high resistance films applied to a cable test specimen or to a parallel plate capacitor as shown in figures 3 and 4 are linear and possess a solution expressible in terms of exponential and trigonometric functions. This is true also for numerous other applications that are characterized by parallel stream line flow of current in the high resistance film.

If a sinusoidal voltage be impressed across the parallel plate capacitor or cable specimen of figures 3 and 4, respectively, and if

x represents the distance from the edge of the metal to any zone of width dx

i represents the instantaneous value of the current in the x direction per unit width of the zone dx

e represents the potential of the zone dx relative to the corresponding zone on the opposite side of the dielectric

C represents the capacitance per square centimeter of coating

r represents the resistance measured between opposite sides of a centimeter square of high resistance film

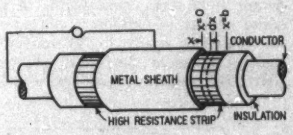
then the differential equations for the film are

$$\frac{\partial i}{\partial x} = -C \frac{\partial e}{\partial t} \tag{11}$$

$$\frac{\partial e}{\partial x} = -Ri \tag{12}$$

For the parallel plate capacitor of figure 3, having resistance strips on both faces, the resistance R is

Fig. 4. Cable test specimen



equal to $2r$; for the cable illustrated in figure 4, the resistance R is equal to r.

Performing the following substitutions for the sinusoidal current and potential difference in the exponential forms,

$$\begin{aligned} i &= I \exp j\omega t \\ e &= E \exp j\omega t \end{aligned} \tag{13}$$

the following equations result

$$\frac{\partial I}{\partial x} = -jC\omega E \tag{14}$$

$$\frac{\partial E}{\partial x} = -RI \tag{15}$$

Eliminating I between equations 14 and 15 yields

$$\frac{\partial^2 E}{\partial x^2} - jRC\omega E = 0 \tag{16}$$

1. See reference at end of paper.

The solution of this linear differential equation is

$$E = E_1 \epsilon^{-kx} (\cos kx - j \sin kx) + E_2 \epsilon^{kx} (\cos kx + j \sin kx) \quad (17)$$

in which

$$k = + \sqrt{\frac{R\,C\,\omega}{2}} \quad (18)$$

Upon evaluating the integration constants E_1 and E_2 to satisfy the boundary conditions, namely, $I = 0$ at $x = b$ (the distance to the edge of the coating) and $E = E_0$ (the impressed voltage) at $x = 0$, it is found that

$$E_1 = \frac{E_0 \epsilon^{kb} (\cos kb + j \sin kb)}{2 (\cosh kb \cos kb + j \sinh kb \sin kb)} \quad (19)$$

and

$$E_2 = \frac{E_0 \epsilon^{-kb} (\cos kb - j \sin kb)}{2 (\cosh kb \cos kb + j \sinh kb \sin kb)} \quad (20)$$

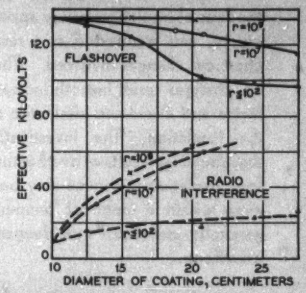
Numerical values pertaining to any example to which the differential equations 11 and 12 apply may be substituted in equation 17 for E, and curves may be drawn for the potential distribution over the film.

Application of a High Resistance Film to the Pin Type of Insulator

The method of controlling the potential distribution over the surface of a dielectric by utilizing the resistance drop resulting from the charging current in a high resistance surface film may constitute a practical solution of the problem of eliminating radio interference from the pin type of insulator. As already pointed out, radio interference is caused by corona at the tie wire and pin hole, or on some special insulators, at the edge of a metallic flux distributor. In some instances, interference at low line voltages may arise also from corona in constricted regions between shells or over cement junctions, but it has been demonstrated by several manufacturers that these sources of radio interference can be eliminated by one piece construction and attention to proper geometrical configuration if the operating voltage does not exceed the rated voltage appreciably.

In order to obtain experimental confirmation of the effectiveness of the principle when applied to a pin insulator, a 50-kv one-piece commercial insulator without metal cap or thimble was selected as a model to receive coatings of different resistivity and diameter on the head and complete coating in the pin hole. The procedure followed in determining the lowest voltage giving rise to radio interference was to reduce the applied insulator voltage, beginning with a high value, until no interference could be detected by a superheterodyne radio receiver placed 6 feet from the insulator. The results of these tests are shown in figure 5. Radio interference measurements were not extended above a line voltage of 66 kv (16 kv above the manufacturer's rating), at which voltage corona appeared between the shells of the insulator. For all other tests, corona made its first appearance at the periphery of the coating.

It should be noticed especially that the low resistance coatings ($r < 10^2$ ohms per centimeter square) offered relatively little protection against radio interference and that prohibitive reduction in the flashover voltage occurred whenever the diameter of this coating was large enough to afford any appreciable advantage over the simple uncoated insulator. However, figure 5 depicts also the unique property of the high resistance coating of reducing the potential at the coating periphery to the extent that no radio interference existed in the voltage range 0–66 kv with coatings of large diameter. Furthermore, it



Diameter of tie wire groove, 10 centimeters; diameter of top shell, 28 centimeters

Fig. 5. Dry flashover voltage and lowest voltage causing radio interference from a 50 kv pin insulator versus diameter of conducting coating on the head for 3 coating resistivities (in ohms per centimeter square)

is important to note that there was no material decrease in flashover voltage of the insulator.

It may be observed also that a latitude of at least 100 fold in the value of coating resistance on the head and in the pin hole is permissible without leading to radio interference. The upper limit for resistance will be attained when the potential gradient near the tie wire becomes large enough to cause corona and a lower limit will be set when the reduction of potential at the periphery of the coating is not sufficient to prevent corona.

A suitable manufacturing process for imparting the proper resistance to the head and pin hole of the pin insulator has not been devised. Temporary films were employed successfully for experimental purposes in the laboratory, but it is evident that a coating intended for service in the field must be permanent under the influence of a variety of destructive agents. The best method of imparting the resistance to the proper surfaces of the porcelain insulator would appear to be the use of a surface glaze possessing the desired resistivity. If this plan be followed, the resistance of the glaze in the line and tie wire grooves should be much less than that required on the head in order to avoid poor tie wire contacts and high potential drops in the region surrounding these points of contact.

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Pyrochemical Behavior of Cellulose Insulation

Tests on unbleached unsized linen paper of high purity indicate that the physical defects implied by the various pyroelectric theories of insulation failure appear secondary to, and manifested as a result of, the chemical changes involved. These chemical changes result in both increased power factor and decreased dielectric strength of the insulation. The investigation shows that chemical results of overheating of cellulose insulation in service may be disastrous even within a range of temperatures not generally associated with dangerous physical effects.

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HEAT DISSIPATION has long been recognized to be one of the most important factors upon which the successful operation of commercial dielectrics depends. Cooling surfaces must be so arranged that excessive heating is avoided. The general acceptance of the various pyroelectric theories of insulation breakdown[1,5] has reflected the universal importance associated with the thermal characteristic. The physical effects of cumulative heating have occupied the attention to such an extent, however, that in many instances the chemical changes produced have been overlooked. Unlike the physical results, the chemical effects of cumulative heating rarely, if ever, are recognized as being directly connected with the dielectric failure of insulation. The chemical results of overheating may be disastrous even within a range of temperatures not generally associated with dangerous physical effects. The insidious chemical action is of slow growth and may be traced only with difficulty. In its final stages, dielectric deterioration from chemical causes becomes physically manifest in accordance with the usual pyroelectric phenomena. The purpose of this paper is to trace the chemical change in cellulose insulation directly produced from thermal causes, the occurrence of which seriously may affect the successful use of the insulation as part of electrical design.

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1. For all numbered references, see list at end of paper.

As illustrative of cellulose insulation, unbleached unsized linen paper of high purity was used in this investigation. It is recognized that chemical reactions are affected greatly by contaminating materials. As such, ligneous matter in other types of paper as well as sizing or other fillers might well be expected to produce variations in chemical stability. Unbleached linen paper was selected as being representative of a commercial type of cellulose insulation substantially free from such secondary effects. The paper used was 0.0005 inch thick.

From the results obtained it is concluded that for the successful application of cellulose insulation as an integral part of electrical machine design, proper consideration of thermal phenomena is fundamentally essential. Important though they may be, the physical effects implied by the various pyroelectric theories of insulation failure appear secondary to, and manifested as a result of, the chemical changes involved. Cellulose insulation, as represented by unbleached unsized linen paper, deteriorates mechanically and electrically as a result of thermally produced chemical changes clearly evident at temperatures higher than 100 degrees centigrade even when of relatively short duration. These chemical changes not only produce increased power factor but are accompanied by gas formation with subsequent decrease in dielectric strength. Even for lower temperatures not normally associated with short time chemical change, cellulose insulation may deteriorate with consequent decrease in electrical characteristics if high potential stress be applied concurrently.

Removal of Moisture From Cellulose

Mechanical as well as electrical properties of cellulose insulation are associated with its water content, which is present both as an absorbed surface film and as an integral part of the chemical structure. The drying of the material in preparation for its use as a dielectric involves the removal of the absorbed water film. Like the removal of all films, the separation of the absorbed moisture presents increasing difficulty as the drying progresses. Elimination of the final traces merges into the removal of the molecularly associated water. The exposure of cellulose to progressively higher and

Fig. 1. Relation between oil absorption by paper and thermally produced chemical change gauged by means of the acidity value

This figure is based upon data of tables I and II. For acidity test, see footnote (*) under table I

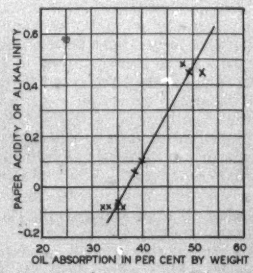


Table I—Chemical Change in Unbleached Linen Paper Produced by High Temperature in Air, as a Function of the Method of Exposure

Treatment	Properties of Paper After Treatment: In Loosely Wound Rolls: Color	Acidity*	Oil Absorption**	Width, Inches	In Tightly Wound Rolls: Color	Acidity*	Oil Absorption**	Width, Inches
None	White	−0.08	32	2	White	−0.08	32	8 7/16
110 deg C, 48 hr	White	−0.08	36	1.9	White	−0.08	35	8 1/8
150 deg C, 27 hr	Yellow	+0.10	40	1.8	Brown	+0.44	48	8 1/8
150 deg C, 48 hr	Yellow	+0.52	45	1.8	Deep brown	†	†	8

* Acidity is expressed as positive or negative. A negative value indicates the milligrams of sulphuric acid necessary to neutralize one gram of paper. A positive value indicates the milligrams of sodium hydroxide necessary to neutralize one gram of paper.
** Oil absorption is the amount of oil retained expressed in per cent by weight of the original (dry) paper.
† Deterioration was so great that reliable acidity and oil absorption values could not be obtained.

higher temperatures leads to more and more moisture removal until, at a sufficiently high temperature, chemical degradation clearly is observed. The problem of satisfactory drying of cellulose insulation thus becomes one of distinguishing between those conditions necessary to obtain the best dielectric and mechanical properties and those accompanied by chemical disintegration. The problem becomes increasingly difficult when it is recognized that chemical changes may result from prolonged exposure to almost any temperature. Thus when heated in air, cellulose first will decrease in weight with loss of water to an apparently stable value. Further heating, however, eventually will produce a slowly increasing weight[2] with accompanying changes in chemical acidity and color, and mechanical and electrical deterioration. Factory drying of insulation preparatory for use as an integral part of electrical machines clearly recognizes this behavior. The treatment is carried out under conditions carefully eliminating the second stage. Service use of the insulation, however, knows no such limitations and is favored only by the characteristically lower temperature encountered, with resultant slower chemical change in the cellulose.

The Chemical Change Is Accelerated by the Products Formed

There is one important factor that necessarily accompanies the use of cellulose as a dielectric in electrical design: The products of chemical change are not easily removed. Even if gaseous or liquid, the products of decomposition usually are adsorbed

Table II—Chemical Change in Unbleached Linen Paper When Subjected to High Temperature and Vacuum in the Form of Tightly Wound Rolls

Treatment	Properties of Paper After Treatment: Color	Acidity*	Oil Absorption*	Width, Inches
None	White	−0.08	33	8 7/16
110 deg C, 48 hr	White	−0.06	35	8 1/8
150 deg C, 27 hr	Yellow	+0.08	38	8 1/8
150 deg C, 48 hr	Yellow	+0.49	45	8 1/8

* See footnotes under table I.

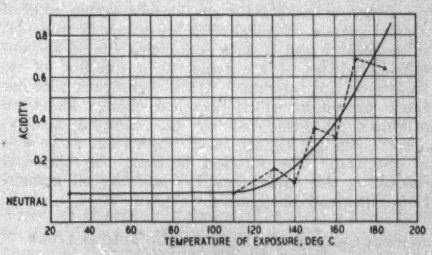


Fig. 2. Acidity change in paper resulting from high temperature treatment

Heating period—48 hours under a pressure of 2 millimeters of mercury
Test samples—Tightly wound rolls as described for table I
For acidity test, see footnote (*) under table I

or at least remain in more or less direct contact with the material from which they are formed. It is not a rarity that chemical reactions of this type are autoaccelerated. That such effects arising from cellulose degradation cannot be ignored is illustrated in the data of table I, which describes the behavior of unbleached linen paper as a function of the method by which it was exposed to high temperature. To obtain the best thermal distribution, the paper was heated with a sheet of aluminum foil between each 4 mil pad. In one group of tests the paper was in the form of loosely wound rolls about 2 inches wide, in order to allow easy volatilization of the products of degradation. In the other group the paper was in the form of tightly wound rolls about 8 inches wide in order to present greater difficulty for the volatilization of the reaction products. In each roll the paper was 50 feet long. The chemical change produced in the paper from such treatment is accelerated in those rolls presenting the greater possibility for the retention of the products resulting from the chemical change in the cellulose.

To illustrate further the retardation produced by treatment that removes the chemically formed products of degradation from contact with the cellulose, rolls similar in construction to the tightly wound samples of table I were heated in a vacuum of approximately 2 millimeters of mercury. The re-

Fig. 3. Mechanical deterioration in paper resulting from ionization effects

This paper was tested at 25 degrees centigrade between sheets of mica in an atmosphere of hydrogen gas. The voltage applied was sufficiently high to cause corona streamers across the mica surface

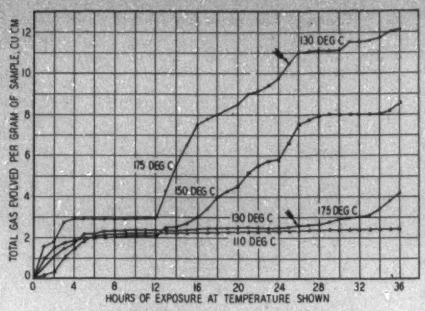


Fig. 4. Gas evolution from paper produced as a result of thermal decomposition under vacuum

Test samples—Tightly wound rolls as described for table I
Test conditions—Paper heated as shown under a pressure of 2 millimeters of mercury
The arrows appearing on the 175 and the 130 degree curves indicate a temperature change from 175 to 130 and from 130 to 175 degrees as illustrated

sults obtained are practically duplicates of the data presented in table I for the loosely wound rolls of similar paper. Typical data are given in table II.

In tables I and II data concerning the oil absorptive properties of the paper as a function of its treatment are tabulated. It is significant that for those papers in which chemical change has been produced as evidenced by the changed acidity, a corresponding change in oil absorption value also is obtained. The relation between the chemical change in the paper (acidity) and the oil absorption is illustrated in figure 1.

Acidity Change as a Function of Temperature

In the data of tables I and II, acidity increase is not pronounced for temperature treatment at 110 degrees centigrade, irrespective of the method of test. At temperatures higher than 110 degrees, even when heated in a vacuum of 2 millimeters of mercury, decomposition of the paper results, as evidenced by increased acidity; figure 2 illustrates this effect. The data of figure 2 are based upon changes that occurred when tightly wound rolls, similar to those already described in connection with table I, were heated for 48 hours under a vacuum of 2 millimeters of mercury. Even for such short thermal exposures under the most favorable conditions for stability, a pronounced deterioration of the paper occurs when temperatures higher than 110 degrees centigrade are used. Longer periods of treatment at lower temperatures must be expected to produce similar chemical changes.

Dielectric Deterioration Accompanying Paper Degradation

Increased electrical losses accompany the chemical changes produced by high temperature exposure of paper. The relation is shown in figure 9 for unbleached oil-treated linen paper. A condition dangerous to the successful commercial operation of cellulose dielectrics arises where chemical change of this type is allowed to continue unchecked. A more immediately dangerous condition, however, would result were noncondensable gases also evolved from the insulation. The increased power factor of the insulation under such conditions would be accompanied by ionization effects under high potential. Figure 3 shows the disintegration of unbleached linen paper produced by high voltage ionization. The paper illustrated was placed between sheets of mica in an atmosphere of pure hydrogen in order to eliminate carbonization and oxidation of the cellulose under corona discharge. The deterioration shown in figure 3 is typical of ionization effects arrested before complete disintegration of the cellulose. If allowed to run its full course, the cellulose sheet is completely disintegrated with the production of a finely divided dust. In figure 3, the disintegration is plainly under way as is witnessed by the screen-like structure which distinguishes the area directly between the electrodes.

That noncondensable gases are evolved from unbleached linen paper when exposed to high temperatures is illustrated in figure 4. These data were obtained with tightly wound rolls similar in con-

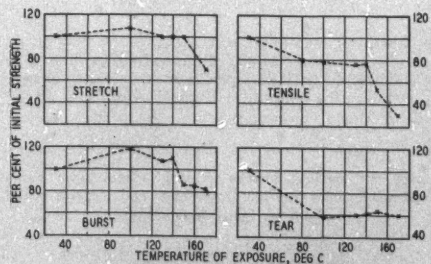


Fig. 5. Mechanical deterioration of paper resulting from high temperature treatment

Mechanical strength was measured after 48 hours' heat treatment at the temperature shown. All data shown here were taken at 20–25 degrees centigrade, during the same day under prevailing atmospheric humidity. (40 per cent relative humidity at 68 degrees Fahrenheit)

struction to those of table I and suspended in a vacuum chamber under a pressure of 2 millimeters of mercury. Means were provided for collecting and measuring the reaction products normally gaseous at 25 degrees centigrade and 760 millimeter pressure. As illustrated in figure 4, irrespective of the testing temperature, the first rush of gas, which was largely air with some water vapor, was succeeded by a quiescent period the duration of which was a definite function of the experimental conditions. With temperatures maintained at 110 or 130 degrees centigrade, no further noncondensable gases were evolved within the limits of the experiment. With higher temperatures, gassing again started after a total heating period of about 12 hours.

The data of figure 4 are important from another viewpoint. In commercial practice, it is often necessary to decide whether insulation once subjected to overheating, is fit for further use. Gauged from the standpoint of gassing tendencies, one would conclude that cellulose insulation once severely overheated is not suited for further successful use. Thus in figure 4, the cellulose when actively "gassing" in the final stage of the 175 degree test showed but little change when the temperature was decreased to the normally safe value of 130 degrees. Contrariwise, the insulation at 130 degrees, as illustrated, showed a prompt response in gassing when the temperature was increased to 175 degrees.

Mechanical Deterioration Accompanying Chemical Change

The mechanical strength of paper, so necessary in some of its dielectric applications, decreases with extended drying. When chemical deterioration of the cellulose is produced, the mechanical strength decreases at an increasing rate. This is illustrated in figure 5. A more definite picture of the decreased mechanical strength accompanying the short-time high-temperature treatment of the cellulose is given in figure 6. Here the mechanical properties of figure 5 are given equal weight and averaged. Taking the normal mechanical strength of the undried paper at 25 degrees centigrade as 100 per cent, it is evident that drying, even within the limits of temperature not conducive to marked acidity or dielectric deterioration, produces decreased mechanical strength. As the temperature rises above 130–140 degrees, the drop in "average" mechanical strength may assume dangerous proportions. It is obvious that longer periods of heating at lower temperatures cannot be ignored in the application of cellulose insulation where the maintenance of good mechanical properties is paramount.

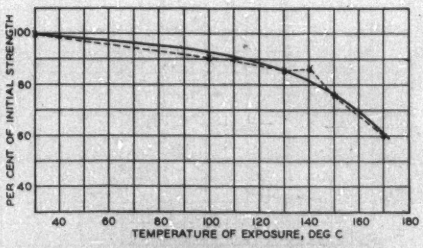


Fig. 6. "Average" change in mechanical properties of paper produced by high temperature treatment

Data of this figure are based upon the experimental results given in figure 5, each point being the average obtained for the deterioration as represented by the tensile, stretch, tear, and bursting strengths, each test being given equal weight in determining the average value

Behavior of Oil Treated Paper

In general the technical procedure used in the investigation of oil treated cellulose insulation duplicated that applied to the study of the insulation not oil treated. It may be observed that the results obtained bear strong resemblance, differing merely in degree. Thus figure 7 shows the changing paper acidity produced by thermal decomposition of oil-treated unbleached linen paper heated under conditions similar to those applying to the untreated paper, the acidity change in which is described in figure 2. The presence of oil merely affects the degree of change. In figure 7 chemical degradation of the cellulose is evident from temperatures higher than 100 degrees centigrade, as is true for the untreated paper of figure 2; but whereas untreated paper shows pronounced acidity change for the higher temperature, figure 7 shows a more slowly increasing acidity. This difference might well be expected, since the cellulose decomposition products are in part at least oil-soluble and are thus difficult to evaluate.

To illustrate the gassing of oil-immersed oil-treated cellulose is difficult because of volatilization of materials derived from the oil and the oil-solubility of the cellulose formed gases. The behavior is illustrated roughly in figure 8, resort being made to a gas bubble counter to express the rate of gas evolution under a pressure of 2 millimeters of mercury. The gases arising in the heated vacuum chamber containing the oil-treated oil-immersed cellulose, were led through cooling towers into the bubble counter. Under a steady vacuum the number of bubbles

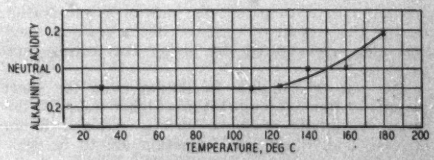


Fig. 7. Acidity change in oil immersed paper resulting from high temperature treatment

Heating period—48 hours under a pressure of 2 millimeters of mercury
Test sample—Tightly wound rolls as described for table I, vacuum oil-impregnated at 50 degrees centigrade
For acidity test, see footnote (*) under table I

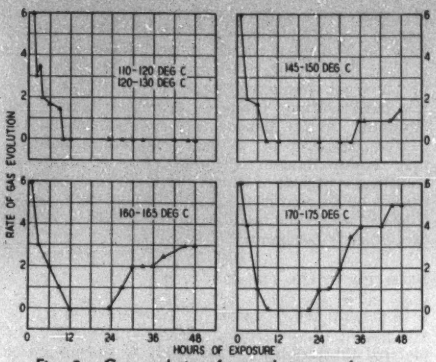


Fig. 8. Gas evolution from oil immersed paper produced as a result of thermal decomposition under vacuum

Test sample—Tightly wound rolls as described for table 1
Test conditions—Paper heated as shown under a pressure of 2 millimeters of mercury
Rate of gas evolution expressed as:
0. No gas evolved in bubble counter
1. Occasional bubbles noted in bubble counter
2. Approximately 1 bubble each 3 minutes in bubble counter
3. 3 to 5 bubbles each 3 minutes in bubble counter
4. 5 to 20 bubbles each 3 minutes in bubble counter
5. 20 to 40 bubbles each 3 minutes in bubble counter
6. More than 40 bubbles each 3 minutes in bubble counter

formed per minute from the 2 millimeter gas tube of the bubble counter was determined. A blank correction is applied for the expression of the behavior illustrated in figure 8. For temperatures up to 130 degrees centigrade, no gaseous decomposition of the cellulose was observed within the limits of the experiment. For higher temperatures, a second stage of gassing occurred, indicative of cellulose degradation. The duration of the quiescent period following the first rush of gas (air) is a function of the testing temperature, cellulose decomposition being evidenced by gas formation after an interval that is shorter, the higher the temperature applied. Thus at 145 degrees the second gassing stage began after 33 hours of heating, at 160 degrees after 23 hours, and at 170 degrees after 19 hours of heating. As might be anticipated, the rate of gas formation during the second or cellulose decomposition stage was more pronounced the higher the testing temperature.

The use of cellulose insulation even for short periods of time at temperatures higher than 130 degrees centigrade must be strictly avoided if increased acidity and gas formation are to be prevented.

Power Factor of Oil Treated Cellulose

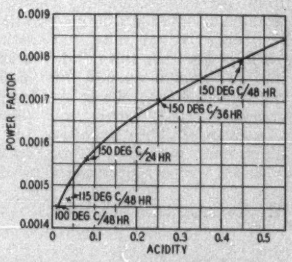
Thermally produced chemical changes resulting in increased acidity is accompanied by pronounced increases in power factor; this is shown in figure 9.

Unbleached linen paper was exposed for various periods at selected high temperatures under a pressure of 2 millimeters of mercury and later vacuum-oil-impregnated at 100 degrees centigrade. The effect of the thermal history is clearly evident in the power factor and acidity, which both increase with the severity of the previous exposure.

The service use of oil-treated cellulosic insulation must always be made with clear recognition of the power factor-temperature relation (figure 10). Increased temperature may produce a rapidly rising power factor for temperatures higher than 40 degrees centigrade. Such rapidly rising power factor promotes cumulative heating, which in turn may produce disastrous results because of the resulting thermal degradation of the cellulose itself. Cellulose insulation can be operated at temperatures higher than 50 degrees centigrade under conditions

Fig. 9. Effect of thermally produced chemical change on the power factor of oil treated paper

Power factor measured at 25 degrees centigrade, 1,000 cycles. For acidity test, see footnote (*) under table 1



Samples were heated as shown under pressure of 2 millimeters of mercury. Temperature then was lowered to 100 degrees centigrade and the samples oil-treated while still maintained under 2 millimeter pressure. After impregnation, the temperature was lowered to 25 degrees for power factor measurement at atmospheric pressure

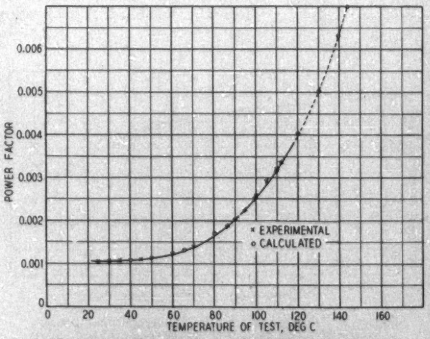


Fig. 10. Relation between power factor and temperature for paper vacuum-dried and oil-treated at 100 degrees centigrade

Calculated values are based upon the logarithmic relation between power factor and temperature of test. Power factor was measured at 1,000 cycles

that reduce to a minimum the possibility of "spot" thermal concentration.

Dielectric Strength of Oil Treated Cellulose

The short-time dielectric strength of oil treated cellulose insulation is recognized to involve a minimum of cumulative heating effects. The fact that increase in testing temperature, entirely aside from chemical degradation, may result in decreased breakdown strength in accordance with figure 11, as well as in increased power factor, serves to limit the maximum permissible temperature of electrical apparatus dependent on impregnated paper or like material for its successful operation.

Chemical change in oil treated cellulose produces decreased dielectric strength as well as disadvantageous effects arising from other mechanical or electrical causes. Figure 12 presents test results obtained on oil-treated unbleached linen paper dried and oil-impregnated under a vacuum of better than 2 millimeters at 100 degrees centigrade for 48 hours, a condition that has been shown to give little, if any, chemical or electrical deterioration. Subsequent to drying and oil-impregnation the dielectric pads were sealed under degassed oil in nonbreathing containers. The assemblies were heated at temperatures from 80 to 150 degrees centigrade for periods up to 170 hours, whereupon the minute-test dielectric strength at 25 degrees centigrade was determined without removal from the sealed container. The dielectric strength for the 80 degree aging test was not affected. For temperatures of 115 degrees or higher, the dielectric strength seriously was affected. At the end of about 100 hours, the breakdown strength of the insulation was only approximately 71 per cent of the initial value for the 115 degree treatment, 68 per cent for the 130 degree treatment, and 57 per cent for the 150 degree treatment.

"Life" Test Characteristics

It is difficult to interpret "life" test information concerning the behavior of insulation in terms of commercial practice. Because of time limitations, conditions necessarily must be exaggerated with respect to one or more factors. It is usual in work of this type to exaggerate the temperature of the test, the voltage applied, or both. Because of the evident danger from thermal decomposition of the cellulose at temperatures higher than 115 degrees centigrade, ambient temperatures of 25 and 95 to 100 degrees were chosen in the life test analysis of this investigation. Each life test was carried out in sealed containers to protect from atmospheric oxidation and the loss of thermally formed volatile products. Figures 13 and 14 illustrate typical results using unbleached linen paper of high purity as the cellulose insulation.

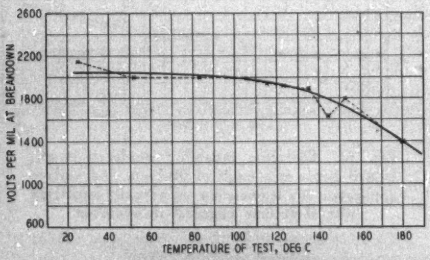


Fig. 11. Minute-test dielectric strength of paper vacuum-dried and oil-treated at 100 degrees centigrade, as a function of the testing temperature

Thickness of dielectric—0.004 inch

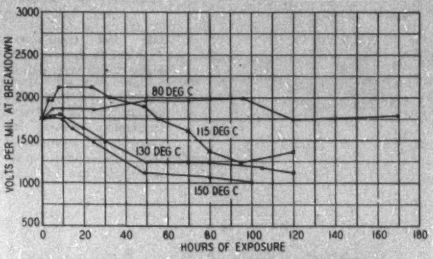


Fig. 12. Decrease in the minute-test dielectric strength at 25 degrees centigrade of vacuum-dried and oil-treated paper resulting from thermally produced chemical change

Thickness of dielectric tested—0.004 inch
Treatment of insulation—Vacuum dried at 100 degrees centigrade for 48 hours and mineral oil impregnated under vacuum; then aged at temperature shown while immersed in degassed oil in sealed containers

In figure 13, 0.0025 inch pads of unbleached oil-treated linen paper were used. Such pads normally have an average minute-test breakdown strength of approximately 2,600 volts per mil. A "life" test potential of 3,300 volts, 60 cycles, giving 1,280 volts per mil, was used to determine the long-time 25-degree dielectric stability of the insulation as a function of its previous thermal history. This electrical stress was chosen since experience had shown that a materially lower potential gradient normally would not produce dielectric failure of the insulation within the period of 100 days assigned for the test interval. At 1,280 volts per mil, previous experience had shown that at least 50 per cent of the samples would fail even when treated in accordance with the best procedure. A comparison of curve A with curve B of figure 13 shows the effect of the chemical degradation of cellulose insulation in affecting its long time dielectric strength. Curve A is based upon insulation heated at 115 degrees centigrade under vacuum for 3 days. Curve B is based upon similar insulation heated at 135 degrees under vacuum for 3 days. Subsequently to such treatment, both types of insulation were vacuum oil-treated at 100 degrees.

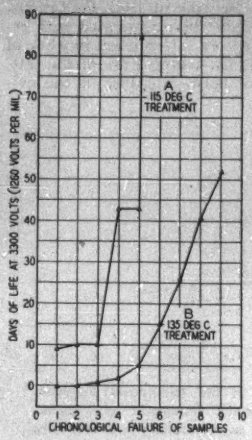


Fig. 13. Effect of thermal treatment on the 60-cycle "life" test dielectric strength of oil-treated paper

Thickness of dielectric pad—0.0025 inch

Life test conditions—Ambient 25 degrees centigrade 1,280 volts per mil

Insulation was dried under vacuum for 72 hours at temperature shown, followed by oil impregnation while still under vacuum at 100 degrees centigrade

The characteristics of the paper after the vacuum temperature treatment were:

	Curve A	Curve B
Paper acidity (See footnote* under table 1)	+0.05	+0.19
Power factor (25 degrees centigrade —1,000 cycles)	0.0015	0.0020

The breakdown values of figure 13 are plotted chronologically. The insulation of curve *A* showed only 5 breakdowns out of 9 samples on test. The insulation of curve *B* showed 9 breakdowns out of 9 samples on test. Considering only the first 5 samples of each group, the average breakdown period of Curve *A* is 23 days; that for curve *B* only 1.6 days. In curve *B* a zero value for time to breakdown indicates failure within 1 hour on test. The chemical degradation of the cellulose insulation exhibited in an increasing power factor and acidity is therefore not without marked effect on the long-time dielectric strength of the insulation.

Even without visible chemical or short time electrical affect, the application of high temperature to oil-treated cellulose insulation may cause slow deterioration of a cumulative type capable of producing diastrous results. Thus it has been shown that short time applications of temperature lower than 110 degrees centigrade normally do not produce chemical change as determined by the acidity or electrical change as evidenced by the dielectric strength or initial power factor. Figure 14, however, clearly shows that temperatures as low as 95 to 100 degrees may produce electrical deterioration if coupled with simultaneously applied high potential stress. In figure 14 the insulation consists of unbleached linen paper of high purity similar to that used throughout this investigation. The paper was vacuum-dried for 48 hours at 100 degrees centigrade and oil-impregnated. The arrangement of the insulation was in the form of small, flat pads. Two groups were prepared, one containing 0.008 inch pads of dielectric and the other group 0.004 inch pads. Following the drying and oil impregnation, the dielectric assemblies were placed on test at 95 to 100 degrees centigrade under a potential of 3,250 volts, 60 cycles in sealed containers to protect from atmospheric oxidation and the loss of thermally formed volatile products. The slowly increasing power factor of the 0.008 inch samples operating at 425 volts per mil, indicative of chemical and electrical deterioration, is accelerated by the higher voltage stress (850 volts per mil) of the 0.004 inch insulation. The data of figure 14 represent typical group behavior, each testing group consisting of 6 individual samples. No electrical failures occurred during the duration of tests covered by investigation of this type.

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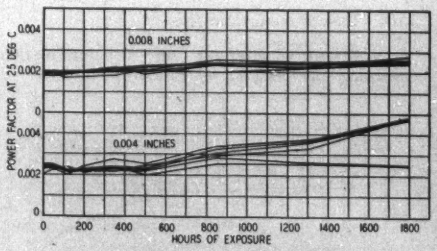

Fig. 14. Dielectric instability produced in oil-treated paper as a result of 60-cycle high-voltage application at a temperature not normally associated with short time chemical deterioration

Life test conditions—95 to 100 degrees centigrade in sealed containers, 3,250 volts applied

Treatment of insulation—Vacuum dried at 100 degrees centigrade for 48 hours, followed by oil impregnation while still under vacuum and temperature

Power factor was measured at 25 degrees centigrade, 1,000 cycles

A Cathode Ray Oscillograph for Observing 2 Waves

A general purpose cathode ray oscillograph is described in this paper which embodies a cathode ray tube of high beam efficiency, a description of which has not hitherto been published. This tube makes it possible to use a high frequency oscillator for supplying both the beam and sweep voltages. An electronic switching circuit is described which greatly extends the usefulness of the cathode ray oscillograph by making it possible to portray simultaneously 2 or more different waves in their proper phase relation, provided both waves have frequencies which are in a simple multiple relationship to each other.

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As a result of the development of a glass type cathode ray tube[1] and a system of cathode ray television reception at Purdue University, a number of new tubes and auxiliary circuits were made available which have proved very useful in the development of cathode ray oscillograph equipment. The field of application of the cathode ray oscillograph has also been greatly extended by the development of a stable electronic switching circuit for the simultaneous observation of 2 different wave forms.[2]

Five portable oscillographs have been constructed, 4 of which were developed for special industrial applications, and 1 for lecture room demonstration and general laboratory use at the university. The special oscillographs, however, are not described in the present paper, which is concerned principally with the description of the cathode ray tube, the high voltage power supply, and the electronic switching circuit as embodied in the general purpose oscillograph.

General Description of Oscillograph

The general purpose oscillograph, figure 1, is built as a self-contained unit for operation from a 110-volt 60-cycle power source. The complete schematic wiring diagram is represented by figure 2. On the left of the diagram, the parts, in order from top to bottom are: power and filament transformers, low voltage d-c power supply, synchronizing and sweep circuits, combination amplifier and timing oscillator, and full-wave high-frequency rectifier for modulation measurements. On the right of the diagram in the same order are: the sweep voltage and high voltage d-c power supply, the cathode ray tube, and the electronic switching circuit.

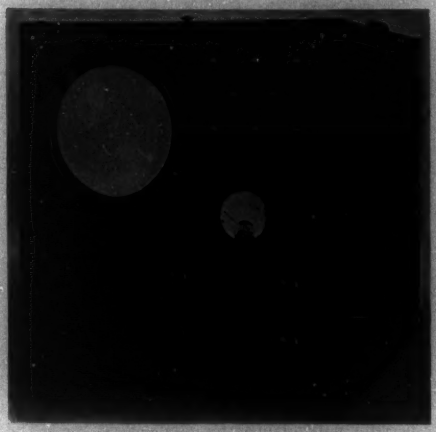

Fig. 1. Front view of the cathode ray oscillograph for observing 2 waves simultaneously

The cabinet consists of a welded "dow-metal" supporting frame with removable sheet metal panels, which permit access to all parts, but provide complete electrostatic shielding. The equipment is mounted in double deck arrangement. In order to minimize 60 cycle disturbances all power supplies are located on the lower deck and provided with special shielding where necessary. The cathode ray tube is mounted in a magnetic shield supported from the top of the frame. The auxiliary circuits are mounted on the upper deck as illustrated in figure 3. The finished cabinet is 17 inches high, 16 inches wide and 20 inches deep and the complete oscillograph has a total weight of 72 pounds.

A paper recommended for publication by the A.I.E.E. committee on instruments and measurements, and scheduled for discussion at the A.I.E.E. Great Lakes District meeting, West Lafayette, Ind., Oct. 24–25, 1935. Manuscript submitted Aug. 8, 1935; released for publication Sept. 9, 1935.

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* Now with General Electric Company, Schenectady, N. Y.

1. For all numbered references, see list at end of paper.

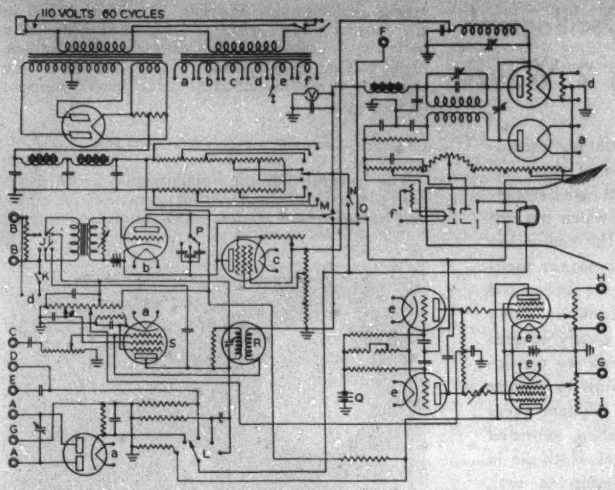


Fig. 2. Schematic wiring diagram of oscillograph

The Cathode Ray Tube

The method of focusing an electron stream developed several years ago[3] has been modified and adapted for use in glass cathode ray tubes developed for television purposes. Because of their ability to produce a sharply defined beam over a wide range of operating voltages, these tubes have proved to be especially well adapted for oscillograph use. The general arrangement of the electron gun is shown schematically in figure 4. Referring to this figure, the electrons are emitted from a small area on the end of the cathode. The shield which surrounds the cathode brings the beam to a short focus near the plane of the aperture and also controls the beam current. Focusing is accomplished by varying the potential on the first anode with respect to the cathode and second anode. The beam reaches its maximum velocity as it emerges from the second anode, which is usually operated at ground potential.

The cathode consists of a piece of No. 22 platinum-nickel alloy wire which has a 0.01 to 0.015 inch hole drilled or pressed in the end, and this hole packed with barium and strontium oxides. The emitting surface is therefore limited to a relatively small area. The tungsten heater wire is wound in the form of a double spiral to make it noninductive and to permit the cathode to be spot welded to the mid-point. Since the cathode is heated by conduction, the heater filament operates at a relatively low temperature. Platinum-nickel cathodes have been used because of the very high temperature required to melt them loose from the heater filament. The filament current can be increased to about double the normal operating value without melting off the cathode. The ends of the double spiral heater filaments are held in place by means of a short section of ceramic tubing. A connection is made directly with the cathode and the lead brought out through the center of the spiral heater and insulating cylinder. The cathode is held in the center of the shield by means of a mica spacer.

The cathode shield serves the double purpose of shielding the cathode and acting as the control electrode for modulating the beam. The stem end of the shield is left open as the heater filament operates at a temperature too low for electron emission.

The first anode is made in the form of a cylinder with a plate across the end facing the cathode. The hole in the plate is approximately 0.04 inch in diameter, which is sufficient to permit the entire beam to pass through it when properly focused. The cylindrical section of the first anode is made sufficiently long to allow the beam to gain the necessary diameter before entering the intense portion of the accelerating and focusing field near the second anode. Usually 90 per cent or more of the total accelerating voltage appears between the first and second anodes.

In the glass type cathode ray tube the second anode is made stationary and in the form of a flat disk. The hole in the second anode should be slightly larger than the diameter of the beam at this

Table I—Average Characteristics of Cathode Ray Tubes

	Minimum	Maximum
Diameter of tube, inches	7	
Length of tube, inches	18 1/2	
Cathode voltage to ground	−250	−5000
Cathode shield voltage with respect to cathode	+ 10	− 60
First anode voltage with respect to cathode	+ 25	+ 500
Second anode voltage with respect to cathode	+250	+5000
Filament current in amperes, average	2.7	
Beam current in microamperes	0 to 250	

point. The beam is focused by the converging electric field between the first and second anodes. As previously mentioned, the beam is brought to a focus at the screen by varying the potential on the first anode with respect to the cathode and second anodes.

When the electron gun is operating properly, from 70 to 90 per cent of the electrons leaving the cathode space charge reach the screen in the form of beam current. Consequently, the energy required to operate the electron gun is so small that it can be supplied from a small high frequency oscillator.

The coating on the inside of the glass envelope provides a return path for the electrons and eliminates instability when the tube is operated as a television receiver. The sharpness of the beam is improved by impressing a negative potential of 20 to 50 volts on the conducting coating.

The fluorescent screen material is sprayed on the inner surface of the tube before the conducting coating is applied. For visual observation the screen material is usually synthetic willemite which produces a yellow-green light, but for photographic reproduction and television reception a screen material which produces a light closely approaching white is used. This screen material was developed for reproducing television pictures in black and white.

Tubes are provided with 2 pairs of deflecting plates, with one plate of each pair connected to the second anode and grounded. In order to eliminate keystone distortion (the distortion of a rectangular figure into the shape of a keystone) due to an uncompensated change in velocity of the beam as it passes through the fringing field from the ends of the deflecting plates and to divergence of this field, the plates are provided with grounded guard plates, as shown in figures 4 and 5. The guard plates prevent the fringing flux from becoming divergent, and also practically eliminate changes in beam velocity by limiting the extent of the fringing flux and providing a compensating component.

In some of the tubes a ground plate is mounted just beyond the deflecting plates for the purpose of minimizing the electron current which may tend to drift back to the deflecting plates.

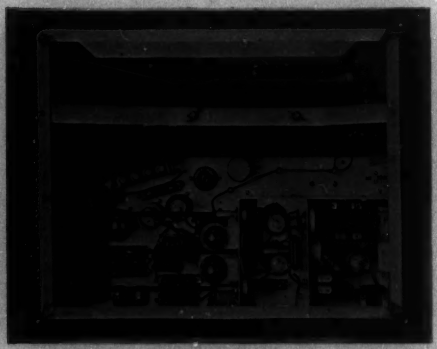


Fig. 3. Top view of oscillograph with cover removed

The electron beam focuses to a sharply defined spot of 0.1 to 1 millimeter diameter over range of voltages from 250 to 3,000 volts, and with only a slight increase in size up to 5,000 volts. Although in the past it has been necessary to use 0.5 to 1.5 microns of argon gas in the tubes to obtain a sharply defined beam over this wide range of beam voltage, recent calculations indicate that a sharp focus may be obtained in a hard vacuum by some changes in the dimensions of the electron gun. Further development is being directed along this line.

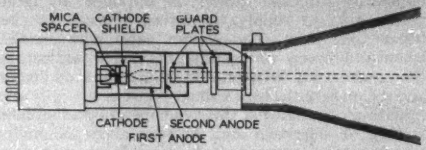


Fig. 4. Schematic diagram of electron gun

Despite the facts that the tubes contain a small amount of argon, and that no effort has been made to prevent positive ion bombardment of the cathode, the life of the tubes usually runs well over 1,000 hours. Moreover, tubes which have lost their emission can be repaired by repacking the oxides in the cathode and re-exhausting. Since the holes in the anodes are larger than the diameter of the cathode the oxides can be replaced without dismounting the gun parts.

The average characteristics of the cathode ray tubes are shown in table I.

The filament current is supplied from a 2.5 volt transformer winding and adjusted by means of a high current rheostat. Although the voltage across the filament at normal current is approximately 0.5 volt the filament cannot be damaged by the full 2.5 volts.

The High Voltage D-C Power Supply

As a result of the high beam efficiency of the cathode ray tube it has been possible to use a high frequency oscillator and rectifier to supply both the beam and sweep voltage for the cathode ray tube. The circuit developed for this purpose is shown in the upper right hand corner of figure 2. This circuit was originally designed for use in television receivers where safety is an important factor, and where plate voltage for the oscillator is available from the amplifier plate supply.

The high frequency power is supplied from a special tuned-grid tuned-plate oscillator, the plate coil of which forms the primary of a high frequency step-up transformer. Current from the secondary of this transformer is rectified by means of a half-wave high voltage rectifier to supply the beam voltage. In order to obtain maximum high voltage output, the oscillator is tuned to the natural frequency of

the rectifier circuit, which is usually about 100,000 cycles. The tuning of the oscillator circuits is accomplished by means of mica trimmer capacitors which are not disturbed after the correct adjustment is found. At a frequency of 100,000 cycles good filtering is obtained with 2 0.002-microfarad mica capacitors and a 100,000 ohm resistor. The use of such small capacitors in the filter circuit greatly reduces the danger from serious shock by accidental contact with the high potential circuit and eliminates the necessity for a discharging switch.

By the use of high excitation on the grid of the oscillator, sufficient power is obtained by grid rectification to supply the sweep voltage for the linear time axis. The correct ratio between the beam and sweep voltages is obtained by adjusting the capacitance between the grid of the oscillator and the plate of the high voltage rectifier.

With an oscillator of this type operating at a plate voltage of 400 volts and drawing about 35 milliamperes plate current, it is possible to supply a beam voltage of 4,500 volts and a sweep voltage of 500 volts. However in the case of the oscillograph being described, the oscillator is so adjusted that beam voltages of 500 to 3,500 volts can be obtained in 500 volt steps by varying the plate voltage of the oscillator by means of a tap switch.

The deflection sensitivity can be checked readily by closing a push-button switch on the front of the panel, which applies the plate voltage of the oscillator to one pair of deflecting plates, and reading the plate voltage on the panel voltmeter. This is necessary when making accurate voltage measurements with the oscillograph since the regulation of

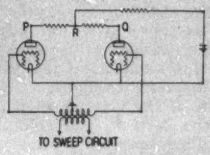
Fig. 5. View of section of cathode ray tube showing the guards on the deflecting plates

the high frequency power supply permits some change in beam voltage with change in beam current.

The high frequency power supply has proved itself to be quite flexible and well adapted to most applications.

An Electronic Switching Circuit for the Simultaneous Observation of 2 Waves

The application of the cathode ray oscillograph has been greatly restricted, in the past, because of its inability to portray more than a single phenomenon at a time. Since it is often desirable, or even essential, to show 2 or more waves simultaneously in their correct relative phase positions, this limitation has proved to be a serious handicap in the general usefulness of this type of oscillograph. One possible



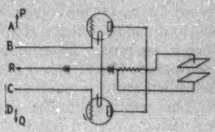


Fig. 6 (left). Schematic diagram of a circuit that might be used as the basis for an oscillograph for simultaneous observation of 2 waves

Fig. 7 (right). Schematic diagram of an auxiliary circuit for use with figure 6

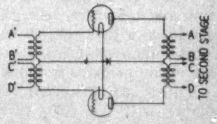


Fig. 8. General arrangement of first stages of amplifiers used with circuit finally adopted

solution is to devise a single tube with a multiplicity of beams, corresponding to the multi-element vibrator type of oscillograph. Since it is recognized that such a plan would greatly complicate the manufacture and functioning of the tube, a much more feasible scheme would be to utilize a single beam. This could be accomplished by impressing the different signal voltages across the deflecting elements of the tube in succession, one during each sweep. In this manner, due to the persistence of vision and provided that the frequency of the cycles of operation were not too low, 2 or more waves whose frequencies are in a simple relation could be caused to appear simultaneously in their correct relative phase positions on the screen.

Such a method has been devised to show 2 waves, the switching being accomplished by means of a rotary switch[4] operated by a synchronous motor that was driven from the same power supply as the observed phenomena. Although this arrangement has proved to be quite practical as far as power applications are concerned, it cannot be synchronized when either the frequency is too high or the power supply too limited to permit the use of a synchronous motor. It is likewise obvious that any system of electromechanical relays would suffer similar limitations. The latter could be removed, however, by means of an electron tube relay system that was actuated by the sweep circuit. It is the purpose of this portion of the article briefly to discuss the development of such a device.

A circuit that might be used as the basis in the development for an oscillograph for the simultaneous observation of 2 waves is shown schemati-

cally in figure 6, the tubes being small grid-controlled rectifiers. Since this is similar in construction and theory of operation to the simple 2 tube inverter,[6,8] its action will not be discussed in detail at this time.

In connection with the actual application of this circuit to the particular project being undertaken,

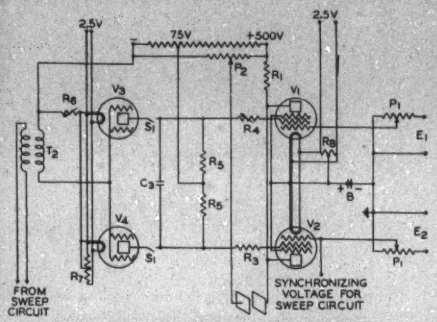


Fig. 9. Diagrams showing use of pentodes in control circuit

it was first proposed that the tubes themselves might be caused to function as switches. Because of the necessarily high impedance of the deflecting plate circuit, however, no simple arrangement of this sort that would be applicable over a wide range of frequencies could be devised. Accordingly, instead of permitting the tubes to function directly as switches, it was then proposed that they might be utilized to control the bias on a pair of amplifier tubes, the grids being connected to the 2 signals and the plates being tied together and feeding into the deflecting circuit of the cathode ray tube. The schematic diagram for this arrangement is shown in figure 7. In this, points P, Q, and R would be connected to the correspondingly lettered points in figure 6, the large differences of potential that occur alternately across the resistors permitting first one amplifier to pass a signal and then the other.

In the actual working out of a circuit to give the desired result when triode amplifiers were used, it was found necessary to introduce 2-stage rather than single-stage amplifiers. This was for the purpose of simplifying the plate supply problem as well as because of the necessity of isolating the switching circuit from the signal circuits; the additional stages being inserted to act as buffers rather than for the purpose of introducing additional amplification. The general arrangement of the first stages is shown in figure 8, the 2 signals now being impressed across $A'B'$ and $C'D'$, respectively.

The first electronic switching circuit built into an oscillograph made use of the 2-stage amplifier. Although it operated in a very satisfactory manner in most cases, the amplifier was the weak point, as it would obviously neither pass the average component of a pulsating wave nor faithfully reproduce a flat-topped alternating wave. One possible solution considered in this regard was to develop an appropriate direct-coupled amplifier. It was instinctively felt, however, that such an amplifier would be prohibitively complicated in that it would require several separate plate voltage supplies. No attempt was accordingly made to carry out such a project but another method was developed.

It has already been mentioned that the 2-stage amplifiers were made necessary because of both the blocking and signal voltages being applied to the same grids. With this inherent disadvantage in mind, it was proposed that single-stage, direct coupled, screen-grid tube amplifiers might be used. In this, the signal voltages would be impressed across the control grids as before but the blocking would be done on the screen grids. In the actual carrying out of this proposal, pentodes were used as shown in figure 9, the power supply, sweep circuit, etc., being essentially the same as used in the earlier set-up.

The performance of the multiwave oscillograph in this final form proved to be quite satisfactory. The stability of the switching circuit has been materially improved in the later model. This was done by introducing the synchronizing impulse into the switching circuit by means of capacitive rather than inductive coupling. It is expected that it might be

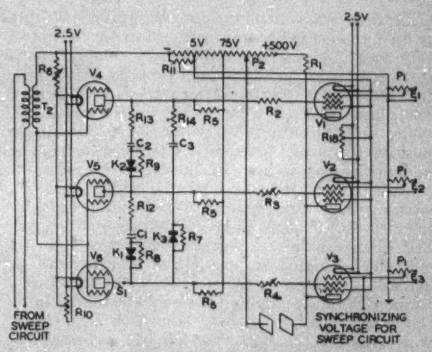


Fig. 10. A possible circuit for an oscillograph for observing 3 waves simultaneously

otherwise improved, or even simplified in certain respects. In this regard, the following topics are in mind for investigation:

1. Substitution in place of 2 tube inverter circuit of:
   (a) Single-tube inverter circuit; or
   (b) Vacuum tube oscillator of an appropriate type.
2. Modification of switching circuit in such a manner that waves whose frequencies were not necessarily in simple multiple relationship could be stabilized.
3. Construction of a circuit for showing more than 2 waves.

So far as item 3 is concerned, a possible circuit for showing 3 waves is given in figure 10 and the same

idea could be extended to the case of an unlimited number of waves. It should be recognized, however, as soon as the frequency of the complete cycle of operation drops below 20 cycles per second that there would be a noticeable flicker.

The electronic switching circuit as embodied in the general purpose oscilloscope is illustrated in the lower right hand corner of figure 2. It may be noted that the switches in the plate leads of the inverter tubes have been eliminated in this circuit as it was found that the inverter would start of its own accord if the cathode resistor was properly adjusted. The battery Q is used for the purpose of compensating for the drop in potential in the inverter tubes, thus causing the inverter to reduce the potential on the screen grids of the amplifier to zero or even to a negative value. This prevents the blocked tube from passing current when the maximum normal signal is impressed on the control grid.

The use of capacitive coupling between the sweep and inverter circuits has proved very satisfactory for tripping the inverter. With this arrangement the inverter has been made to operate satisfactorily when the sweep circuit was being discharged as many as 14,000 times per second, thus permitting observation of phase relation between 2 waves at frequencies as high as 70,000 cycles per second.

Other Auxiliary Circuits

In the sweep circuit, figure 2, a type 57 tube is used to charge the sweep capacitor at a constant rate, and a special gaseous discharge tube is used to discharge it. The discharge tube has a control factor of 100 or more and is capable of withstanding the entire sweep voltage which may exceed 800 volts. By throwing the switch M to the upper position the sweep voltage can be almost doubled by adding the plate voltage of the oscillator to that obtained by grid rectification. In either case the sweep voltage varies with the beam voltage in such a manner that changes in beam voltage produce very little change in the rate of sweep. By throwing switch J to the left the sweep can be synchronized with an external signal applied across BB; or by throwing it to the right and applying the signal between C and G the signal is amplified first. If switch K is closed, with switch J thrown to the left, the sweep can be synchronized with the 60 cycle power supply.

When the coils R are plugged in, the tube S acts as a fixed frequency oscillator for use in calibrating the time axis, but when the coils are out it acts as a resistance coupled amplifier.

If a suitable loop antenna is connected to the terminals AGA, strong radio frequency signals can be rectified for modulation measurements, and for checking distortion in the modulating waves.

Lissajou's figures can be studied by impressing the waves between CG and FG with switch O in the upper position.

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The Production of Impulse Test Voltages

In performing surge tests on electrical power apparatus to determine ability to withstanding lightning or switching surges, the shape of the impulse voltage wave should be approximately the same as 1 of the 3 test wave shapes commonly in use. Methods of producing a wave shape having the prescribed time constants are described in this paper, and oscillograms are presented which show the correctness of calculated design characteristics of the generator for producing these surges.

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MUCH of the equipment used on modern electric power systems is tested by being subjected to artificially produced surge voltage waves which simulate the lightning or switching surges which may occur on the system. With the rapid development of surge testing equipment and technique during the last decade, has come an increasing tendency toward standardization of testing methods and procedure. The various factors which affect the wave shape and the accuracy with which the wave may be measured and recorded have been investigated and reported in previous papers.[1-4] Mathematical and experimental determinations of the wave shape with calculated or measured generator con-

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1. For all numbered references, see list at end of paper.

Table I—Values of "a" and "b" for the Proposed Waves in the Equations RC = a, seconds; LC = b, seconds squared

Wave Shape	a	b
$1^1/_2 \times 40$	55.35×10^{-6}	15.54×10^{-12}
1×10	12.90×10^{-6}	3.180×10^{-12}
1×5	5.595×10^{-6}	1.800×10^{-12}

stants have been made under various conditions of load and generator circuit,[5-7] the characteristics of resistance and capacitance potentiometers have been studied, and material progress has been made toward standard calibrations for sphere gaps for measuring voltages under impulse conditions.[8-13] Naturally, many of the factors which influence the methods and technique of impulse testing depend upon local laboratory conditions and cannot be subject to definite specifications; nevertheless, certain general rules of established procedure have been noted.[8,14]

One of the most important steps of the standardization process was the recommendation of the 3 impulse wave shapes,[14] designated as the $1^1/_2 \times 40$, the 1×10, and the 1×5 microsecond waves; the first figure in each of these 3 designations indicates the time in microseconds for the wave to increase from zero voltage to crest voltage and the second figure indicates the time from zero voltage to one-half crest voltage on the tail of the wave. The time constants of these impulses were the result of a careful study, not only of the impulse voltages produced by lightning, but also of the facility with which they could be reproduced in the various laboratories throughout the country.

Recently the engineering experiment station at Purdue University has devoted a portion of its time to the determination of the constants of the impulse generator for producing impulses of the prescribed time constants. The present paper shows the degree to which the actual waves, as recorded by the cathode ray oscillograph, check the calculated values. Traveling wave effects and reflections which always exist in surge generator circuits are shown in their relation to the several constants of the surge generator.

Conclusions

1. With a suddenly applied electromotive force, a series circuit of resistance, inductance, and capacitance is inherently subject to reflections and traveling wave phenomena, due to the finite lengths of the circuit and the finite velocity of propagation of energy through the circuit. In proportion to the main response characteristic of the circuit the relative importance of these reflections depends upon the lengths of wire in the circuit and upon the circuit constants, including the load, if the latter is appreciable. The effect of the reflections upon the main response characteristic is minimized with short wire lengths and low discharge resistances and high load capacitances.

2. In the surge generator the obvious and direct method of minimizing the effect of reflections is to use a large value of capacitance, which, for a given wave shape, reduces the necessary values of inductance and resistance. Unfortunately for the economic aspects of the case this entails a rather large investment in the condenser units. Theoretically, the connection of an appreciable load capacitance in parallel with the load resistance should diminish the effect of reflections, providing sufficient series resistance is incorporated in the generator gap circuits to prevent oscillation of the generator circuit inductance and the load capacitance. The load capacitance might be provided by a capacitance potentiometer or by the test piece itself. The desirability of using some such arrangement as the above will of course depend upon the conditions and the type of testing in a particular laboratory.

3. The wave shapes calculated from equations for the simple series circuit of capacitance, resistance, and inductance check closely the actual wave shapes, under the following conditions:

(*a*). The load resistance (including sphere gaps and test piece, if any) is essentially noninductive and has negligible capacitance for the wave shape under consideration.

(*b*). Reflections are sufficiently minimized by the use of low values of inductance and resistance.

(*c*). The load resistance is slightly increased to compensate for the decrease in the effective capacitance due to the phenomena of residual charge and the slight loss of energy in the resistors of the charging circuit.

4. From the standpoint of the length of wire and the flashover characteristics under transient conditions, the most efficient inductances are those having an axial length approximately equal to their diameter (single layer, helically wound coils with uniform turn spacing).

Description of Apparatus

The condenser bank of the surge generator consisted of 48 25-kv $^1/_4$-microfarad units, mounted in such a manner that adjacent banks might be readily connected in parallel, providing several values of potential and capacitance.

The series inductance was provided by a coil wound upon an octagonal form 2 or 3 feet in diameter. Turn spacings of from $^1/_2$ inch to 2 inches were available depending upon the number of turns and the surge potential.

The load resistance and the dividing resistance were provided by a water column resistor contained in several parallel lengths of rubber hose. With this arrangement a wide range of resistance values could be obtained by varying the conductivity of the water solution, and, if necessary, the number of lengths of hose in parallel. Taps were provided along the hose for a rough adjustment of the test voltage, with fine control obtained by varying the charging voltage of the surge generator. With the load and divider resistance each having one end grounded, a large volume of the water solution could be readily circulated through the hose, eliminating any appreciable change in resistance due to heating. A resistance-cable divider was used in obtaining all the oscillograms reproduced in this paper. The cable was terminated, at the cathode ray oscillograph, in a resistance equal to its surge impedance.

The cathode ray oscillograph was of the George hot-cathode type, having a beam potential of about 15 kv and employing automatic vacuum tube circuits for initiating and synchronizing the sweep and the cathode beam.

Calculation of Constants

The values of resistance and inductance necessary to produce the desired wave shapes were calculated for the several values of capacitance afforded by the surge generator. These calculations were made from the equations developed for the simple series circuit, assuming lumped constants and negligible load on

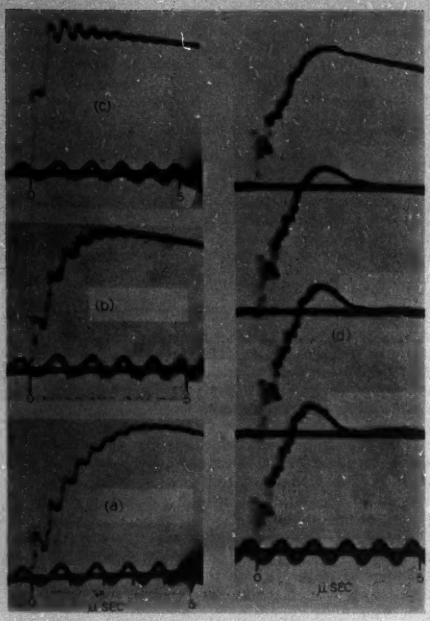

Fig. 1. Showing reflections across load resistance in surge generator circuit. Time in microseconds

(*a*). $C = 0.096 \times 10^{-6}$ farads, $L = 0.18 \times 10^{-3}$ henrys, $R = 175$ ohms
(*b*). $C = 0.096 \times 10^{-6}$ farads, $L = 0.18 \times 10^{-3}$ henrys, $R = 353$ ohms
(*c*). $C = 0.096 \times 10^{-6}$ farads, $L = 0.18 \times 10^{-3}$ henrys, $R = 860$ ohms
(*d*). $C = 0.00614 \times 10^{-6}$ farads, $L = 2.53 \times 10^{-3}$ henrys, $R = 4{,}090$, 5,700, 7,700, and 9,800 ohms, respectively, reading from top down

the surge generator. It was realized, of course, that with certain types of testing the capacitance or reactance of the equipment under test might not be negligible, and that further adjustments would be necessary to provide the prescribed wave shape with the test piece connected. However, one of the objects of this work was to determine to what degree the surge generator approximated the simple series circuit, hence the calculations were made as stated.

For a particular wave shape and capacitance the values of resistance and inductance were calculated with a good degree of accuracy, then for this same wave shape, but for other values of capacitance, the values of resistance and inductance were determined by the relations, $RC = a$ and $LC = b$. (See appendix.) Table I presents the values of the constants a and b for each of the 3 wave shapes, and table II gives the calculated values of inductance and resistance for several available values of capacitance.

Design of Inductance Coils

Both experience and theoretical considerations lead to the conclusion that traveling waves and reflections must exist in the surge generator circuit. In particular, reflections occur across the load resistance. These reflections may be positive or negative depending upon the value of the resistance and the constants of the inductance coil.

With fair analogy, the inductance coil and the discharge resistance may be considered as similar to a transmission line grounded through a resistance and having potential suddenly applied at the open end. According to the usual relations governing the reflection of traveling waves, the voltage across the resistance at the first reflection will depend upon the value of the resistance in relation to the surge impedance of the line, being greater than the voltage of the approaching wave if the resistance is greater than the surge impedance of the line (positive reflection), and less than the wave voltage when the resistance is less than the surge impedance of the line (negative reflection). With positive reflection, the successive reflections at the resistance produce voltages alternately greater and less than the wave voltage. In actual practice the losses which are always present give the appearance of a damped oscillation riding upon the main wave. This type of wave is sometimes called an "overshooting" wave. With negative reflections the voltage across the resistance increases at each reflection by successive increments and approaches the wave voltage, causing the wave front to have the familiar "stair-step" appearance, characteristic of negative reflections. Reflections of both types have been encountered in surge generator work, even though the circuit lengths are relatively short compared to those of a transmission line.

Figure 1 shows several oscillograms illustrating positive and negative reflections and the effect upon the reflections of varying the load resistance. It is obvious that the surge travels through the inductance and reflects across the load resistance in a manner analogous to surges upon a transmission line. If the load resistance can be made low, and if the inductance coil contains only a short length of wire it is apparent that the wave front will be built up by a series of negative reflections of low amplitude and short period. Under these conditions the characteristic stair steps are usually rounded off quite rapidly and a relatively smooth wave results. On the other hand, with a greater length of wire in the inductance the period of the reflections will be greater and the individual reflections will be more pronounced. Similarly, with a fixed inductance, the period of the reflections is constant while the amplitude varies with the value of load resistance as shown in figure 1, parts *a*, *b*, and *c*. With the higher values of resistance positive reflections occur as shown by figure 1*d*.

It is obvious from the foregoing discussion that the necessary inductance should be obtained with a minimum length of wire. Primarily, the axial length of the coil and the spacing between turns must be sufficient to prevent the impulse voltage from flash-

ing over the inductance. If, say, the spacing between turns is assumed, the axial length and the coil diameter may be varied to determine the proportions which give the required inductance in a minimum length of wire If the resulting coil will not withstand the impulse voltage, a greater spacing between turns must be assumed, and the optimum proportions determined as before.

Using Nagaoka's formula,[15] inductance values were calculated for turn spacings varying from $^1/_2$ inch to 2 inches, and for coil diameters varying from 2 feet to 10 feet. For each given turn spacing the curves of inductance versus number of turns were plotted for the several diameters.

For any of the above spacings, it was possible to determine, for each diameter, the number of turns necessary to produce any assigned inductance within the range covered. From the diameters and the corresponding numbers of turns, the necessary lengths of wire were determined readily. The necessary lengths of wire were plotted against the corresponding coil diameters; the diameter providing the minimum length of wire could then be determined easily. The axial length of the coil was found from the turn spacing originally assumed and the number of turns corresponding to the optimum diameter.

Several curves of this nature were prepared for different values of inductance and for different turn spacings. A study of these curves provided the following general conclusions.

1. For any turn spacing the diameter which provides a given value of inductance with a minimum length of wire is such that the ratio of axial coil length to diameter is approximately 0.4.

2. For any turn spacing and given value of inductance the ratio of axial coil length to diameter may vary from about 0.2 to about 1.1 with an increase in the length of wire of about 10 per cent over the minimum length.

From conclusion 2 it is obvious that the axial length of the coil may be equal to the coil diameter

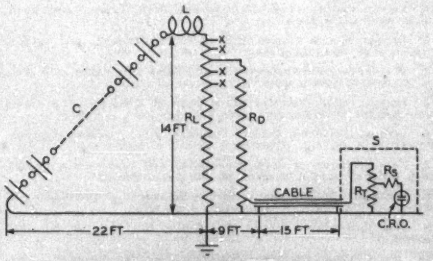

Fig. 2. Surge generator circuit diagram

C = effective capacitance (0.0056 to 0.23 microfarad)
L = added series inductance (0 to 3,000 microhenrys)
R_L = effective load resistance (100 to 10,000 ohms, including R_D)
R_D = divider resistance (1,000 to 15,000 ohms)
R_T = cable terminating resistance (50 ohms)
R_S = series damping resistance (2,000 ohms)
= shielding cage for cathode ray oscillograph
X = taps for coarse adjustment of test voltage

Table II—Calculated Values of Resistance and Inductance to Produce Standard Test Impulses With Different Values of Capacitance*

Wave Shape	Maximum Released Voltage Kv	Capacitance Microfarads	Resistance Ohms	Inductance Millihenrys
1 1/2 x 40	1,075	0.00613	9030	2.54
1 1/2 x 40	575	0.0230	2420	0.678
1 1/2 x 40	375	0.0528	1050	0.295
1 1/2 x 40	275	0.096	577	0.162
1 x 10	1,075	0.00613	2105	0.518
1 x 10	575	0.0230	562	0.139
1 x 10	375	0.0528	244	0.060
1 x 10	275	0.096	134	0.0331
1 x 5	1,075	0.00613	912	0.294
1 x 5	575	0.0230	244	0.079
1 x 5	375	0.0528	106	0.0341
1 x 5	275	0.096	58	0.0188

* Calculated from equations for simple series circuit of resistance, inductance, and capacitance.

without serious increase in the length of wire. It is hardly necessary to remark that the longer coils would be more desirable from the standpoint of preventing flashover.

The inductances were wound with iron wire as the damping effect of the distributed resistance was found to be of some benefit in providing smoother wave fronts.

Oscillograms of Actual Waves

For the several values of surge generator capacitance, the values of inductance and resistance were adjusted as closely as possible to the calculated values for the particular wave shape as given in table II. Figure 2 provides the circuit diagram together with the range of values of the circuit constants and with dimensions to indicate circuit lengths. As stated before, all waves were recorded using a resistance cable divider to provide the proper voltage for the deflecting plates. With the short length of cable (15 feet) and with divider resistances not over 15,000 ohms, there was no perceptible distortion of the wave shapes.

Oscillograms were obtained of the impulse voltages produced with the circuit constants adjusted to the calculated values. In general, the values of time to reach the crest were closely equal to those of the standard impulses but the time at which the voltage decreased to 50 per cent of crest value was less than the prescribed time. Two probable causes of this were apparent. The first was the loss of energy due to the series resistors in the Marx circuit charging arrangement and the second was the phenomena of residual charge or the inability of the condensers to give up all their stored energy during the short interval of discharge. The effect of this latter is to cause an apparent decrease in the capacitance of the surge generator.

Figure 3 shows several of the oscillograms taken after the series resistance had been increased to provide the prescribed attenuation of the wave tail. Each wave was recorded with 2 sweeping rates, one to show the wave to the 50 per cent value on the tail and one to show the wave front alone and pro-

vide a more accurate determination of the time to reach the crest. Oscillogram *a* of figure 3 illustrates a $1^1/_2 \times 40$ wave taken under conditions of low generator capacitance and high resistance and inductance. The positive reflections are indicated by the overshooting wave. All the oscillograms were obtained under conditions of minimum load capacitance with no sphere gaps or test piece connected. That the overshooting of the wave at its crest was not due to oscillations of the generator circuit inductance with any load capacitance was indicated by the fact that large amounts of series resistance in the generator gap circuits had no effect upon the overshooting. Likewise, the overshooting was not affected by connecting a 50 centimeter sphere gap across the load resistance, the sphere gap having a capacitance of at least of the same order of magnitude as the effective distributed capacitance of the load resistance.

Oscillograms *b*, *c*, and *d* of figure 3 show the 3 standard wave forms obtained with generator capacitances sufficiently large to allow the use of relatively low values of inductance and resistance. In these latter oscillograms, positive reflections are entirely absent; the negative reflections which must exist have sufficiently small magnitude and low period to be readily attenuated, thus providing a smooth wave front.

Table III provides a comparison of the actual with the calculated circuit constants for each of the oscillograms of figure 3, together with the time constants of the actual impulses.

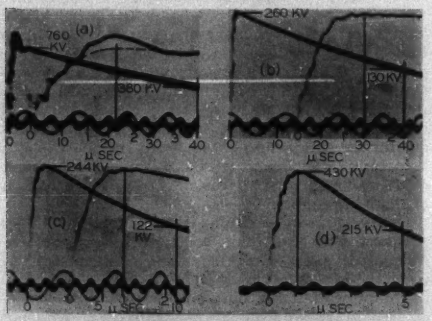

Fig. 3. Oscillograms taken after series resistance had been increased to provide prescribed attenuation of the wave tail. Time in microseconds

(*a*). $1^1/_2 \times 40$ wave with positive reflections (low generator capacitance). $C = 0.00614 \times 10^{-6}$ farads, $L = 2.53 \times 10^{-3}$ henrys, $R = 9{,}180$ ohms. Maximum released voltage = 1,075 kv

(*b*). $1^1/_2 \times 40$ wave (high generator capacitance). $C = 0.0528 \times 10^{-6}$ farads, $L = 0.270 \times 10^{-3}$ henrys, $R = 1{,}130$ ohms. Maximum released voltage = 375 kv

(*c*). 1×10 wave (high generator capacitance). $C = 0.0528 \times 10^{-6}$ farads, $L = 0.060 \times 10^{-3}$ henrys, $R = 259$ ohms. Maximum released voltage = 375 kv

(*d*). 1×5 wave (high generator capacitance). $C = 0.023 \times 10^{-6}$ farads, $L = 0.082 \times 10^{-3}$ henrys, $R = 245$ ohms. Maximum released voltage = 575 kv

Table III—Impulse Generator Circuit Constants and Time Constants for Oscillograms of Figure 3

			Inductance		Resistance		Time	
Oscil	Wave	Capacitance μf	Calc. mh	Actual mh	Calc. ohms	Actual ohms	To Crest μSec	To 50% μSec
3a	$1^1/_2 \times 40$	0.00614	2.53	2.53	9,000	9,180	1.6	40
3b	$1^1/_2 \times 40$	0.0528	0.270	0.270	1,050	1,130	1.4	40
3c	1×10	0.0528	0.060	0.060	244	259	1.0	10
3d	1×5	0.023	0.079	0.082	244	245	1.1	4.9

μf = microfarads
mh = millihenrys
μsec = microseconds

Appendix

The calculation of circuit constants to produce a given wave shape is a rather laborious task. In the usual case the capacitance is known and the inductance and resistance are determined by trial and error substitutions.

It is true that the substitution of the time constants of the wave (say $1^1/_2 \times 40$ microseconds) and the value of the capacitance into the circuit equations gives rise to 2 equations with 2 unknowns, R and L, but since the equations are of transcendental nature their solution for the values of R and L cannot be obtained in the usual manner. A graphical solution has been presented in a paper by C. M. Foust, H. P. Kuehni, and N. Rohats.[5] If, for any particular wave, the values of resistance and inductance to produce that wave are calculated for several values of capacitance, and then plotted against the capacitance, it will be found that the curves are hyperbolas (or straight lines if plotted on paper having logarithmic scales on both axes). Having once demonstrated the hyperbolic relations, $RC = a$ and $LC = b$, the values of a and b may be quite accurately determined by cut-and-try methods, once and for all. For that particular wave shape, the values of R and L may henceforth be quickly obtained by a simple slide-rule calculation. Since the constants a and b may be determined to any desired degree of accuracy, and since their use is not restricted to any given range of capacitance values, it would seem desirable to determine the values of R and L from these constants rather than from curves.

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Discussions

Of A.I.E.E. Papers—as Recommended for Publication by Technical Committees

ON this and the following 16 pages appear the author's closure of a paper presented at the induction motor session of the 1935 A.I.E.E. winter convention, New York, N. Y., January 22–25, and discussion of papers presented at the electrical machinery, instruments and measurements, power generation, and selected subjects and sessions of the 1935 A.I.E.E. summer convention, Ithaca, N. Y., June 24–28. Author's closures, where they have been submitted, will be found at the end of the discussion on their respective papers.

Members anywhere are encouraged to submit written discussion of any paper published in ELECTRICAL ENGINEERING, which discussion will be reviewed by the proper technical committee and considered for publication in a subsequent issue. Discussions should be (1) concise; (2) restricted to the subject of the paper or papers under consideration; and (3) typewritten and submitted in triplicate to C. S. Rich, secretary, technical program committee, A.I.E.E. headquarters, 33 West 39th Street, New York, N. Y.

Induction Motor Locked Saturation Curves

Author's closing discussion of a paper published in the April 1934 issue, pages 536–41, and presented for oral discussion at the induction motor session of the winter convention, New York, N. Y., January 24, 1935. Other discussion of this paper was published in the September 1934 issue, page 1312, and in the July 1935 issue, page 761.

H. M. Norman: In reply to the point brought up by P. H. Trickey, it seems that there is possibly a misunderstanding regarding the limitation placed on the method outlined in the paper when dealing with totally bridged slots. As explained in the first section of the paper, the reason for the work was to enable the designer to calculate the starting condition more accurately, and therefore it is the upper part of the locked saturation that stress was laid upon and not the very low values of locked current of value approximately equal to full load current. These low values of current would enable the calculation of a more accurate power factor for various loads and such curves as Trickey suggests would help in this direction because for each value of load current there is a different value of rotor slot reactance which causes the locus of the primary current to deviate from a circle.

The paper does cover the case of bridged slots, however, when the upper part of the locked saturation curve is required, by the use of equations 8 and 9. The comparison of test and calculation is given in figure 7 of the paper.

In discussing the curve and formulas given by Trickey I would like to point out that if 2 machines of identical construction but different stacking be compared, then the value of H given in his discussion would be inversely proportional to the stacking. This would result in a different value of slot constant for each machine, while actually they should be the same because there is the same value of current per rotor slot in each machine resulting in the same amount of saturation of the bridge. Perhaps the value of slot constant given on this curve is supposed to include the stacking so that in finding the rotor slot reactance the stacking length is not introduced, but if so then the only curve that would check would be a hyperbola, and this curve deviates somewhat from a hyperbola. I cannot agree with the quantity H being called flux density. For a given magnetomotive force per slot, the flux density in the bridge is fixed regardless of the stacking, and also regardless of the thickness of bridge for all similarly shaped punchings.

Notwithstanding our different view points on this matter, I think that a set of curves on this order would materially help to obtain the load power factors more accurately but would have to be used with discretion for starting conditions on account of the assumption of a constant zigzag reactance.

The points brought up regarding punching strains, machining tolerances, and varying permeability of the iron are true; but it is fortunate that these various disturbing factors seldom pull all in the one direction. Indeed, if this were not so, then the method outlined in the paper would itself not be reliable, because the same disturbing factors apply to the saturated zigzag flux path.

S. F. Henderson has brought up a case of an extreme machine which had only 46 per cent zigzag leakage at starting compared with load conditions. This is a lower percentage than any motor I have checked so far, and as stated in the paper 50 per cent was the lowest percentage checked.

I might comment on the fact that the maximum torque of this particular machine has been calculated with and without correction for saturation of the leakage paths. It brings out the point that the method used in the paper can be applied all along the speed torque curve, as has been done successfully on other machines, including double cage motors where the calculated speed torque curve did not check the test, but came reasonably close to it when the calculated curve was adjusted for saturation.

Regarding the reactance formulas of the machines which Henderson requests, those used for the various slot shapes in figure 6 are given here. They are given in the same sequence, and the same nomenclature applies, as in figure 6, and are for the tooth tip part only.

$\frac{a_1}{t}$ for the first 2 slot shapes

$$\frac{a_1}{t} + \frac{3a_2}{2t + t_1}$$

$$\frac{a_1}{t} + \frac{4a_2}{3t + t_1}$$

$$\frac{a_1}{0.02} + \frac{3.3a_2}{t_1}$$

$$\frac{a_1}{0.02} + \frac{2a_2}{t_1}$$

The last 2 of these formulas, being for bridged slots, are correct for only one value of current and might well be replaced by a system of curves as suggested by Trickey.

The zigzag formula used was

$$W^3 f\, 10^{-8} \frac{\text{total area of gap} \left(\frac{K^2_s + K_s}{2}\right) 1.14}{S_1 S_2 g_e}$$

where g_e is the equivalent air gap; for the other terms see the nomenclature used in the paper. The end leakage formulas were developed to suit the construction of the line of motors from which the various tests were taken and as they could not be generally applied they are not included here.

Rehabilitation of the Connors Creek Plant

Author's closing discussion of a paper published in the June 1935 issue, pages 610–17, and presented for oral discussion at the power generation session of the summer convention, Ithaca, N. Y., June 25, 1935. Other discussion of this paper was published in the September 1935 issue, pages 1001–2.

R. E. Greene: C. M. Gilt correctly states that each problem presented in rehabilitating and increasing capacity of old power plants must be settled on its own merits. He further points out that frequently an old plant can be advantageously used for stand-by and peak load service. Although such a considerable portion of system standby concentrated at one location would have been in some degree awkward in view of The Detroit Edison Company's practice of allocating load areas to each plant with loose-linking ties between, this difficulty would not have been insuperable. Serious

consideration was in fact given such an alternative. Apart from some relatively minor objections, the controlling reason for rehabilitating the old plant, rather than holding it for peak or emergency reserve, was the doubt in the minds of the company's engineers of the real value of reserve capacity of this nature if the considerable expense of keeping the plant manned and banked is to be avoided.

Gilt also states that Table II of the paper shows that for new money plus value of equipment from other locations amounting to a total of $20,826,100, an increase of 150,000 kw in capacity is obtained at $139 per kilowatt. This is not a proper interpretation of this table as the sum mentioned not only covers the cost of this additional capacity but also includes money required to modernize the old plant. He refers also to the ultimate book value of $30,367,200, showing that the final book value per kilowatt will be approximately $92. This is true but in considering these figures it should be remembered that the final book value includes nearly $10,000,000 in land, buildings, and equipment retained from the old plant.

C. A. Powell questions the statement "if high pressure units had been superimposed on the old plant, more maintenance and lower reliability, inherent with old equipment, would be retained." This statement applied to the old low pressure units and is borne out by the fact that the turbines were due for rebucketing in a very short while if they were to be retained. Additional factors which led to the decision not to superimpose were: (1) the low pressure turbines were nonbleeding and superimposition would have involved an undesirable system for feed water heating; (2) 2 30,000 kw generators were available for the construction of the new units and many parts of the old units could be used; (3) the use of existing machine foundations, which were adequate for the new and larger high pressure machines, would provide a very acceptable station arrangement; and (4) as the new machines were to be single shaft and operated on a simple regenerative cycle, they would provide a very rugged and easily operated group of units. Obviously, many of these factors could not be evaluated in terms of dollars and a great deal of personal judgment, based on local conditions, entered into the decision.

D. F. Pennell evidently feels that with the load area system of operation it is necessary to predict locations of load increases very closely or else the necessary added capacity will not be able to serve them. No difficulty from this occurs in Detroit as the system ties are capable of transmitting considerable blocks of power between areas. He also believes that this method of operation does not permit the best use of machines in obtaining system efficiency. Again this is a matter of size of area ties, and as evidence that these are ample in Detroit, the net average system heat rate for the company's entire system in 1934 was 14,630 Btu per kilowatt-hour. During that year the new and more efficient machines at Connors Creek were, as yet, supplying practically no energy. With 2 of the new 30,000 kw units now in service, the average system heat rate of the company's territory is approaching 14,000 Btu per kilowatt-hour and will presently better that figure. Additional improvement may be expected with further development of the Connors Creek rebuilding program.

Capacitive Excitation for Induction Generators

Discussion of a paper by E. D. Bassett and F. M. Potter published in the May 1935 issue, pages 540–5, and presented for oral discussion at the electrical machinery session of the summer convention, Ithaca, N. Y., June 26, 1935.

R. E. Hellmund (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): As an old induction motor designer, I always have taken some interest in the possible application of induction machines as generators. In the early days when it generally was considered that induction machines were cheaper and simpler than synchronous machines and when certain difficulties were experienced from hunting with reciprocating prime movers, there seemed to be a possibility of applying induction generators. More recently, however, the economic relation between synchronous and induction machines for larger capacities has become such that the synchronous machine is replacing the induction machine in a great many applications.

For very small capacities it appears that the recent development of a great many different permanent magnet steels will tend toward the design of small synchronous generators with permanent magnets. There is, however, an intermediate range, such as mentioned by the authors, where there still seems to be a possibility of induction generators finding occasional application; particularly in the case of isolated engines and machines for some special purposes where higher frequencies are used, capacitive excitation may work out economically.

In the paper, an arrangement for obtaining self-compounding of these generators is discussed. It may be quite worth while, however, to consider voltage regulators for adjusting the capacity, or, in some cases where there is no need for maintaining constant frequency, the regulation might be accomplished through speed regulation of the prime mover.

Charles Kingsley, Jr. (Massachusettes Institute of Technology, Cambridge): This paper presents interesting test data concerning certain characteristics of induction machines which, for the most part, have been well known for a number of years. I should like to mention that the determination of the operating characteristics of a 3-phase induction generator with shunt capacitive excitation has been used for several years as the basis of a dynamo laboratory experiment regularly assigned to senior students in electrical engineering at M. I. T. (See "Electrical Engineering Laboratory Experiments," C. W. Ricker and C. E. Tucker, McGraw-Hill Book Co., second edition, third impression, 1930, p. 297.) The obvious disadvantage of this method of excitation is the resulting poor voltage regulation, as shown in figure 2 of the paper. The method of "compounding" the induction generator by the use of the appropriate value of series capacitance is interesting and, I believe, original.

In discussing in the paper the effects of short circuits suddenly applied to the induction generator with shunt capacitive excitation, the statement is made that the machine current "never can be greater than that flowing in the windings at the time of application of the fault." This statement is incorrect, as is clearly pointed out in a paper entitled "Short-Circuit Current of Induction Motors and Generators" by R. E. Doherty and E. T. Williamson (A.I.E.E. Trans., v. 40, 1921, p. 509–39). The transient current can be calculated readily by the methods presented by S. J. Levine ("An Analysis of the Induction Motor," Elec. Engg., v. 54, May 1935, p. 526–9) or by the methods given in the references at the end of Levine's paper.

Although the final steady-state short-circuit current is zero for 3-phase short circuit of an induction generator with shunt capacitive excitation, the first peak of the transient current may well be several times rated full load current. In fact, since the transient reactance of an induction machine is usually smaller than that of a synchronous machine of the same rating, the transient short-circuit current of an induction generator is usually larger than that of a synchronous generator of the same rating.

The experimental work of this paper was done on small machines which usually have relatively high ratios of resistance to reactance, and consequently the transient currents die out rapidly. It is probably for this reason that the authors did not observe the large transient short-circuit currents which can be expected when larger machines are short-circuited.

C. G. Veinott (Westinghouse Elec. and Mfg. Co., Springfield, Mass.): This paper is an unusually fine exposition on the subject treated, and furthers existing fundamental knowledge of induction machines. I was particularly interested in this paper because this phenomenon is likely to occur in a high

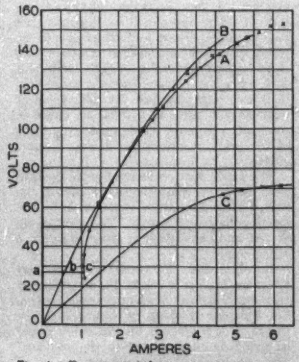


Fig. 1. Test curves taken on a capacitor-start motor
See text for explanation

torque capacitor motor which coasts for a long time after the power is removed.

To check the theory given by the authors, a 1/4 horsepower capacitor-start motor was selected and a no load saturation curve taken in the manner shown by the authors in their figure 1. For this test, different values of capacitance were connected across the main winding and the motor was driven by a direct connected duplicate motor. The points indicated by squares on curve A in figure 1 of this discussion were obtained.

For comparative purposes, the results of a conventional "running saturation"—such as is normally taken to separate core loss from friction and windage—were plotted as curve B in figure 1 of this discussion. In the middle range of voltages, the agreement is practically perfect; at the lower voltages, the current ac is greater than the current ab because of the power component necessary to drive the motor, whereas in ab this power component is absent because the machine is externally driven; the discrepancy between the curves at the higher voltages is explained almost entirely by the drop in speed of the driving motor at the high loads. (At 5 amperes, the speed was only about 1,750 revolutions per minute.) These results thus substantiate the theory of the authors.

In an actual motor of the capacitor-start type, the capacitor is not connected directly across the main winding but may be considered as being shunted across the 2 windings in series, as shown in figure 2 of this discussion. It was assumed that these 2 windings, for the purposes of our discussion, could be thought of as a single winding having a number of turns equal to $\sqrt{T_m^2 + T_a^2}$, where T_m and T_a are the turns on the main and auxiliary windings, respectively.

To check this assumption, the starting switch was short-circuited and a saturation curve was obtained by connecting different values of capacitance in place of the capacitor shown in figure 2. For each value used the machine built up to voltage E with an exciting current I being supplied by the capacitor. To compare the points obtained in this manner with those previously taken, I was multiplied by a constant C and the corresponding E was divided by C where $C = \sqrt{\frac{T_m^2 + T_a^2}{T_m}}$. The points thus obtained were plotted as crosses in figure 1 of this discussion.

It will be noted that these points agree remarkably well with curve A, thus substantiating the authors' theories, as well as justifying the assumption that the 2 windings may be considered as a single winding. (The voltages across the main and auxiliary windings were measured separately, as well as the voltage across the condenser, and it was found that the voltages across the main and auxiliary windings were not in exact quadrature but were slightly more than 90 degrees apart, although this angle seemed to remain nearly constant for several different values of capacitance.)

It was particularly interesting to note that values of less than half the normal capacitance used with this motor would cause the motor to build up to such high voltages that the power losses were 2 to 3 times the motor rating. If the starting switch of this motor had been short-circuited, so that the motor's own capacitor had been connected across the windings, and the motor driven at synchronous speed, the motor would have burned up in a very short period, and it is quite likely that this is typical of any high torque capacitor motor.

However, this situation is not nearly so serious as it seems and very rarely causes trouble. The starting switch normally does not reclose until the motor has slowed down to approximately half speed where the conditions are very much different. Curve C

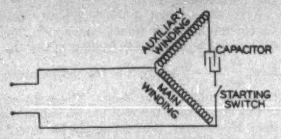


Fig. 2. Connections of a capacitor-start motor

in figure 1, shows a saturation curve taken with the motor driven at approximately 850 rpm. It may be noted that at any given current, the voltage is approximately half of that obtained at full speed. This is as might be expected. However, the number of microfarads required for the machine to build itself up to any given current at half speed is 4 times as great as the number of microfarads to build it up to the same current at full speed because not only is the voltage halved by the reduction in speed, but so is the frequency. Below a certain critical value of capacitance the machine will not build up as a generator, as pointed out by the authors. This critical value is inversely proportional to the square of the speed. Thus it happens that, at half-speed, difficulty from the motor building up as a capacitor-excited generator is seldom encountered.

The methods of the authors may be extended as indicated in this discussion to study just such phenomena.

Time-Temperature Tests to Determine Machine Losses

Discussion and author's closure of a paper by M. D. Ross published in the May 1935 issue, pages 513–5, and presented for oral discussion at the electrical machinery session of the winter convention, Ithaca, N. Y., June 26, 1935.

R. E. Hellmund (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): In view of the fact that time-temperature curves given by the author have met the rather exacting requirements of loss determination in a very satisfactory manner, it is surprising that no greater use is made of such curves in connection with the rating of electrical machinery where intermittent duty cycles have to be precalculated. During the International Electrotechnical Commission meeting at Prague last fall, serious consideration was given to standardizing on a multiplicity of intermittent duty ratings for electrical machinery. It may readily be seen what an enormous amount of testing would be required with the great number of machinery ratings to establish for each of them a number of intermittent duty ratings. It has been repeatedly shown in literature that intermittent duty cycles can be readily calculated, with an accuracy sufficient for such purposes, from the continuous rating and certain data relating to the rate of temperature rise as can be determined from the tangent of the time-temperature curve. Therefore, it would seem that when ratings of machinery are to be standardized to assist in the application of machinery to intermittent duty cycles, it should be along such lines.

As pointed out in the paper, it is not convenient to obtain time-temperature curves for the rotating parts, and at times it may be difficult to obtain such curves even for the stationary parts. It is, however, quite possible in such cases to obtain short time ratings, that is, 5, 10, or 15 minute ratings, which give a rather close indication of the time-temperature characteristics of the machine. The American Committee on Railway Machinery, which deals with one of the applications where intermittent duty cycles are always encountered, is seriously considering the proposal of short time ratings to take the place of the former one hour rating. This, I believe, is a step in the right direction and one worth-while following in the standardization of ratings of other electrical machinery.

L. A. Kilgore (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper presents a method of measuring the loss density in the various parts of electrical machines which has proved very useful in determining the actual distribution of losses throughout the machine.

Where the loss is uniform throughout a body which is fairly well insulated thermally from other bodies the simple relations given in the paper are sufficiently accurate for practical measurements. However, in some cases where the thermal resistance between 2 bodies having different loss densities is relatively low, the initial slope measured in the 5 minutes required by the ordinary methods of test deviates considerably from the initial value which is a true measure of the loss density. Methods of empirically correcting for these effects have been given in the paper.

It is interesting to consider the theoretical analysis of the thermal transient of 2 masses with some thermal conductivity between them. This approximates the condition of the stator copper and stator iron and also the conditions in the ring sample used for calibration.

Let q_1 and q_2 be the rates of heat generation of the 2 bodies in watts per second; C_1 and C_2 the thermal capacities in watts second per degree centigrade; K_1 the thermal conductivity from the first body to the air, and K_2 the thermal conductivity between the 2 bodies. Then

$$C_1 \frac{d\theta}{dt} + K_1\theta_1 - (\theta_2 - \theta_1)K_2 = q_1$$

and

$$C_2 \frac{d\theta_2}{dt} + K_2(\theta_2 - \theta_1) = q_2$$

Writing P for $\frac{d}{dt}$ and reducing to one equation for the general solution with θ_1 and $\theta_2 = 0$,

$$[C_1C_2P^2 + (K_2C_1 + K_1C_2 + K_3C_2)P + K_2K_1]\theta_1 = 0$$

Let $-\alpha$ and $-\beta$ be the roots of this equation, then

$$\theta_1 = A_1e^{-\alpha t} + B_1e^{-\beta t}$$

$$\theta_2 = A\left[\frac{K_1 + K_2}{K_2} - \frac{\alpha C_1}{K_2}\right]e^{-\alpha t} + B\left[\frac{K_1 + K_2}{K_2} - \frac{\beta C_1}{K_2}\right]e^{-\beta t}$$

where A and B are constants to be determined from the initial conditions.

It will be noticed that each temperature now contains 2 exponential terms. It can be shown that the initial value of $d\theta/dt$ is a measure of the loss density. However, if numerical examples are taken, it will be found that the slope over a 5 minute interval deviates appreciably from the initial values.

Calibration tests were made on a ring sample with an exciting winding wound over a thin layer of insulation. The specific heat determined from the known loss and the slope of the time-temperature curve based on the readings taken for 5 minutes deviated widely from the theoretical value. However, when the above analysis was used and the complete theoretical curves drawn, it became apparent that the experimentally determined slope was being influenced by the surrounding copper and the copper loss. At low values of flux the exciting current and the copper loss were very low so that the thermal capacity of copper caused the apparent specific heat of the iron to be too high. At high values of flux the exciting current was such as to cause a much higher loss density in the copper than in the iron, causing the apparent specific heat to be too low. At the point where the loss densities were equal the test checked the theoretical specific heat quite accurately.

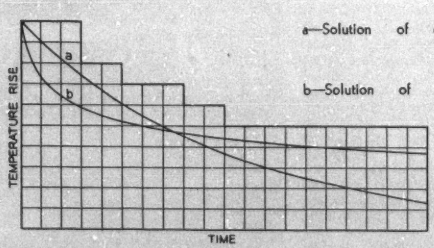
P. M. Lincoln (Cornell University, Ithaca, N. Y.): I note that certain deductions as to losses are made by determining the slope of the cooling curve during the first few minutes after shutting off the load. It is obvious that under the test conditions described, cooling takes place almost entirely by forced convection. I would like to ask whether or not any tests have been made to determine the law which connects cooling rate with temperature elevation under forced convection. It is well known that convection in still air does *not* follow a first power law. Is the same true with forced convection? This is important since any deductions drawn from the slope of the cooling curve during the first few minutes of cooling are affected by this cooling law. A slope taken on a given machine at a given temperature elevation does not hold for slopes taken at other temperature elevations unless the first power cooling law holds. Has this first power law for forced convection been confirmed?

It is obvious that if the first power law for cooling holds for forced convection, the differential equation for cooling takes the form $\frac{d\theta}{dt} = -\theta$ where θ is the temperature elevation and t is the time. The solution of this equation is the well known exponential. If, however, the cooling law for forced convection is the same as for convection in still air, it is well known that the differential equation takes the form $\frac{d\theta}{dt} = -\theta^{1.25}$. The solution of this equation is *not* an exponential, although it has some of the characteristics of an exponential. The solution of these 2 differential equations is plotted in figure 1 of this discussion. It is obvious from these curves that any deductions drawn from the rate of cooling during the first few minutes after shutting off the load are vitally affected by the cooling law.

May I suggest that the author would do the electrical industry a great favor if he will demonstrate by experiment whether or not the first power law holds for forced convection?

There is no intention of disputing the soundness of the method of loss determination suggested in the paper. The slope of the time-temperature curve at zero time is a true measure of losses. The curves in figure 1 of this discussion are deceiving in that they indicate a marked difference in the slopes at zero time. If we were at liberty to change the law of cooling at will, the temperature at zero time would be different with different cooling laws, but slope at zero time would always be the same. If the first power law holds, the resulting exponential time-temperature curve has the property that the intercept between a tangent and a vertical at the point of tangency on the $\theta = 0$ line is the same at any point on the curve. If the first power law does not hold, the resulting time-temperature curve does not possess this property. Consequently, any deductions drawn from the slope at zero time will depend on the temperature elevation at which the slope is taken.

If this discussion has emphasized the need for more accurate experimental data on the laws which govern forced convection, it will have accomplished its object.



a—Solution of differential equation $\frac{d\theta}{dt} = -\theta$

b—Solution of differential equation $\frac{d\theta}{dt} = -\theta^{1.25}$

Fig. 1. Comparison of slopes of cooling curves

V. M. Montsinger: (General Electric Company, Pittsfield, Mass.): While not tied up directly with cooling of revolving apparatus windings after shutdown, I believe it may be of interest to point out some of my experience in connection with the cooling of transformer windings after shutdown. Since it is not possible to measure the resistance of transformer windings at the instant of shutdown, it is necessary to have a simple method of correcting for the temperature drop between the instant of shutdown and the time of resistance measurement, which in some cases may amount to several degrees. A cooling curve is, of course, the most accurate method but for economic reasons is not always practical.

A few years ago I undertook the problem of working up a simple rule for the cooling of transformer windings after shutdown. The general formula for the cooling of a body is of the form

$$T = T_0(1 - e^{-\beta t}) \qquad (1)$$

where

T = the temperature rise at any instant over its ambient temperature
T = the temperature rise at shutdown
β = time constant
t = time

As shown in my paper on "Cooling of Oil-Immersed Transformer Windings After Shutdown" (A.I.E.E. Trans., v. 36, 1917, p. 711–30) the value of β may be written

$$\beta = \frac{0.676}{\theta_0}\frac{aW_c}{A + a}$$

where

a = the cross-sectional area of the copper, and
A = the cross-sectional area of the copper plus the insulation

Equation 1 is not rigorously correct since it is based on the assumption that the loss of heat is proportional to the temperature rise, which is seldom true. The loss by convection (for either gas or liquid) is generally proportional to the temperature rise raised to the 5–4 power.

I soon discovered that this formula could not be used for transformer windings, apparently for the reason that the cooling medium or ambient was the oil (flowing through the ducts) which changed in temperature along and with the winding temperature during the cooling period. Furthermore, the temperature of the oil in the ducts could not be determined very easily.

According to equation 1, for the same initial temperature rise the winding with considerable insulation on it should cool off at a slower rate than a winding with a small amount of insulation on it. Tests made on a variety of transformer windings showed that for the first 3 or 4 minutes the cooling

appeared to be approximately independent of the amount of insulation. At first this was difficult to understand. It soon became evident that some other factor was present which offset the increase in thermal capacity and expected slower cooling.

A further study showed that this other factor was the higher initial temperature rise due to the insulation. This is well illustrated by 2 cooling curves taken on 2 duplicate coils, one of which had no tape on it, and the other of which had 18 layers of 0.012 inch varnished cambric wound over both sides. These curves are given in figures 4 and 5 of the above mentioned paper.

These curves show that while the taped coil started cooling at a slower rate than the untaped coil, yet due to its greater initial rise the 2 curves crossed when considered only from the standpoint of cooling in degrees centigrade. For practical purposes the cooling of transformer windings can, therefore, be based on the copper loss only for the first 3 or 4 minutes. For periods longer than about 4 minutes, the cooling of the taped coil became greater than that of the untaped coil.

It should be stated, however, that this condition does not hold where the increase in insulation increases the surface dissipating the loss as, for instance, where heavy turn insulation is used in line end or buffer coils, and where the extra insulation does not materially increase the initial rise. In most transformer windings the influence of the heavier turn insulation in the buffer coils is negligible and, hence, the cooling after shutdown can be made a function of the copper loss only. The present rule in A.I.E.E. Standards No. 13 for the cooling of transformer windings after shutdown is based only on the copper loss.

M. D. Ross: The discussions by V. M. Montsinger and R. E. Hellmund bring out the importance of time-temperature measurements to the designer of electrical machinery, especially in regard to short time ratings. In predetermining the performance of machines on intermittent loading, it has been customary to calculate the losses in the machine parts and from these losses and the heat storage and cooling properties of the machine, determine the shape of the time-temperature curve corresponding to the estimated values of losses. The procedure described in the present paper is merely a reversal of this process by which we are able to obtain the actual value of losses which could not otherwise be experimentally obtained.

P. M. Lincoln in his discussion asks if the rate of change of heat flow in machines such as were tested is a linear function of the temperature difference between the machine surfaces and the cooling air. The following is quoted from page 642 of an article by G. E. Luke ("The Cooling of Electric Machines," A.I.E.E. TRANS., v. 42, 1923, p. 636–51) in regard to heat transfer rates with forced convection as in turbine generators.

"The unit heat transfer increases slightly with the temperature of the surface and air, but tests by the writer show that, for all practical purposes, the unit heat transfer is independent of the temperature over a range of from 20 degrees centigrade to 100 degrees centigrade."

Even where natural ventilation is used, the test method is theoretically correct. If the rate of heat flow is assumed to be proportional to $(\theta - \theta_c)^{1.25}$, equation 1 of the paper becomes

$$q_i = k(\theta - \theta_c)^{1.25} + C\frac{d\theta}{dt}$$

Under steady conditions,

$$q_i = q_c = k(\theta_0 - \theta_c)^{1.25} \text{ or } k = \frac{q_i}{(\theta_0 - \theta_c)^{1.25}}$$

At time $t = 0$,

$$C\frac{d\theta}{dt} = -k(\theta_0 - \theta_c)^{1.25}$$

$$= \frac{-q_i}{(\theta_0 - \theta_c)^{1.25}}(\theta_0 - \theta_c)^{1.25}$$

or

$$\frac{d\theta}{dt} = \frac{-q_i}{C}$$

In other words, the initial slope of the time-temperature curve is the same for natural or forced ventilation. As the slope is measured by taking readings over about a 5 minute period, there might be some slight difference in the results depending upon the type of ventilation.

L. A. Kilgore's discussion is very important as it gives a method of determining the possible error due to rapid heat flow from one part of the machine to another which might affect the accuracy of the loss measurements. A rough calculation, using the equations given in his discussion, will quickly establish the possibility of errors in the values determined by test.

Sparking Under Brushes of Commutator Machines

Discussion and authors' closure of a paper by R. E. Hellmund and L. R. Ludwig published in the March 1935 issue, pages 315–21, and presented for oral discussion at the electric machinery session of the summer convention, Ithaca, N. Y., June 26, 1935.

J. C. Aydelott (General Electric Co., Erie, Pa.): Those who have examined the contact surfaces of brushes are familiar with the characteristic marking consisting of discolored areas in the otherwise polished surface. These areas may be of greater or less width extending back from the trailing edge of the brush and ending at a very distinct line.

Possibly this brush face marking may be related to the phenomenon which is the subject of this paper. In figure 9 of the paper there is shown a ripple in the current flowing from a commutator segment at the instant that the preceding segment breaks contact with the brush. If commutation is bad enough these ripples may be quite pronounced. The rapid increase in current density, according to the paper, will cause sparking under the brush resulting in the discolored brush surface just mentioned. If the phenomenon is caused by the preceding segment under the same brush, the discoloration will extend exactly one segment width under the brush face. In some cases a similar result is caused by flux linkages in common between upper and lower conductors in the slot when a segment breaks contact with a brush of opposite polarity. In such a case, the width of the discoloration on the brush face may be some fraction of the width of a commutator segment.

In some instances there are 2 or more grades of discoloration, but in each there is a distinct line of demarcation between the various grades of discoloration or between the discolored areas and the polished surface. It is the sharpness of this line which confirms the authors' observation that sparking is caused by the rate of rise of current density. The location of the line as explained above is related to segment spacing and brush spacing.

V. P. Hessler (Iowa State College, Ames): I would like to add a few thoughts to the authors' statements concerning the theory of the sliding contact. The various theories of the sliding contact as presented in the literature fall into 3 classes: the point conductance theory, the thermal emission theories, and the oxide film theory. The point conductance theory alone fails to explain most of the phenomena of the sliding contact but is useful as a part of the oxide film theory.

The various thermal emission theories have been most widely advocated and seemed to explain many of the voltage phenomena of the sliding contact. The fact that visible sparking does occur on occasion between the brush and the ring indicates that thermal emission does take place under certain conditions, and that it must be considered in the complete theory of the sliding contact. The decided effect of ring temperature upon contact drop was the first phenomenon to come to the writer's attention which seemed inexplicable on the basis of thermal emission. It was found by E. Arnold (*E.T.Z.*, v. 28, 1907, p. 263–6) that increasing the ring temperature from 20 to 90 degrees centigrade sometimes produced almost a 10 to 1 decrease in contact drop. These results seemed so paradoxical to the writer that they were repeated and similar results were obtained. The magnitude of the effect varies quite widely with the various grades of brushes.

A. Schliephake (*Elektrotechnische Zeitschrift*, v. 55, 1934, p. 814–15) and R. M. Baker (*Elec. Jl.*, v. 31, 1934, p. 359–60 and 448–50) have found that an oxide-free ring acts as a constant resistance as the current is varied. Also, the contact drop of the oxide-free contact is much less than the ordinary contact. Thus the oxide film seems to be rather largely responsible for the voltage phenomena of the sliding contact.

If the temperature effects mentioned above and the drooping characteristic of the voltage current curves are to be explained upon the basis of the oxide film it would seem that cupric oxide should have a negative temperature coefficient of resistance. This is found to be the case as shown by F. Horton ("The Electrical Conductivity of Metallic Oxides," *Phil. Mag.*, v. 11, 1906, p. 521). The conductivity of fused cupric oxide increases many times as the temperature is increased from 12 to 150 degrees centigrade. Thus it is apparent that certain sliding contact phenomena are ex-

plained upon the negative temperature coefficient of resistance of cupric oxide.

On the basis of the above theory the transient voltage drop characteristic of a sliding contact would be expected to lie above the static characteristic as found by the authors. In some similar experiments made by the writer on stationary contacts the resistance continuted to decrease for 5 seconds after the current was suddenly increased.

W. A. Boyer (Anaconda Copper Mining Co., Butte, Mont.): In connection with the operation of d-c machines, the problem of commutation is an ever interesting one. The general opinion is that the various coils of an armature as they come into the commutating zone are all treated alike; in other words, that a voltmeter reading from a point on the surface of the commutator under the leading and trailing edges of a brush to the brush arm indicates a commutating condition which all the coils on the armature are subjected to when they come within that zone. Also, it is more or less taken for granted that this condition remains the same with respect to time unless some change in the mechanical adjustment of the machine has been made.

This general opinion does not give a true story of what actually is taking place. In figure 1 of this discussion is shown a portion of an oscillogram taken on a 1,650 kw d-c generator shortly after it was stoned. This particular machine is used in connection with a Ward-Leonard controlled electric mine hoist, so that its working conditions are continually changing.

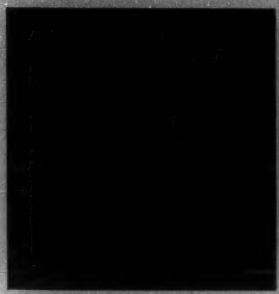
Figure 2 shows a portion of an oscillogram of the same machine taken after 14 days, and figure 3 shows another taken just before the commutator was stoned, or 3 months after that in figure 1 was taken.

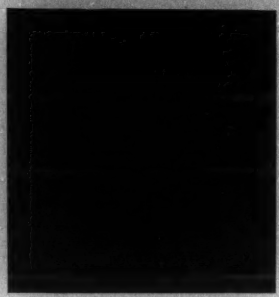
When these various figures are compared the contact drop curves are seen to change considerably. The change in figure 2 from figure 1 has been the result of growth of commutator film. When figure 2 was taken commutation was very good, no visible sparking taking place even on peak loads of 250 per cent of normal load.

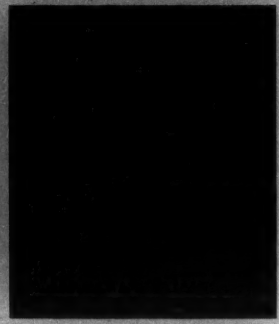
In figure 3 commutator film and mechanical roughness of bars causes the extreme fluctuations. The edges of some of the bars were burned in this instance, and commutation had become very poor.

After a commutator has been newly stoned, the film does not enter into the commutation problem. The differences in contact drop as the various bars are passing under the brush are due to the variation in the voltages that the various coils are subjected to as they pass through the commutating zone. Their voltages of self and mutual induction may vary due to the construction of the coil and their placement in the slot. The commutating flux that the coils pass through may vary due to either a magnetic oscillation caused by varying reluctance of the flux path as the armature rotates or a magnetic oscillation caused by a variation of the magnetomotive force causing the flux to pass through the commutating zone. All of these influences may be seen clearly in figures 1 and 2.

With this variation in the resultant voltages affecting the coils as they come into the commutating zone, the short circuit currents vary. Thus the commutator bars







Figs. 1–3. Oscillograms of commutation of a 1,650 kw d-c generator operating at full load of 750 volts and 2,200 amperes

Figure 1 (upper left) taken shortly after stoning commutator; figure 2 (left) taken 14 days after stoning; figure 3 (upper right) taken 3 months after stoning

V_1 = voltage between 2 adjacent bars

V_2 = voltage between a point on the commutator under the leading edge of the brush and the brush arm

V_3 = voltage between a point on the commutator under the leading edge of the brush and a point under the trailing edge

will have formed on them a commutator film of different physical and electrical characteristics, as may be observed on practically any machine by the slight variation in color of the commutator bars. In all instances it will be found that the order of coloring or burning of bars repeats itself more or less closely, every single or double pole pitch.

The contact voltage variations continue to increase with the growth of the film. If the film reaches a stable condition and the contact drop voltages are within the sparking limit of the brush, commutation may hold for an indefinite period and the brush application is said to be all right. When the film does not reach a stable condition before the voltage variation reaches the sparking limit of the brush, sparking results with its burning of bars and poor commutation. The length of time necessary for the film to reach a stable condition depends upon a great number of factors, such as the design of the machine, nature of the brush, nature of the load, speed of the machine, spring tension of the brush, temperature, character of the surrounding atmosphere, etc. The length of time to reach the sparking limit of the brush may be from a few days to several years.

My observations check fairly well with those given in the paper, in that transient voltages under the brush may reach over 3 volts with no visible sparking. From a large number of observations I am led to believe that the transient characteristic curve for any grade of brush will vary when taken on copper rings upon which a film has been formed previously using various current densities. That is, the transient characteristic curve taken while using copper rings upon which a film has been formed previously with the brushes having a current density of 60 amperes per square inch will be different from a curve taken the same way but with the film on the rings formed while the brushes had a current density of 120 amperes per square inch.

The static characteristic curve may vary somewhat, also, when using these different rings but I expect the greatest difference in the transient characteristic curve. I am led to believe, also, that the static and transient characteristic curves may not differ so much using various grades of brushes on rings newly polished, the difference appearing when rings are used upon which the films have been formed with the various current densities.

R. E. Hellmund and **L. R. Ludwig:** Since our paper made but very brief reference to the various theories previously advanced for contact phenomena, the discussion contributed by V. P. Hessler, giving a brief review of such theories and also adding information regarding the temperature coefficient of cupric oxide and its bearing on the phenomena, is very appropriate. The paper mentions that we did not wish to discount the importance of the oxide film theory. There is a great deal of evidence supporting this theory. For example, Doctor Holm in Germany has made striking tests by developing oxide on a slip ring and subsequently removing it over half the circumference. Voltage drop tests with such

a ring very clearly demonstrated the difference caused by the oxide film. The work done by R. M. Baker also gives quite conclusive evidence along this line. The entire matter may be further complicated, however, because of other variables in addition to the temperature coefficient of the oxide.

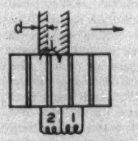
There have been described in some publication certain tests made with constant current on knife switches closed over a considerable period, which showed periodic variation in temperature. The explanation given was that a certain oxide film was formed with a low temperature, such film having a rather high resistance. Because of this high resistance, the temperature of the switch would further rise, resulting in the formation of a different oxide having a lower resistance. This in turn reduced the losses and the temperature to the point where the first oxide began to form, leading to a repetition of the cycle described. It is quite conceivable that similar conditions may prevail with a sliding contact and account for some of the phenomena encountered in practice. Particularly on account of the relatively low average temperature of the commutator and the very high local temperatures at certain points, especially where sparking occurs, the formation of different oxides at different portions of the surface and for different load conditions is quite likely. It has further been definitely established in Westinghouse laboratories that the humidity of the air affects the contact resistance over certain ranges, so that we may actually expect changes in commutation with changes in the weather.

Most of the theories advanced by various research workers for the sliding contact phenomena relate chiefly to normal load conditions. While the consideration of these conditions is the first step necessary in such investigations, the designer is really more interested in what occurs under abnormal conditions, that is, with very high current densities, etc. The reason for this is that under normal conditions he does not encounter any unusual problems and it is only in overcoming the limitations imposed by abnormal conditions that his best efforts are put forth. It is quite conceivable that a certain set of phenomena are involved when a glossy oxide surface is formed, while different or additional phenomena have to be considered under conditions causing a smudgy contact surface.

The great variety of conditions and variables is well demonstrated by the discussion given by W. A. Boyer. The data presented by him are particularly valuable because they have been collected under operating conditions such as found in actual practice. This is information of a kind that usually cannot be obtained by the designer and research worker and it would, therefore, be highly desirable for him to publish a rather full account of his work, giving the results obtained together with certain design data relating to the machines tested, such as the number of slots, the number of coils per slot, the armature chording, and so on.

We were interested particularly in his statement to the effect that different characteristics will be obtained if the oxide film has been formed with a current density of 60 amperes, for instance, than if it has been formed with a density of 120 amperes per square inch. This is quite in line with other experience to the effect that the conditions obtained during a certain load and operating condition are much influenced by the character of the preceding loads and the previous history of the commutator surface of certain parts thereof.

Figure 2 given by Boyer particularly seems to indicate that there can be a difference in different parts of the commutator not only because the electrical conditions vary periodically with the number of slots and the inductive relations of the armature coils and the slots to each other, but also because different portions of the commutator have had a different history. It will be noted for instance that the voltage V_1 varies periodically with the pole pitch. This is a condition frequently observed and which also agrees with his statements that certain coloring and burning of bars repeat themselves more or less closely every single or double pole pitch. The explanation for this seems to be that whenever the machine is standing still for some time after an operating period, the cooling conditions of certain segments near the brushes are different from the cooling conditions of the segments between brushes. Such a difference in cooling conditions seems to leave the various portions of the commutator surfaces in a different condition with regard to the oxide film and other characteristics. If subsequently the machine begins to rotate again, this difference seems to persist, as indicated in figure 2 of Boyer's discussion, even though various portions of the commutator carry the same load during the operating period.



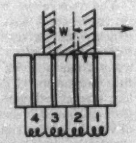
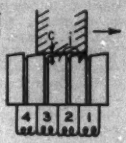


Fig. 4 (left). Transfer of short-circuit current concentrated in portion of brush

Fig. 5 (right). Transfer of short-circuit current with relatively low density in brush

The discussion contributed by J. C. Aydelott brings up a very interesting question. With conditions as shown in figure 4 of this discussion, where the short-circuit current of coil *1* may be suddenly transferred to coil *2*, which is assumed to be located in the same slot, there will occur in the brush portion *d* not only a sudden change in current but also a high density because *d* is very small. However, if in figure 5 of this discussion the short-circuit current of coil *1* is suddenly transferred to coil *2*, there will be a sudden change in current but the density will not be very high because the entire width *w* of the segment carries such current. As pointed out in the paper, it requires a combination of sudden current change and high density to cause sparking. However, previous considerations were under the assumption that there was contact between the entire width of the segment and the brush. With the many irregularities occurring in the contact phenomena, it is quite conceivable that one edge of the commutator segment, for instance the leading edge, will heat to a greater extent than the trailing edge, causing greater expansion of the leading edge and resulting in conditions indicated in a very exaggerated manner in figure 6 of this discussion. In actual practice, the difference in expansion may be very small and the clearance *c* may be in the order of only 0.0001 or 0.0002 inch. Nevertheless this may be sufficient to cause most of the current *i* to flow through the leading edge and thus bring about a combination of sudden change and high current density. As a matter of fact, it frequently can be noted that the appearance of the 2 edges of the segments of commutators is entirely different, indicating that their participation in the carrying of the current and in the commutating phenomena is different.

Fig. 6. Effect of greater heating of leading edge of commutator segment



In order to avoid misunderstandings, it may be well to point out that the references made in our paper to phenomena at or near the edges of the brush relate to what happens near the edges but under the brush. In a previous paper, entitled "Commutation Considered as a Switching Phenomenon," (R. E. Hellmund and L. R. Ludwig, A.I.E.E. TRANS., v. 51, June 1932, p. 465–8) consideration was given to what occurs at the very edge which forms the last or first point of contact in the opening or closing of the circuit of an armature coil. In this earlier paper it was pointed out that certain damping effects are beneficial to commutation at the very edge of the brush. In the present paper it is shown that sudden changes in current are undesirable, which in turn means that any damping effects that can be introduced to avoid such sudden changes would be beneficial in preventing sparking under the brush as well. Similarly, such features as split-throw coils, which were considered beneficial in the previous paper, may prove of advantage with reference to the phenomena discussed in the present paper.

Saturated Synchronous Reactance

Discussion and author's closure of a paper by Charles Kingsley, Jr., published in the March 1935 issue, pages 300–5, and presented for oral discussion at the electrical machinery session of the summer convention, Ithaca, N. Y., June 27, 1935.

S. B. Crary (General Electric Co., Schenectady, N. Y.): This paper is of particular interest as it presents a comparison between a calculated and a test power angle characteristic which is further evidence as to the correctness of the well-known cylindrical rotor vector diagram which was used.

There is a point in the paper, however, which probably could be clarified.

In the second paragraph of his paper the author states that "the synchronizing power of the equivalent machine," as given in reference 3, "will not in general be the correct value for the actual saturated machine" and "This may introduce considerable error as shown in table II." It should be noted that the error he speaks of is in the synchronizing power coefficient $dP/d\delta$ and not in the calculated power limit, i. e., $dP/d\delta_{eq}$ of reference 3 for the cylindrical rotor case does not necessarily equal $dP/d\delta$ (actual). This was discussed in the closing discussion of reference 3 (A.I.E.E. Trans. [Elec. Engg.], v. 53, April 1934, p. 605–7) in which a method was given for obtaining $dP/d\delta$ and in which it was shown that for a particular case, $dP/d\delta_{eq}$ approaches $dP/d\delta$ at pull-out. It would be of interest if Kingsley would use the method of reference 3 and compare it with the results given in his table I.

An equivalent unsaturated machine for the cylindrical rotor case can be obtained, in a similar manner as was obtained for the salient pole case, which will have all the characteristics of the actual machine for small changes. This more accurate equivalent would require 2 equivalent reactances instead of one so that the additional condition of $dP/d\delta_{eq} = dP/d\delta$ can be satisfied. However, as in the salient-pole case, this additional refinement is not usually necessary for practical calculations as both salient pole and cylindrical rotor machines are quite accurately represented at pull-out by one equivalent reactance.

H. B. Dwight (Massachusetts Institute of Technology, Cambridge): This paper is characterized by a feature which is of great advantage in this type of work, namely, the author of the paper has made tests which show the accuracy of his method.

If a stability calculation whose purpose is to show the load angle for a certain case or the maximum load for certain conditions, transient or otherwise, is put forward, then the person making the calculation should, if at all possible, make tests on practical machines to show the correctness of the calculation. Such tests should involve as complete a set-up of apparatus as possible and a variety of machines, and should include actual measurements of load angle and of maximum power, since these are the results for which the calculation is made. Greatly improved instruments for measuring load angle are now available, among the new types being those developed by Prof. H. E. Edgerton. It is to be hoped that more of such tests will be published.

L. A. Kilgore (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper presents in a very clear manner one method of dealing with saturation in calculating power angle curves and maximum power for a synchronous machine. Any method of accurately calculating the excitation of a machine for different loads is suitable for calculating maximum power in a step-by-step process. The A.I.E.E. method of calculating excitation at different power factors from the no load and zero power factor curves gives good results, although it is largely empirical.

The assumption is made that the saturation is the same under load as at no load for the same air gap voltage. This assumption is not so incorrect for turbine generators but for salient pole machines it is seriously in error. If the author had used Potier's reactance x_P throughout instead of stator leakage, the accuracy would be greatly improved for Potier's reactance empirically makes an allowance for the field leakage and although it does vary somewhat, it gives quite good results. Using Potier's reactance equation 2 becomes: $x_s = x_P + \frac{x_d - x_P}{k}$ and none of the other equations are affected.

It is interesting to consider the difference between the "saturated synchronous reactance" as described in this paper and the "equivalent reactance" described in reference 3. The saturated reactance represents at least approximately the correct relations between the fluxes in the machine and gives the true angle. It is necessary to correct the internal voltage by a factor k to get a measure of the field current and since k and the reactance are variable, the synchronizing power or rate of change of power with respect to angle can only be calculated by a step-by-step process.

The equivalent reactance as described in reference 3 was intended as a value which would give the correct change in terminal conditions for a small change away from a given operating point with field excitation. The value of the equivalent reactance is generally much lower than the saturated reactance, and has less physical meaning since it does not represent the flux in the machine and it does not give the true internal angle. The equivalent reactance is easier to use once it has been determined, since it requires no factor k for the internal voltage. The problem of calculating or testing this quantity is difficult for an accurate analysis shows that the value is not only different for each operating condition, but varies appreciably for different directions of change away from each point.

The conclusion is that the equivalent reactance is a quantity easy to use but difficult to determine whereas the saturated reactance as defined here is more readily determined and has a direct physical meaning. Both of these quantities have their use in special problems but it is doubtful if either will supplant the short circuit ratio as a measure of a machine's stability under steady state conditions.

Sterling Beckwith (The Metropolitan Water District of Southern California, Los Angeles): The author has made a valuable contribution to the knowledge of saturated synchronous reactance. He has, by the artifice of representing a machine by a "saturated" reactance that must be used with a changing internal voltage, obtained a much simpler expression for saturated synchronous reactance than is otherwise possible, so that in many cases his method should be superior to others.

A question I wish to raise, however, is whether as a general method of attack in a complicated problem the method of using varying internal voltages is as powerful or simple a method as the method (references 1, 2, 3, 4, and 5 of this discussion) which uses either a fixed internal voltage, or an internal voltage which is constant during the incremental interval in which stability is being checked.

In Kingsley's method there is a simple expression for saturated reactance; a simple expression for the voltage behind it; a reasonably simple method of calculating power angle characteristics; a fairly simple method of calculating maximum power; and the limitation that the external system must be reduced to an equivalent series impedance.

In the other methods, there is a complicated expression for saturated or equivalent or adjusted reactance (but a simple approximation) a fairly simple expression for internal voltage (it must be merely the internal voltage that gives proper terminal conditions) a simple method of checking stability at the point of operation (any of the conventional methods may be used) a difficult step-by-step method of obtaining a power angle characteristic (because of the changing saturation) and a simple means of allowing for complicated external systems by means of transfer and driving point impedances. There is also a further advantage in that 2 machines of equal reactance at the pull-out point will have equal stability limits, which is not true of the reactance Kingsley defines as saturated synchronous reactance.

In the problems with which I have dealt in the past, the second method has appeared to be better than Kingsley's method but different problems and more experience with his method are necessary before drawing a final conclusion.

1. Equivalent Reactance of Synchronous Machines, S. B. Crary, L. A. March, and L. P. Schildneck. Elec. Engg. (A.I.E.E. Trans.), v. 53, Jan. 1934, p. 124–32.

2. Adjusted Synchronous Reactance, and Its Relation to Stability, H. B. Dwight. *Gen. Elec. Rev.*, v. 35, Dec. 1932, p. 609.

3. Discussion by G. C. Dahl of ref. 1. Elec. Engg. (A.I.E.E. Trans.), v. 53, April 1934, p. 604–5.

4. Discussion by J. W. Butler of ref. 1. Elec. Engg. (A.I.E.E. Trans.), v. 53, March 1934, p. 484.

5. Discussion by Sterling Beckwith of ref. 1. Elec. Engg. (A.I.E.E. Trans.), v. 53, March 1934, p. 486–7.

Charles Kingsley, Jr.: S. B. Crary believes that the statement in the second paragraph of the paper in regard to the synchronizing power of the equivalent machine may be misleading. I believe that the statement in the paper is correct, though perhaps it should be amplified, i. e., "the synchronizing power of the equivalent machine will not *in general* be the correct value for the actual saturated machine." However, as Crary has pointed out, it is expected that this error usually will be small at pull-out.

I did not use the method of reference 3 of the paper to calculate the maximum power, as Crary has suggested, since I do not believe that this method is readily adapted to this type of calculation. As stated in the fourth paragraph of the paper, the method of reference 3 is, practically speaking, restricted to cases where the terminal operating conditions are explicitly

known. In calculating maximum power at given constant values of field excitation and receiver bus voltage, the terminal load conditions at pull-out are not explicitly known. Hence, in order to use the method of reference 3, it would be necessary to resort to a rather laborious cut and try process.

I agree with H. B. Dwight that the publication of further test data showing power angle characteristics for a variety of machines under both steady-state and transient conditions would be of great interest.

L. A. Kilgore's discussion raises several interesting points. He mentions the use of the A.I.E.E. method for calculating maximum power. Methods *D* and *E* of table I of the paper are adaptations of the A.I.E.E. method, and the table shows the accuracy of these methods for several different cases. Although the A.I.E.E. method and its various modifications give reasonably close results in calculating excitation at lagging power factors, larger errors may be introduced in calculating maximum power, since the A.I.E.E. method does not give the correct value for the load angle of the machine.

Kilgore suggests that the use of Potier's reactance instead of armature leakage reactance may give increased accuracy, since Potier's reactance empirically makes an allowance for the change in field leakage under load conditions. However, as Kilgore points out, the effects of field leakage are usually not very great in turbine generators, and as shown by March and Crary (Elec. Engg., v. 54, April 1935, p. 378) Potier's reactance is usually approximately equal to armature leakage reactance for cylindrical rotor machines (though I have found a case in which Potier's reactance was about twice the calculated value of armature leakage reactance). Since this paper is confined to the cylindrical rotor case, probably there is in most cases little difference between Potier's reactance and armature leakage reactance. Also I should like to point out that the results obtained by the methods of my paper are only slightly affected by the value of leakage reactance used in the equations. For example, I have calculated case I, method *B* of table I of the paper using a value of $x_a = 0.052$ (half the value used in calculating table I). The result so obtained checks the value given in table I to within a fraction of one per cent. However, I am attempting to extend the methods of this paper to the salient-pole machine, and in this case his suggestion may prove valuable.

Kilgore makes an interesting comparison between the "saturated synchronous reactance" as described in my paper and the "equivalent reactance" of reference 3. I should like to add that an analytical solution for the steady-state synchronizing power can be obtained from saturated synchronous reactance for the simple system of figure 1 as follows:

Differentiating equation 6 of the paper, remembering that (kZ) and α are variables:

$$\frac{dP_a}{d\delta} = \frac{E_f V}{kZ}\left(1 - \frac{d\alpha}{d\delta}\right)\cos(\delta - \alpha) - \frac{1}{kZ}\left[\frac{E_f V}{kZ}\sin(\delta - \alpha) + \frac{2E_a^2 r}{(kZ)^2}\right]\frac{d(kZ)}{d\delta} \qquad (1)$$

It is necessary to evaluate $d\alpha/d\delta$ and $d(kZ)/d\delta$. It can be shown that these derivatives can be expressed as follows:

$$\frac{d\alpha}{d\delta} = \frac{x_m}{kZ}\sin\alpha\,\frac{1}{k}\frac{dk}{d\delta} \qquad (2)$$

$$\frac{d(kZ)}{d\delta} = (kZ - x_m\cos\alpha)\,\frac{1}{k}\frac{dk}{d\delta} \qquad (3)$$

The derivative $dk/d\delta$ can be evaluated in terms of the slope of the saturation curve by differentiating equation 8 of the paper and making use of equation A-6 derived in Appendix A of reference 3. The result is:

$$\frac{1}{k}\frac{dk}{d\delta} = -\frac{sE_f V Z_e x_m \sin(\delta - \alpha_e)}{(kZE_a)^2\left(1 - \frac{sx_m}{kZ}\cos\alpha\right)} \qquad (4)$$

where

s = slope saturation factor = a/E_a

a = intercept shown in figure 2 of reference 3.

For given terminal load conditions, all quantities on the right hand side of equation 4 can be calculated. Hence $\frac{1}{k}\frac{dk}{d\delta}$ can be calculated from equation 4 and the result substituted in equations 2 and 3. Substituting the resulting values of $d\alpha/d\delta$ and $d(kZ)/d\delta$ in equation 1, the corresponding value of the synchronizing power can be obtained. If the field excitation E_f and receiver bus voltage V are given, but the terminal load conditions are not explicitly known, the saturated values of $(kZE_a)^2$, (kZ), α and s to be used in the equations can be obtained as functions of δ by using equation 8 of the paper and auxiliary curves similar to those of figure 5 of the paper, adding to figure 5 a curve of s as a function of $(kZE_a)^2$.

Sterling Beckwith has pointed out a limitation to the method described in the paper. Equations 2 and 3 of the paper give the saturated synchronous reactance and excitation voltage of a cylindrical rotor machine regardless of the external system, and can be used in the analysis of a complicated system by employing a cut and try process to determine the air gap voltage at which the saturation factor k of each machine must be taken. I believe that something of this nature also may be necessary in using the methods of references 3, 4, and 5 of Beckwith's discussion. However, in order to use equation 8 and the auxiliary curves of figure 5 of the paper, the external system must be reduced to an equivalent impedance in series with a constant voltage. I believe that this same limitation is imposed on the method of reference 3 of the paper (reference 1 of Beckwith's discussion), and that any approximations which can be made in reducing the external system for use with the method of reference 3 can also be used in connection with the method of my paper. Since the publication of my paper, I have developed a way of applying my method to more complicated systems by using it to calculate machine performance charts somewhat similar to those described in Beckwith's paper (Elec. Engg., v. 54, July 1935, p. 728–34).

I believe that in any comparison between the methods of this paper and other methods of calculation, consideration should be given to the fact that the methods of this paper are based on a more nearly correct theoretical foundation than the others (with the possible exception of reference 3 of my paper), and that the accuracy is accordingly greater. The accuracy with which the system to be analyzed can be reduced to a simple equivalent system and the accuracy desired in the solution, as well as the relative simplicities of the various methods of calculation, will be important factors in deciding which method should be used.

Effects of Saturation on Machine Reactances

Discussion and author's closure of a paper by L. A. Kilgore published in the May 1935 issue, pages 545–50, and presented for oral discussion at the electrical machinery session of the summer convention, Ithaca, N. Y., June 27, 1935.

Charles Kingsley, Jr. (Massachusetts Institute of Technology, Cambridge): Satisfactory theoretical methods are known for taking into account the effects of saturation on the synchronous reactances under balanced steady-state operating conditions. Under unbalanced or transient conditions, the effects of saturation on the various reactances become extremely complicated, and at present no satisfactory theoretical solution for these effects is known. This paper presents empirical methods based on the average of the results obtained from a large number of tests on representative machines of various types. The paper summarizes the best information which is at present available. The proper use of these empirical methods should, in most cases, increase the accuracy of calculations involving the unbalanced or transient operation of machines which do not differ greatly from average designs. However, it is to be hoped that methods eventually will be developed which take into account more accurately the various factors which affect the results.

Kilgore has raised a question in regard to the specification of the degree of saturation to be understood in giving standard definitions of the various reactance coefficients. This question is one which should be definitely settled. He recommends that some of the reactances be defined as the unsaturated values, while others be defined as the saturated values applying for sudden short circuit at rated voltage with no load.

I should like to suggest that all of the reactance coefficients and time constants be defined as the unsaturated values, and that this be the value to be understood unless the saturation is otherwise specified. My reasons for making this recommendation are:

1. The synchronous machine theories from which these reactance coefficients are derived are based upon the assumption that the magnetic circuit is mathematically linear. This assumption is usually most nearly correct at low flux densities. Therefore, if the reactances are all defined as the unsaturated values, the definitions will have a reasonably correct theoretical basis.

2. The definitions should be consistent. If some of the reactances are defined as the unsaturated values, while others are defined as the saturated values, it is necessary to remember in which manner each of a rather large number of reactances and time constants is defined with respect to saturation.

3. It is easier to measure the unsaturated values. Kilgore suggests that the unsaturated values can be measured and the saturated values obtained from them by the use of empirical saturation factors. This reduces the accuracy of the saturated values so obtained to about the accuracy of these saturation factors. This seems scarcely accurate enough to be standardized in a definition. It is desirable that the value of each reactance given in the standard definitions should be directly and easily measurable.

Kilgore raises the practical point that the reactances and time constants which he suggests be defined as the saturated values are most commonly used in calculating short-circuit currents at full voltage, and that considerable error may be introduced in these calculations if the unsaturated values are used. This practical objection to the use of the unsaturated values in standard definitions can readily be overcome by supplying those who make short-circuit calculations with the saturated values, definitely stating that the values given are the saturated values. The use of the unsaturated values in standard definitions does not mean that these values should be used in full voltage calculations. Perhaps a brief statement to this effect should be included in the definitions, together with a convenient table of approximate saturation factors, such as table III of the paper.

Whenever there is any ambiguity as to the exact meaning of the "unsaturated" value, I recommend that it be understood as the value obtained at rated armature current.

S. B. Crary (General Electric Co., Schenectady, N. Y.): This paper is a valuable contribution to the literature of saturation and its effect on synchronous machine reactances in that it summarizes extensive test data and at the same time presents an approximate method of calculating the saturation factor for transient reactance.

In calculating the effect of saturation in a salient-pole machine, the author has obtained his result by calculating 2 saturation factors k_{sm} and k_{sl} which are determined independently, the net factor is then k_{sm} times k_{sl}. Further, he has assumed that k_s which is used in the calculation of k_{sm} does not change during the transient. Actually k_s changes as the distribution of flux changes. These assumptions are not necessary in order to obtain a comparatively simple expression for x_d' (saturated), as may be shown as follows. Consider the case of a salient-pole synchronous machine with laminated magnetic paths and which for the sake of simplicity in this discussion has no stator saturation. Then the saturation characteristics are defined by the 2 sets of curves in figure 1 of this discussion. The following nomenclature is used:

$k_3 = 1 + \dfrac{\text{rotor saturation mmf}}{\text{air gap mmf}} =$ air gap flux rotor saturation factor

k_2 = field leakage flux saturation factor

i_d = direct axis armature current

i_{fd} = field current

ψ_{ad} = direct axis air gap flux or flux mutual with field and armature

ψ_{fld} = field leakage flux

$\psi_{ffd} = \psi_{ad} + \psi_{fld}$ = total field flux

x_l = armature leakage reactance

x_{afd} = mutual reactance between field and armature

x_{fld} = field leakage reactance

Then

$$\psi_{ffd} = \left[\frac{x_{afd}}{k_2} + \frac{x_{fld}}{k_2}\right] i_{fd} - \left[\frac{x_{afd}}{k_2}\right] i_d \quad (1)$$

$$\psi_{ad} = \frac{x_{afd}}{k_2} i_{fd} - \left[\frac{x_{afd}}{k_2} + x_l\right] i_d \quad (2)$$

Initially, since $i_d = 0$,

$$\psi_{ffdo} = \left[\frac{x_{afd}}{k_{20}} + \frac{x_{fld}}{k_{20}}\right] i_{fdo} \quad (3)$$

$$\psi_{ado} = \frac{x_{afd}}{k_{20}} i_{fdo} \quad (4)$$

At the end of the first half cycle since

$$-\psi_{ado} = \psi_{ad} \quad (5)$$

and

$$\psi_{ffdo} = \psi_{ffd} \quad (6)$$

$$\left[\frac{x_{afd}}{k_{20}} + \frac{x_{fld}}{k_{20}}\right] i_{fdo} = \left[\frac{x_{afd}}{k_2} + \frac{x_{fld}}{k_2}\right] i_{fd} - \frac{x_{afd}}{k_2} i_d - \frac{x_{afd}}{k_{20}} i_{fdo} = \quad (7)$$

$$\frac{x_{afd}}{k_2} i_{fd} - \left[\frac{x_{afd}}{k_2} + x_l\right] i_d \quad (8)$$

Solving for i_d,

$$i_d = \frac{\dfrac{x_{afd}}{k_{20}}\left[\dfrac{x_{afd}}{k_2} + \dfrac{x_{fld}}{k_2}\right] + \dfrac{x_{afd}}{k_2}\left[\dfrac{x_{afd}}{k_{20}} + \dfrac{x_{fld}}{k_{20}}\right]}{\left(\dfrac{x_{afd}}{k_2} + x_l\right)\left(\dfrac{x_{afd}}{k_2} + \dfrac{x_{fld}}{k_2}\right) - \dfrac{x_{afd}^2}{k_2^2}} i_{fdo} \quad (9)$$

Similarly i_f may be calculated. Therefore, from equation 9,

$$x_{d\,(saturated)}' = 2 \frac{\left(\dfrac{x_{afd}}{k_2} + x_l\right)\left(\dfrac{x_{afd}}{k_2} + \dfrac{x_{fld}}{k_2}\right) - \dfrac{x_{afd}^2}{k_2^2}}{\dfrac{1}{k_{20}}\left[\dfrac{x_{afd}}{k_2} + \dfrac{x_{fld}}{k_2}\right] + \dfrac{1}{k_2}\left[\dfrac{x_{afd}}{k_{20}} + \dfrac{x_{fld}}{k_{20}}\right]} \quad (10)$$

When no saturation exists, $k_2 = k_3 = 1.0$, and equation 10 reduces to the well-known relation for transient reactance

$$x_d' = x_d - \frac{x_{afd}^2}{x_{ad} + x_{fld}}$$

The initial saturation coefficients k_{20} and k_{30} are known and the coefficients k_2 and k_3 can be obtained from figure 1 and equations 1 and 2 for estimated values of i_{fd} and i_d. The above expression is more general than that obtained by Kilgore in that it takes into account the change in the flux distribution from the initial condition to that at the end of the first half cycle.

In determining the saturation factors for the case of transient stability we would be interested in knowing in more detail what assumption Kilgore has made. We have made an analysis of the effect of saturation on the performance of synchronous machines for small oscillations. In this analysis the rate of change of saturation with respect to the flux, $\partial k/\partial\psi$, constitutes an important factor which cannot be neglected. It is apparent, therefore, that for any study which involves any oscillation such as that obtained in stability that the correction for the reactance cannot be arrived at as simply as in the case of calculating the peak of the first half cycle of armature short-circuit current. The equivalent transient reactance obtained from this analysis of small angular oscillations for the case of a machine having laminated magnetic paths, no stator saturation, and no saturation affected by quadrature axis flux, is

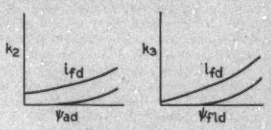


Fig. 1. Saturation characteristics assumed for salient pole machine

See text for explanation

$$x'_{d(eq)} = x_{d(eq)} - \frac{x_{afd(eq)}\, x_{fad(eq)}}{X_{ffd(eq)}} \quad (11)$$

where

$$X_{ffd(eq)} = x_{fad(eq)} + x_{fld(eq)} \quad (12)$$

$$x_{d(eq)} = x_l + \frac{x_{afd}}{k_2\left[1 + \dfrac{\psi_{ad}}{k_2}\dfrac{\partial k_2}{\partial \psi_{ad}}\right]} \quad (13)$$

$$x_{afd(eq)} = \frac{x_{afd}}{k_2\left[1 + \dfrac{\psi_{ad}}{k_2}\dfrac{\partial k_2}{\partial \psi_{ad}}\right]} \quad (14)$$

$$x_{fad(eq)} = \frac{\left[x_{afd} - \psi_{ad}\dfrac{\partial k_2}{\partial i_{fd}}\right]}{k_2\left[1 + \dfrac{\psi_{ad}}{k_2}\dfrac{\partial k_2}{\partial \psi_{ad}}\right]} \quad (15)$$

$$x_{fld(eq)} = \frac{\left[x_{fld} - \psi_{fd}\dfrac{\partial k_3}{\partial i_{fd}}\right]}{k_3\left[1 + \dfrac{\psi_{fld}}{k_3}\dfrac{\partial k_3}{\partial \psi_{fld}}\right]} \quad (16)$$

Equation 12 corresponds to equation 9 of reference 2 for the same conditions, i. e., no stator saturation or rotor saturation affected by quadrature axis flux.

S. H. Mortensen (Allis-Chalmers Mfg. Co., Milwaukee, Wis.): This very able paper shows that a number of the reactances and time constants used in the method of

symmetrical components and analysis of transients are not constants, but due to saturations in various leakage paths, change with the current values involved. This means that each current value has a corresponding reactance, and to prevent complications the author suggests that only one value of the respective constants be standardized which, unless otherwise specified, he proposes should be the saturated value. This suggestion would have merit if the current values involved always would correspond to one operating condition, such as a short circuit at machine terminals, etc. As this is not the case where line constants enter into the picture, it would seem preferable to both operators and designers to base guaranteed reactance constants upon a current value that can readily be obtained and checked by test, such as would be the case if reactances corresponding to rated current were standardized upon. Corrections corresponding to other current values could then be made with sufficient accuracy with the aid of characteristic saturation factor curves similar to those shown in this paper. For that reason it would seem justifiable to recommend that the one value of reactance and time constant corresponding to the rated machine current be standardized.

E. H. Freiburghouse and **C. E. Kilbourne** (both of General Electric Co., Schenectady, N. Y.): The author has presented a very interesting paper summarizing tests on the effects of saturation on synchronous machine reactances and also has given a useful approximate method of obtaining a saturation factor for the transient reactance. As a result of this study a suggestion is advanced that one value of certain so-called constants is sufficient to define the machine behavior and that that value is the saturated value, this meaning the value obtained from a sudden short-circuit from full voltage. This is an excellent and simple treatment of the problem and will undoubtedly give the industry more accurate values of these constants than an indiscriminate use of the unsaturated values would give. However, these are instances when the industry could be served to further advantage with some additional information and other cases where the limiting values of these constants are not the minimums as given by the saturated values but the maximums as given by the unsaturated values.

A survey of approximately 20 constants, including reactances and time constants which can be affected by saturation, indicates that for salient pole machines only 2 frequently used constants, the transient reactance x_d' and its associated quantity T_d' show significant changes with saturation in the operating ranges where they are used in calculations. On wound rotor machines saturation has a much more important effect. Here the transient reactance x_d', the subtransients x_d'' and x_q'', the negative sequence x_2, the zero sequence x_0, and all their associated time constants change with saturation. On double winding generators the through reactance is also affected, and on a few machines the stator leakage reactance x_1 has appreciable variations. However, there are reactances x_d, x_q, etc., which are essentially unsaturated.

In each case where saturation plays an important part it is dependent upon the value of armature current existing under the conditions being calculated. Consequently, any one value of a constant that saturates is truly accurate only under the particular conditions existing when it was obtained. This can easily be seen by an inspection of the curves presented in the paper. Therefore, the giving of a single saturated value for these quantities will have their use subject to interpretation for any except the one condition.

Also, the defining of some constants as saturated for all synchronous machines, both salient pole and round rotor, and others as not saturated may produce confusion. Particularly is this true when some of those defined as saturated for one type of machine are unsaturated for the other. Instead of simplifying the existing method as applying to the entire synchronous machine field and producing more accurate results of calculations with less experience required to handle the quantities correctly, this procedure might have the opposite result.

The advantages, which Kilgore has pointed out, in giving saturated values of these constants can be combined with the present general practice so as to further the needs of the industry without omitting some information which can be made available. This can be done if the basis of giving this information remains in nearly its present form, that is, that all constants be given as "normal values," that value being defined as the value existing when normal 3-phase armature current flows under the conditions dominated by the quantity. In addition to these normal values, a "saturation factor" could be given for the particular constants on any machine which needs these values to permit their accurate use.

In order to standardize on practice, the saturation factor generally given can be defined as the ratio existing between the value of the particular constant obtained from a sudden short circuit from full voltage and the normal value. As an equation for the transient reactance this is

$$f = \frac{x_d' \text{ saturated}}{x_d' \text{ unsaturated}}$$

where

f is the "normal saturation factor"

x_d' saturated is the transient reactance obtained from a short circuit from full voltage

x_d' unsaturated is the transient reactance obtained from a short circuit where normal armature current existed

Further, certain constants can be specified as having saturation factors appreciably different than unity. These are so shown in table III of the paper. In addition, average values of these normal saturation factors can be published and if felt desirable can be standardized. Also the methods of obtaining such factors can be standardized. Because of the fact that full voltage short-circuit tests are very expensive to make on test set-ups for large machines it is desirable that these factors be obtained as outlined by Kilgore.

If this should be done the basic method now in use in specifying these constants would not be greatly changed and hence little confusion would result. Also the magnitude of these "saturation factors" will definitely point out which constants on a particular machine are subject to saturation without affecting the same constants on other machines and, further, the use of "ratios" to point out these affects indicates the degree of saturation which a single value cannot. This is quite desirable information when interpretations from one condition to another are to be made.

L. A. Kilgore: The chief purpose of this paper was the presentation of data on the effects of saturation on the various machine reactances. The choice of which value should be used as a reference is somewhat arbitrary, but it is important that some agreement be reached on the value to be understood for each constant when the degree of saturation is not specified.

In their discussions, Mortenson, Kingsley, Kilbourne and Freiburghouse state their preference for rated current values rather than saturated values as recommended in the paper. There are good reasons for both methods of dealing with the problem. I do not believe that Kilbourne and Freiburghouse meant to imply, as it would seem from the fifth paragraph of their discussion, that the present practice is to give all reactance values on a rated current basis. It has been our practice to give saturated values, except for synchronous reactance, unless the unsaturated value was specified. Previous to the time when locked tests were first seriously considered for measuring reactances (about 5 years ago), reactances were generally measured by short circuits and the values used generally were saturated values. The new standard decrement curves were worked up on the basis of typical relations between saturated values.

The chief objection to having the rated current values as the reference is that if no correction is used, serious errors may result in certain cases. The worst case is for a 2 pole turbogenerator where the use of rated current values of subtransient reactance will give a short-circuit current 28 per cent low for a short circuit at the terminals. Kingsley suggests that this objection can be readily overcome by giving saturated as well as rated current values where there is appreciable difference. Kilbourne and Freiburghouse suggest a saturation factor which would be the ratio of saturated to the rated current value. Both of these suggestions are good in that they would give more information; nevertheless, they will undoubtedly lead to some complication and confusion. However, it would seem that some such method would be most satisfactory to the majority of those who have so far expressed an opinion.

S. B. Crary asks concerning the assumptions made in calculating the saturation of the transient reactance for use in stability calculations. The methods given in the appendix and the curves of figure 7 are sufficiently general to calculate the saturated value for each point in the transient swing. The typical curves of figure 2

were intended to be used with the maximum value of current which occurs as pull-out is approached.

Crary's discussion gives another method of calculating a saturated transient reactance for each instant. He also presents a new concept of an "equivalent transient reactance." It would be interesting if he can publish some quantitative data on such a constant and compare it with the "saturated value" as used in the paper. It would not seem reasonable to expect so large a difference between "saturated" and "equivalent transient reactances" as between "saturated" and "equivalent" synchronous reactances described in references 1 and 2 of the paper.

Armature Leakage Reactance of Synchronous Machines

Discussion and authors' closure of a paper by L. A. March and S. B. Crary published in the April 1935 issue, pages 378–81, and presented for oral discussion at the electrical machinery session of the summer convention, Ithaca, N. Y., June 27, 1935.

P. L. Alger (General Electric Co., Schenectady, N. Y.): It is desirable to keep clearly in mind the object of continuing this rather involved discussion of various kinds of reactance.

Originally, there was thought to be just one important reactance of a synchronous machine, the reactance which, in conjunction with the armature reaction, determined the voltage regulation. Potier gave a useful method for finding this reactance from test data, and so it has been called after his name. Then, it was found that this reactance did not check the reactance required to determine the momentary short circuit current, so that this latter, or "transient" reactance, was separately considered. It was thought that the transient reactance was equal to the Potier reactance plus an element due to the field. Next, it was learned that the difference between the transient reactance and the field reactance is normally much smaller than the Potier reactance. Thus, the true armature leakage reactance which, added to the field reactance, accounts for the transient reactance, came to be more accurately calculated and generally used as distinct from the Potier reactance. The Potier reactance was then recognized to be larger than the leakage reactance, because of the drop in voltage under load, due to the increased saturation of the pole body resulting from increased field leakage. For correct calculation of voltage regulation by the Potier diagram, it was necessary to use a fictitiously high value of leakage reactance.

The authors of this paper have now shown that this increment of leakage reactance due to pole saturation, which is a part of the Potier reactance, varies markedly with machine saturation, thus fairly completing our understanding of the nature of all of these machine reactances.

It is evident that the actual value of Potier reactance is only useful for problems of calculating regulation, and so is not pertinent to ordinary machine performance guarantees. The importance of the paper lies in the improved understanding it gives of the actual flux densities existing throughout the magnetic circuit, thus enabling designers to more intelligently proportion the parts of a machine to utilize the materials effectively.

C. C. Shutt (Westinghouse Elec. and Mfg. Co., East Pittsburgh, Pa.): This paper presents some interesting data on the variation of Potier's reactance. However, a review of a considerable amount of test data does not seem to justify the conclusion that Potier's reactance as tested at any test results for 100 machines is only 0.6 per cent.

Table I of the present paper gives data on 5 machines. Here the average absolute variation by the high field current method is 28 per cent while by subtracting X_{al} from the tested value of X_d gives an average variation of only 3 per cent.

Another interesting feature brought out by a study of the curves is that for a constant voltage back of Potier reactance; the value of this reactance is practically constant for a variation in the armature current. The variation in the reactance under these conditions is shown by the dashed line K in figure 1 of this discussion.

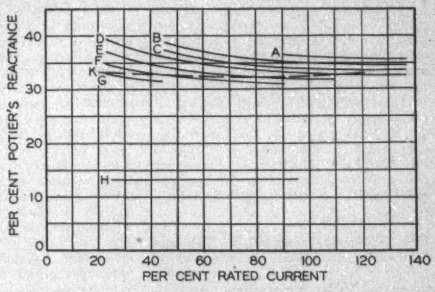


Fig. 1. Variation of Potier's reactance with armature current at various voltages

Voltages: A—57 per cent; B—68 per cent; C—79.5 per cent; D—91 per cent; E—102.5 per cent; F—113.5 per cent; G—125 per cent; K—Constant back of Potier reactance; H—Curve for x_l by Kilgore's method.

practical value of pole saturation may be used as a reliable measure of the armature leakage reactance.

One type of data not presented in the paper is the variation of Potier's reactance with armature current for constant values of voltage. A set of test curves was taken on a standard commercial motor rated 200 horsepower at 450 rpm. This machine had about 70 per cent of its saturation in the pole at open circuit rated voltage.

Figure 1 of this discussion shows the results of these tests, which covered a fairly wide range of current and voltage. Two noticeable points shown by the tests on this machine are:

1. Over the range tested the variation in Potier reactance is only 22 per cent.
2. The Potier reactance, at the lowest value tested, is 240 per cent of the calculated armature leakage reactance.

The same data can be plotted as reactance against voltage for constant armature current.

As stated in the paper, it is desirable to have some means of testing for the armature leakage reactance. Both Alger and Kilgore have pointed out that the value which they calculate is based on arbitrarily classifying a certain portion of the total flux in the machine as armature leakage reactance. The most practical means of checking this value appears to be that used by Alger of measuring the direct axis synchronous reactance and subtracting the properly calculated reactance of armature reaction. This is not a direct test and involves subtraction of a number from another, which is not much larger, to obtain a relatively small number for the answer. But the average absolute variation as given in Alger's paper between calculated and

This curve is derived as follows: Calculate the voltage back of Potier reactance for any point. Using the point of 100 per cent current and 91 per cent terminal voltage, it is found that the voltage back of Potier reactance is 124 per cent. Consider this voltage constant and calculate the terminal voltage for different values of armature current. With a couple of trials the calculated value of terminal voltage can be made to check with the value of Potier reactance as shown on the curve for that value of voltage and armature current.

T. A. Rogers (University of California, Berkeley): Between 1895 and 1905 there were many papers on the subject of alternator regulation discussing the theoretical aspects of the problem and suggesting some methods for experimentally determining the factors to be used in computing the voltage drop under load. Practically all of the methods considered the leakage reactance of the armature windings in some form or other. Of the many methods proposed ("The Regulation of Alternators," D. B. Rushmore, Intl. Elec. Congress *Trans.*, St. Louis, 1904, v. 1, p. 729) that of Potier probably has received the most attention until recent years.

In 1900 Potier pointed out that if one shifted the no load saturation curve downward and to the right by given amounts, it would approximate very closely the zero power factor curve for overexcitation. That is, the no load saturation curve and the zero power factor curves are practically parallel to each other. These latter curves may be drawn for any current, just so long as that current is constant. In addition, by shifting the no load saturation

curve upward and to the left, Potier indicated that it would successively coincide with the underexcited zero power factor curves. The horizontal shift, he states, is due to the effects of armature reaction, the vertical shift to dispersion (leakage).

Two coefficients are suggested in the determination of the excitation of a machine. One of them, λ, has the dimensions of reactance, and is used in conjunction with the armature current to determine the voltage drop due to the leakage fluxes. The other, α, has the dimensions of turns (zero dimensions), and, when multiplied by the phase current, gives the magnitude of the demagnetizing armature ampere turns referred to the rotor field.

Potier proposed his theories only as an attempt to determine the excitation of a loaded alternator, and not to introduce a method of determining armature leakage reactance. He made no mention of armature or pole leakage fluxes, or of leakage reactances, as such. He merely pointed out that magnetic leakage in the machine influenced the vertical displacement of the no load saturation curves, and that the magnitude of the shift is affected by saturation in the poles. He states further that the length of the air gap, and the depth and enclosure of the slots, modify the leakage flux, and hence the vertical displacement. Although one might assume from his discussion that armature leakage flux was implied in the treatment, his writings fail to disclose specific reference to that quantity or to armature leakage reactance.

Many writers have interpreted Potier's theory as a means of determining armature leakage reactance in addition to its value in calculating excitation. In spite of the fact that Rothert pointed out in 1902 that the Potier reactance coefficient was not true armature leakage reactance but contained, in addition, the components of pole leakage occurring under load, many authors of textbooks continue to cite Potier's triangle as the only method which will give the true armature leakage reactance.

It is quite evident, as pointed out by the authors and conclusively indicated by their test results, that the substitution of the Potier reactance for the armature leakage reactance of a machine introduces large errors in the performance calculations. As discussed in an earlier paper by Crary, March, and Shildneck, the value of the air gap voltage is directly dependent upon the correct values of armature resistance and armature leakage reactance, and it is this voltage that serves as a measure of the amount of saturation occurring within the machine. An error of 75 or 100 per cent in the value of leakage reactance used may introduce an error of 200 per cent or more in the calculated value of field amperes necessary to overcome the effect of saturation within the machine.

Furthermore, leakage reactance, because of the calculation of additional field ampere turns required for the saturated machine, affects the torque angle. The angle always is decreased because of saturation. However, depending upon the power factor, replacing armature leakage reactance by Potier reactance may decrease the apparent air gap flux, decrease the apparent saturation, and consequently increase the torque angle. Both excitation and angle thus are influenced appreciably by the value for amature leakage reactance.

This paper provides not only a procedure for experimentally approaching armature leakage reactance but also a rather complete physical picture of the component parts of that fictitious quantity termed Potier reactance. These results should assist even those who are most reluctant in discarding Potier reactance in machine theory and substituting armature leakage reactance which is not only susceptible to an exact definition but also may be calculated.

B. L. Robertson (University of California, Berkeley): The first point of major significance in the paper is that the so-called Potier reactance is not armature leakage reactance but is something quite different. This fact has long been known, but Potier reactance still is very commonly employed in textbooks as true armature leakage reactance, in some instances without the apparent knowledge that these 2 reactances are not the same thing. Potier reactance may include armature leakage reactance as a component, and, as shown by the procedure introduced by the authors, may approach the latter as a limiting value. Nevertheless, Potier reactance as usually found is far too great in magnitude to be substituted for armature leakage reactance with any accuracy.

The continued use of Potier reactance as the substitute for armature leakage reactance is based upon the fact that whereas armature leakage reactance is calculable but difficult of test, Potier reactance is not calculable but is comparatively easy to test. Potier reactance, however, does not possess the nice physical significance which lies behind armature leakage reactance, and it is for this reason that Potier reactance is defined only by stating its method of being found, rather than by picturing it also in terms of physical concepts.

Usual statements are to the effect that in determining Potier reactance one should work at some point above the knee of the saturation curve. Rated voltage is most often taken as that point, although for no quite definite reason. As shown very clearly by the authors, it obviously makes a considerable difference just where the Potier triangle is located.

In the determination of the leakage reactance triangle, the authors do not state explicitly the manner by which they obtain the zero power factor curves, although one should infer that actual runs with circulating currents were taken. Treatments on locating such curves make use of several methods, some of which are for constructions using only one, or perhaps 2, test or calculated points. Because the saturation curve *may not* be shifted parallel to itself to give the zero power factor curve, and because the proposals for obtaining this latter curve do not all agree with each other, it might be well for the authors to indicate definitely their method.

In determining the load saturation curves the authors rely upon the assumption that armature leakage reactance is not affected by saturation, and further imply (there is no attending statement to this) that the direct synchronous reactance is unsaturated. Working out on the curves at such high degrees of saturation as are shown it is hard to believe that these quantities are not so affected, in which case the leakage reactance triangles will be altered progressively, ultimately to change the Potier reactance curves. In this respect, assumption 3 and conclusion 4 appear to require further discussion. The conclusion seems to be more a restatement of the assumption than a conclusion.

Since the authors rely upon the approach of Potier reactance to the *calculated* armature reactance (this, of course, to show the value of their treatment), it would seem that the second conclusion should contain also a recommendation that with data available the calculated armature reactance be used. Certainly, calculation is quicker and more convenient than test.

I think it is of considerable value to have this method which the authors give for approaching armature leakage reactance by test. The only difficulties I see in its use lie in excitation problems and field heating when one is attempting to obtain very high saturation, particularly with a machine which does not saturate easily.

L. A. Kilgore (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper presents some interesting data on Potier's reactance. The conclusion is reached that Potier's reactance varies so widely as to be of limited use and also that the Potier's reactance approaches the leakage reactance at high values of voltage.

Although it is true that the Potier's reactance does vary, it is still a very useful quantity. It forms the basis of the A.I.-E.E. method of calculating the zero power factor saturation curves from the no load curve and one or more zero power factor test points.

For accurate calculations it is possible for the designer to determine the stator and rotor saturation separately at the actual operating conditions. Even here some approximation is necessary since it is seldom possible to determine the complete flux distribution in the teeth. The stator saturation under load may be determined approximately as at no load for a voltage equal to terminal voltage plus half the stator leakage. The rotor saturation is determined by the actual flux in the pole which is the sum of the gap flux on the direct axis and the field leakage. The ampere turns effective in producing field leakage are determined by adding vectorially the armature demagnetizing and the sum of the gap and stator saturation ampere turns.

For others who use machine characteristics and for rapid design calculations, the Potier's reactance is very useful since it gives a method of estimating the total saturation under load from the no load saturation curve.

The Potier's reactance is not entirely empirical since the voltage back of Potier's reactance may be visualized as a flux somewhere between the flux in the stator and the flux in the rotor, which gives an approximate measure of the total saturation. If all the saturation is in the stator x_p is approximately $^1/_2x_l$; if it is all in the rotor $x_p = x_l + x_f$, where x_l = stator leakage and x_q = rotor leakage reactances. When the saturation at no load in the stator is

F_s and in the rotor F_r, the Potier's reactance may be approximated as $x_p =$

$$1/2x_2 + (1/2x_2 + x_l)\left(\frac{F_r}{F_s + F_r}\right).$$

The Potier reactance decreases at higher voltages because of saturation of the leakage paths and in some machines it increases considerably below rated voltage because the ratio of rotor to stator saturation is increasing. This last effect is especially true of machines with gaps under the poles or partially filled dovetail slots. The authors have concluded that the Potier's reactance approaches the leakage reactance for the reason that field leakage due to the armature demagnetizing approaches zero. Actually this component of the field leakage is reduced by the saturation of the pole tip but it does not approach zero. The stator leakage is also reduced appreciably by saturation at high densities. Thus it would seem that although the Potier's reactance may be as low as the stator leakage and even lower in some cases, it cannot be said theoretically to approach the leakage reactance. The data which the authors give does not show any accurate agreement between the minimum values of x_p and the unsaturated value of x_l, and the data which the writer was able to collect gave even less consistent results. Therefore, it does not seem practical to use this as any test for the leakage reactance.

The test curves on 30 machines of all types were studies to determine the variations in Potier's reactance. These results might be summarized by saying that the ratio of the reactance at 90 per cent voltage to that at 110 per cent voltage ranged from 1.05 to 1.2 for salient pole machines with relatively large gaps under the pole and for salient pole machines with little or no gap under the pole, the ratio ranged from 1.0 to 1.15. For turbine generators the variation was, in general, much less and in several cases the Potier's reactance decreased at lower voltages.

Charles Kingsley, Jr. (Massachusetts Institute of Technology, Cambridge): This paper shows that the Potier reactance measured at high saturation is probably approximately equal to the armature leakage reactance; that is, at high values of saturation, the Potier reactance approaches the value of leakage reactance calculated by certain design formulas. Unfortunately, there are at present no entirely satisfactory tests by which the accuracy of these design formulas can be established.

The Potier method assumes that the zero power factor characteristic at any given constant value of armature current is a curve equal to the open circuit characteristic shifted vertically by a voltage drop and horizontally by a magnetomotive force, each of which is proportional to the armature current and is independent of saturation. As is shown in the paper, this is not strictly correct, largely due to the effects of field leakage.

In references 3 and 4 the armature leakage reactance drop is defined as the voltage drop due to certain component fluxes which include all of the component fluxes producing fundamental reactive, armature voltage and which probably are affected only slightly by saturation. Hence, if the Potier reactance were constant, it should be approximately equal to the armature leakage reactance as defined in references 3 and 4, since it too would be that part of the total reactive effect of armature current which would be independent of saturation. It is shown in the paper that at high values of saturation, although the field leakage may be large, its effect on the Potier reactance becomes small and the Potier reactance approaches a constant value. It therefore seems reasonable to conclude that the highly saturated value of Potier reactance is approximately equal to the leakage reactance. This is probably the best test for leakage reactance which is at present known.

L. A. March and **S. B. Crary:** C. C. Shutt has shown, for a given set of test data, the variation of Potier reactance with change in armature current, with voltage as a parameter. We would judge from his results that the test data were not for high degrees of saturation. In this respect, it is unfortunate that he did not present the saturation curves from which the data were obtained, so that this question could be answered and his test results compared with that presented in the paper.

L. A. Kilgore states "The authors have concluded that the Potier's reactance approaches the leakage reactance for the reason that field leakage due to the armature demagnetizing approaches zero. Actually this component of the field leakage is reduced by the saturation of the pole tip but it does not approach zero." It is important in discussing this point to make a definite distinction between saturation magnetomotive force and flux. We have attempted to show that the *additional* field leakage flux at high values of saturation caused by the addition of a field magnetomotive force equal to $x_{ad}i_d$, becomes increasingly less in magnitude, as well as a smaller proportion of the total. It is true that there is a large amount of total field leakage flux producing saturation under these conditions. However, the additional increment of field leakage flux caused by the magnetomotive force $x_{ad}i_d$ becomes less, and is small although the saturation produced by this increment of flux may be large. This is shown by the small vertical and the large horizontal displacements respectively of the curves *a* and *c* of figures 1 and 2.

We cannot agree with Kilgore that under load the stator tooth saturation is proportional to a voltage equal to the terminal voltage plus half the stator leakage. We have been able to calculate, with good accuracy, zero power factor characteristics assuming the stator saturation to be proportional to the voltage back of leakage reactance. Accordingly, for a machine with all the saturation in the stator, we consider that $x_p = x_l$. For any other condition $x_p = x_l +$ *a factor which is a function of the load saturation* (neglecting possible changes in wave form, which may affect the final required magnetomotive force).

B. L. Robertson has asked as to the method used in obtaining the test data. The zero power factor characteristics were obtained by operating the machines as overexcited synchronous condensers and obtaining enough points to draw a curve. Additional machines were used to supply the losses, and to provide zero power factor lagging kilovolt-amperes. The open circuit characteristics were obtained in the regular manner. Machines actually were tested using values of excitation as high as 10 per unit (1,000 per cent of normal). The rotors were watched carefully for heating, and the high values of excitation held only as long as necessary, with ample time allowed between tests.

We have made attempts to calculate the decrease in leakage reactance due to tooth saturation. A sufficient portion of the leakage flux path is in air, so that even though the iron becomes highly saturated, the decrease in the total permeance will be but slight. In addition, the teeth are not saturated uniformly over the entire pole pitch. If an attempt is made to calculate the effect of saturation on slot leakage permeance, it will be found that at a density of 150,000 lines per square inch (over the middle $^1/_3$ of the pole pitch) the decrease will be approximately 5 per cent. As a result, it seems reasonable to conclude that in salient pole synchronous machines leakage reactance is sensibly independent of saturation for practical operating flux densities.

Protective Signaling

Discussion and author's closure of a paper by P. M. Farmer published in the June 1935 issue, pages 617–23, and presented for oral discussion at the selected subjects session of the summer convention, Ithaca, N. Y., June 27, 1935.

Wm. A. Del Mar (Habirshaw Cable and Wire Co., Yonkers, N. Y.): I should like to inquire whether any device has been developed to protect libraries from theft of books. A few years ago I tried inserting a magnet in the back of a book and winding a wire in several turns around a door frame in the hope that the magnet passing through would induce enough current in the wire to give a signal. The wire was plugged to the microphone socket of a radio set and sure enough, the loud speaker clicked whenever the magnet passed through the door. Unfortunately, it did the same when a bunch of keys was passed through the door. It seemed impossible to distinguish reliably between a book thief and John Doe, Member A.I.E.E., with a bunch of keys in his pocket. However, I do not believe that the possibilities of such an arrangement were exhausted and I should like to hear whether the author knows of any success having been attained in the matter of devices for protection against theft of library books.

P. M. Farmer: Commercial burglary alarm service does not ordinarily include the type of protection that would be demanded by the service mentioned by W. A. Del Mar. His approach to the problem seems to be

a most logical one and it is possible that the detector circuit could be made to distinguish between magnetized metal such as would be used in the book and nonmagnetized metal such as the keys and other objects that might be carried in the pocket of the individual "under suspicion." The detector would have to be quite sensitive, and speed of motion through the detector loop would be a factor of course.

D-C Cleanup in Insulating Oils

Discussion and authors' closure of a paper by J. B. Whitehead and S. H. Shevki, published in the June 1935 issue, pages 603–9, and presented for oral discussion at the selected subjects session of the summer convention, Ithaca, N. Y., June 27, 1935.

R. W. Atkinson (Gen. Cable Corp., Perth Amboy, N. J.): When we first began to be interested in the conductivity and dielectric loss of oils, and for a good many years after that, it was thought that these properties were inherent in the material itself. Thus, one type of oil would be considered as having inherently high conductivity and power factor and another type as having inherently low conductivity.

As time went on, however, it began to be recognized that the conductivity of these oils is not due to the main body of the oil itself, but to a relatively small portion of it which is unlike the bulk of the oil. Because the unlike portion has characteristics which are different from those of the bulk of the oil, the term "impurities" is applied to it, although it may differ chemically from the bulk of the oil only in some relatively minor respect, such as the addition of an atom of oxygen to the molecule or the absence of an atom of hydrogen from it. The essential point of difference that makes the impurities conducting is the fact that they contain bonds that are free or easily freed whereas the bulk of the oil does not.

In the early stages of oil purification it was considered fortunate that certain refining processes, such as filtration through fullers' earth, reduced the conductivity of the oil. It is now recognized, of course, that the improvement is not in any way fortuitous, but is due merely to the fact that the impurities adhere to the filtering medium and that what makes them adhere is the same thing that makes them conducting in the first place.

There has been steady progress in removal of the impurities from oils, to such a point that now there are any number of commercial oils, from different sources and made by widely different processes, which have extremely low loss. Indeed, for present day cable of any but the lowest voltages, oils are used whose losses are too small to be measured with apparatus initially available.

The oils discussed by the authors represent increasing refinement and thoroughness of removal of impurities. The almost infinitesimal conductance remaining may no longer be due entirely to impurities in the same sense as before, but may be due in part to free ions present by reason of radioactivity or similar causes. Thus, this type of conductivity is due essentially to the same reason as before, that is, to the presence of a relatively small number of particles different from the rest.

E. W. Greenfield (Johns Hopkins Univ., Baltimore, Md.): In view of the evidence presented in this and other papers by Dr. J. B. Whitehead, on the existence of space charges within the dielectric medium and the consequent variation and distortion of the normal linear electric gradient from electrode to electrode, it is well to give some thought to the correlation of measurements on oil samples varying widely in interelectrode spacing.

The volumetric distribution of space charge as related to interelectrode separation is apparently not a simple function of stress so that dielectric measurements of oils made on very thin samples may yield quite different results from those made on relatively larger samples.

I bring this point up as a result of the increasing tendency for measurements to be made on exceedingly small specimens of oil using quite thin sections between electrodes and then using the results of these measurements to interpret the behavior of insulating liquids in normal bulk. This is the more important due to the fact that the study of chemically pure insulating liquids of known relatively simple structure must be carried out at present with very small samples for the most part because larger quantities are unavailable.

What I believe is needed in this respect, are studies of insulating liquids along the lines presented by Doctor Whitehead where the measurements are carried over a wide range of electrode separation but at each spacing the stress maintained or varied by change of applied voltage only. Such studies should throw more light on the volumetric distribution of the space charge and its behavior as a function of stress.

Wm. A. Del Mar (Habirshaw Wire and Cable Co., Yonkers, N. Y.): A few years ago we made an experiment along the lines described in this paper but using oil-impregnated paper instead of oil, as in the authors' experiments. The idea was to deionize an impregnated paper cable by subjecting it to direct potential for a considerable period. Oil contains ions of both polarities, but tests had shown that the ions of molecular dimensions are mostly positive.

It was therefore decided to try to "wash out" the positive ions by repelling them from the conductor of a cable. Six $^1/_2$ inch copper rods were each covered with 5 layers of butted 5-mil wood pulp paper and impregnated with paraffin base oil containing 15 per cent rosin and covered with shielding tape. They were kept immersed in this oil, maintained at a temperature of about 120 degrees centigrade and treated as follows:

Samples *A*, *B*, *C*, and *D* were connected to d-c supply, the conductors being positive and the shields negative.

Samples *E* and *F* were not connected but were immersed in the same oil.

The initial voltage was 220 volts, as preliminary tests had indicated that "cleanup" of oil occurred at quite low voltages, but after 30 days, no change of power factor having occurred, the voltage was raised to 2,000 volts, which was maintained for 75 hours.

The power factor of all samples remained substantially unchanged throughout the test. In other words, no deionization occurred which affected the power factor of the insulation.

The samples were then subjected to a-c voltage-time tests, at average stresses, starting with 364 volts per mil and working toward 500 volts per mil.

In general the untreated dummies, *E* and *F*, gave slightly better lives than the supposedly deionized samples.

I am interested to know if the authors can explain the failure of this experiment to improve the insulation.

Oscar Hess (Simplex Wire and Cable Co., Boston, Mass.): The authors stated in their paper that the application of a d-c potential across the oil cell decreases the conductivity of the oil. I should like to ask Doctor Whitehead whether it is possible to make this improvement permanent by removing the oil containing the space charges which accumulated during the cleanup near the electrodes.

H. H. Race (General Elec. Co., Schenectady, N. Y.): There are 2 comments which I should like to make regarding this paper. The first is concerned with practical implications. At the 1931 A.I.E.E. winter convention we presented a paper on insulating oils (see "Some Electrical Characteristics of Cable Oils," abstract, ELEC. ENGG., Aug. 1931, p. 673) in which we concluded from variable frequency, variable temperature dielectric loss measurements that in commercial insulating oils at power frequencies and normal operating temperatures the major cause of dielectric loss is some form of ionic conduction. Doctor J. B. Whitehead's work using an entirely different experimental approach confirms this conclusion.

Secondly, from a theoretical point of view it would be very valuable to obtain more information concerning the nature of the ions responsible for observed conduction phenomena. I should like to ask Doctor Whitehead whether he is planning to extend these studies in an attempt to determine quantitative data for such properties of the ions as their sources, range of sizes, charges and mobilities.

J. B. Whitehead: Referring to Oscar Hess's question, no method has been devised for making permanent the improvement in an oil due to the application of continuous potential. If the original conductivity is due to electrolytic ions, theoretically it should be possible to remove these and so reduce the conductivity and loss. There are, however, other causes of conductivity such as radioactive and cosmic ray influence, particularly as related to the contact of the metal with the electrodes. It is my feeling that this is the more important factor and from its nature we would not expect a permanent cleanup following the application of continued potential.

As to W. A. Del Mar's question, I think that the barrier action of the paper is the principal reason why impregnated paper is

not subject to d-c cleanup. The space charges may not separate sufficiently far to cause an over-all polarization.

Doctor H. H. Race raises the question of the date at which conduction was recognized as a cause of dielectric loss in oils. This was first suggested by the work of Tank in 1915. In 1929 Dr. J. B. Whitehead and R. H. Marvin at the A.I.E.E. winter convention ("Anomalous Conduction as a Cause of Dielectric Absorption," A.I.E.E. TRANS., v. 48, April 1929, p. 299–314) reported loss measurements under alternating stress, together with short-time and long-time conductivity measurements and stated that anomalous conductivity is sufficient to account for all the loss in insulating oils. In a subsequent paper at the 1931 A.I.E.E. winter convention, Doctor Whitehead presented further, more intimate measurements concerning the origin of loss (see "The Conductivity of Insulating Oils—II," A.I.E.E. TRANS., v. 50, June 1931, p. 692–8). In these measurements, it was shown that for many oils, the initial conductivity over a period of a second was sufficient to account for all the loss. In certain oils a d-c current curve decaying sharply within the first few thousandths of a second indicated the presence of a polar component. In these cases it was shown that the total measured loss was accounted for principally by a conduction component, but with an added component of loss due to the polar property referred to. It was also shown that the conductivity of liquids computed from d-c measurements one minute after the application of voltage would account for the alternating loss only in the cases of oils relatively impure and of conductivity so great as to obscure the short-time properties referred to above.

Definitions of Power and Related Quantities

Discussion of a paper by H. L. Curtis and F. B. Silsbee published in the April 1935 issue, pages 394–404, and presented for oral discussion at the instruments and measurements session of the summer convention, Ithaca, N. Y., June 25, 1935.

G. M. L. Sommerman (Amer. Steel and Wire Co., Worcester, Mass.): The writers are to be commended on their very complete treatment of the subject of power definitions. While some of the terms and definitions may not meet with extended use, it is well to have a complete set available. It seems proper that the subject of terminology should be kept open for discussion until a general reading and digestion of the paper has taken place.

In figure 2 and throughout the paper the power vector F is called "fictitious" power. The name "nonactive" power for this vector seems preferable to "fictitious" power The writer has no objection to the use of the adjective "fictitious" in scientific writing where such use implies that the noun modified is treated as existing for purposes of discussion only. However, in the present case, the vector F exists just as surely as do vectors D, N, V, and U. What is really meant is that F does not contain any active power. Vector N has been named "nonreactive power" because it represents all the power except the reactive power, Q, i. e.,

$$N = U - Q \text{ vectorially.}$$

Q is perpendicular to both components of N, i. e., N is not a function of Q. In the same manner, F should be called "nonactive power," since it represents all the power except the active power, P, i. e.,

$$F = U - P$$

P is perpendicular to both components of F, i. e., F is not a function of P. The name "nonactive" is also more mnemonic than is "fictitious."

It might be argued that this would be justification for calling the vector V "nondistortion power" since these vectors are also mutually perpendicular. It is true that the adjective "vector" is more generic than specific, and might well be substituted by another word. However, this name has been used a great deal in the past; moreover, the vector V depends on the amount of distortion in many cases. In cases where harmonics appear in the voltage wave only or in the current wave only, i. e., a sinusoidal voltage applied to an over-excited transformer, there exists a finite D of which P and Q are not functions. In such cases the name "nondistortion power" for V is truly applicable.

The use of symmetrical components in the unbalanced 3-phase cases, pages 401 and 402, seems to be the only logical and definite method for treating such cases. It should be noted that, for the sinusoidal case, a unique expression for the apparent power can be obtained directly from the components

$$U = 3(E_pI_p + E_nI_n + E_zI_z)$$

for 3 phases, where E and I are effective values, and p, n, and z refer to the positive, negative, and zero sequence sets, respectively.

For the most complicated case, that of an unbalanced polyphase system with nonsinusoidal voltage and current waves, it is convenient to introduce a double subscript notation, thus: E_{fg}, I_{fg}; where the first subscript refers to the sequence and the second subscript refers to the order of the harmonic. Using this notation, the definite quantity designated on page 402 as the symmetrical apparent power becomes, for the 3-phase case

$$U_z = 3\left\{\begin{array}{l} E_{p1}I_{p1} + E_{n1}I_{n1} + E_{z1}I_{z1} + \\ E_{p2}I_{p2} + E_{n2}I_{n2} + E_{z2}I_{z2} + \\ \vdots \qquad\qquad \vdots \qquad\qquad \vdots \\ E_{pn}I_{pn} + E_{nn}I_{nn} + E_{zn}I_{zn} \end{array}\right\}$$

It is obvious that this expression can be less than the apparent power. Thus, if any E or any I is zero, its cofactor is absent in the expression for U_z, whereas, the cofactor, if it exists, actually contributes to the apparent power. To avoid this difficulty, E_p may be defined as

$$E_p = \sqrt{E_{p1}^2 + E_{p2}^2 + \ldots + E_{pn}^2}$$

and

$$I_p = \sqrt{I_{p1}^2 + I_{p2}^2 + \ldots + I_{pn}^2}$$

and similarly for E_n, I_n, E_z, and I_z. If these quantities are substituted in

$$U_z' = 3(E_pI_p + E_nI_n + E_zI_z)$$

one obtains an expression for symmetrical apparent power which also contains all quantities actually existing regardless of the existence of their cofactors.

With the increasing interest manifest in the application of tensor analysis to electrical engineering problems, it might be well to point out that the voltages and currents with the double subscript notation mentioned above may be regarded as tensors of the second rank. It is interesting to see that the long expression for U_z for the m-phase, nonsinusoidal case becomes simply

$$U_z = mE_{\alpha\beta}I^{\alpha\beta}$$

in the tensor notation.

W. H. Pratt (General Elec. Co., West Lynn, Mass.): This is a very effective summary of the complexity that results when a rigorous extension of the ideas in connection with the simple sinusoidal flow of energy is carried out for nonsinusoidal and polyphase conditions.

Most of the quantities defined cannot be very generally useful for they do not identify but merely summarize.

The designers of apparatus and circuits need to know the magnitude and phase relationships of the currents and voltages of the particular frequencies, i. e., harmonics that appear, but these are not identified in this system of units.

The operating man must in general ignore the quantities of other than fundamental frequency for only those of fundamental frequency are within his control.

For commercial purposes, quantities that broadly summarize conditions and correlate circuit conditions as found with circuit possibilities would be most useful; thus "limiting power" as the basis of the definition of polyphase power factor would seem to be most useful.

In the activity of many electric circuits, the electromotive force and current are accurately represented by a fundamental frequency and its harmonics for the electromotive forces are actually the resultant of a system of identifiable component harmonic frequencies.

In other circuits such as those in which the magnetic qualities of ferromagnetic substances play an important part or where electron discharges are prominent, a Fourier series can only imperfectly represent the situation, perfect within any desired degree of approximation for certain analyses but quite imperfect as a means of solving certain other problems.

For this reason, quantities that are based on a Fourier analysis cannot be considered as having a truly fundamental standing unless they happen to fully identify a characteristic of the circuit.

True power does not suffer from this limitation. It is undeniably a very fundamental and definite physical conception, and the writer feels that it is unfortunate that the word should be freely used as a component part of the names of other quantities that have only a superficial resemblance to power. This remark applies even to "reactive power."

The writer also objects to the use of the word "vector" where the vector characteristic is present, only in the representation not in the nature of the quantity. The geometrical relationship that appears in the diagrams is a convenient way of represent-

ing a combination in which $C = \sqrt{A^2 + B^2}$, but the quantities here used are not by nature vectors.

As a more specific illustration of the writer's views, the quantity that in this paper is called "reactive power" has great importance when sinusoidal conditions are under discussion. Its importance seems to be due to its proportionality to the derivative of power, but with the extension to periodic quantities in general this derivative relationship is lost and with it all practical significance to the quantity as defined in the paper, except when sinusoidal conditions are approximated.

W. V. Lyon (Massachusetts Inst. of Tech., Cambridge): In this paper there is presented a proposal to define 17 different kinds of power. Eight of these definitions relate to single-phase circuits while the remainder relate to polyphase circuits. The very number of these definitions is arresting and invites discussion as to the need for this particular differentiation. The writer is of the opinion that the sole test by which the proposed definitions will stand or fall is whether they define useful quantities, and not whether they appear to form a "complete and logical set." An electrical quantity may be useful because it has physical reality such as do the instantaneous potential, the instantaneous current and the instantaneous power. It may be useful in the solution of the varied problems that arise both in theoretical investigations and in practice. Finally it may be useful as an aid in establishing equitable rates for the sale of electric energy. From this point of view of usefulness the writer wishes to discuss briefly some of the proposed definitions and to point out certain of the desirable and undesirable characteristics that they possess.

Instantaneous power possesses the following very important characteristic. The total instantaneous power supplied to any network equals the algebraic sum of the instantaneous powers supplied to the individual branches of the network. That is, the whole is equal to the sum of its parts. This is true regardless of the arrangement of the branches or of the wave forms of the potentials and currents that are involved. Since active power is the average value of the instantaneous power, taken over a complete cycle, it also possesses this same important characteristic.

Reactive power is usually associated with the reactance in the circuit although there are exceptions to this relationship. For example, the reactive power taken by a synchronous motor may be capacitive rather than inductive. Again a resistance which varies cyclically may take reactive power whereas an inductance which varies cyclically may take active power as well as reactive power. Under sinusoidal conditions the reactive power is often linked with the "amplitude of the alternating component of the power resulting from the reactance of the circuit," as in paragraph III, 4, *h* of this paper. This conception readily leads to confusion, as the writer has shown ("Reactive Power and Power Factor," W. V. Lyon, A.I.E.E. Trans., v. 52, Sept.–Dec. 1933, p. 763–70), when the reactive powers supplied to the individual branches of a network are combined in order to determine the total reactive power supplied to the network. The best physical conception of reactive power is given in paragraph III, 4, *i*, although this is not universal. In the sinusoidal case reactive power is best defined as $EI \sin \theta$. It then has the important characteristic that the total reactive power input at the terminals of any network equals the algebraic sum of the reactive powers supplied to the individual branches of the network. Should it be considered desirable to extend the definition of reactive power to the nonsinusoidal case, as the authors propose, the reactive power would still possess the foregoing characteristic. In spite of this great advantage the writer questions the usefulness of this extension and believes that before it is adopted, carefully selected numerical illustrations should be presented which indicate its probable usefulness in connection with the calculation of power network problems. The measurement of the quantity should also be considered as well as its possible effect on the rates at which electric energy is sold. If the extension of the definition of reactive power to the nonsinusoidal case cannot be justified by its usefulness the proposal to so extend it will in effect be rejected by common consent even though "the possibility of the further extension of power concepts would (thereby) vanish." However, let us assume that the extension of the definition is accepted in order that the discussion can continue.

In a single-phase circuit the distortion power is the third of the 3 mutually perpendicular components into which the apparent power (volt-amperes) is divided. The other components are the active power and the reactive power. The distortion power is due to the presence of harmonics in the potential or current. If the potential and current are both sinusoidal the distortion power is zero. However, if a *nonsinusoidal* potential is impressed on a constant resistance the distortion power is also zero. If a nonsinusoidal potential is impressed on a constant inductance (of zero resistance) the power, although it results wholly from reactance, is not wholly reactive but has a distortion component. For example, if a potential consisting of a fundamental component E_1 and a third harmonic component E_3 is applied to a resistanceless inductance having a fundamental reactance X_1, the active power is zero, the reactive power is $\frac{E_1^2}{X_1} + \frac{E_3^2}{3X_1}$ and the distortion power is $\frac{2}{3}\frac{E_1E_3}{X_1}$. The authors present no evidence as to the usefulness of the distortion power either in regard to its bearing on the calculation of power networks or on the establishment of more equitable energy rates. The direct measurement of the distortion power presents some difficulty.

It should also be noted that the proposed definition of distortion power places a certain restriction upon its usefulness inasmuch as it ignores the *frequencies* of the harmonics in the potential and current, whereas the heating losses in alternating-current machines depend upon the frequency as well as upon the amplitude of the potential and current.

The division of the single-phase apparent power (volt-amperes) into 3 mutually perpendicular components corresponds to the resolution of a force into such components. In the latter case the resolution has proved an invaluable aid when it is desired to combine a number of forces, inasmuch as the resultant component along one of the mutually perpendicular axes equals the sum of the components of the individual forces along that axis. As the writer has pointed out this additive law is also true in regard to the active power and to the reactive power. Most unfortunately, however, it is not true in regard to the distortion power. That is to say, the distortion power measured at the terminals of a single-phase network does not in general equal the sum of the distortion powers in the individual branches of the network. In the writer's opinion this is a vital defect. For example, consider 2 parallel branches to which is applied a nonsinusoidal potential. If the impedance at fundamental frequency of the first branch (*a*) is $1 + j\,1$ units and of the second branch (*b*) is $1 - j\,1$ units, and the applied potential consists of a fundamental of one unit and a third harmonic of one unit, the following values of the component powers are obtained:

$P_a = 0.6$ unit $\qquad P_b = 1.4$ units

$Q_a = -0.8$ unit $\qquad Q_b = 0.8$ unit

$D_a = \sqrt{0.2}$ unit $\qquad D_b = \sqrt{0.2}$ unit

These parallel branches are equivalent to a nonreactive resistance at all frequencies. Thus $Q_a + Q_b = 0$. This being true the resulting distortion power calculated at the terminals is zero, whereas the sum of the distortion powers in the 2 branches is $2\sqrt{0.2}$ unit. Of what significance then is the sum of the distortion powers in the various branches of a single phase of a polyphase network?

Finally let us consider 2 simple illustrations of the application of the definitions of arithmetic apparent power, algebraic apparent power, and vector power. The circuit in the first illustration consists of 3 impedances each having the same ohm value but with angles of zero, + 60 degrees, and −60 degrees. These impedances are connected between the lines and neutral of a balanced 3-phase system in such a phase order that the currents in the lines and in the neutral conductor are each *I* amperes. If the line-to-neutral potentials are sinusoidal and have values of *E* volts, the total active power is 2 *EI* and the total reactive power is zero. There is no distortion power. The arithmetic apparent power is 3 *EI*, the algebraic apparent power is 2.73 *EI*, while the vector power is 2 *EI*. The vector power factor is unity, the algebraic apparent power factor is 0.732, while the arithmetic apparent power factor is 0.667. Which of these factors should be used in computing the charge for energy according to a power contract?

The second illustration relates to a balanced 4-phase, 4-wire system which has 2 equal lamp loads connected across opposite pairs of adjacent line terminals. The line potentials are each *E* volts and the line currents are each *I* amperes. In this case the active power is 2 *EI* and the reactive power is zero. Thus the vector power is 2 *EI*, but arithmetic and algebraic apparent powers are each 2.83 *EI*. The vector power factor is unity as is customary in the case of a lamp load. Both the arithmetic and algebraic apparent power factors, however, are 0.707, which is a most unusual rating for a lamp load and might well be the cause of considerable friction in the matter of power contracts.

News
Of Institute and Related Activities

Pacific Coast Holds 23d Annual Convention at Seattle

FOR the third time since Pacific Coast conventions of the Institute were initiated in 1910, the Seattle Section (first in 1916 and again in 1925) played host to a national convention of the Institute; this occasion was the 23d Pacific Coast convention, held at the Olympic Hotel in Seattle, Wash., from Tuesday morning through Friday, August 27–30, 1935. (For those who will check the mathematics involved: no Pacific Coast conventions were held in 1917, 1918, or 1933.)

Although the convention committee was set up and ready for business Monday afternoon at 3 o'clock, advance registrations were few, and activities did not start in earnest until Tuesday morning, when the registration rush caused a slight delay in the opening of the initial session. However, at about 10:15 a.m. Prof. E. A. Loew, chairman of the general convention committee, called to order the 130 members and guests present in the meeting hall, and introduced Dr. Lee Paul Sieg, president of the University of Washington. Following Doctor Sieg's cordial welcoming remarks, President E. B. Meyer was called upon by Professor Loew. President Meyer in his brief response paid tribute to the several convention committees for the evident thoroughness of arrangements made; he also spoke briefly of the scope of Institute activities available to members, urging each individual member to participate directly in as many such activities as possible, not only in order that he might make a contribution toward professional development, but that he might also receive the maximum benefit from his membership.

Analysis of Attendance at 1935 Pacific Coast Convention

Classification	Location: Seattle	Dist. 9*	Dist. 8	Dist. 10	Misc.	Totals
Members	56	50	23	9	7	145
Men Guests	25	2	4	1	1	33
Women Guests	32	19	10	1	2	64
Students	14	9	3		1	27
Totals	127	80	40	11	11	269

* Outside of Seattle, Wash.

Attendance is analyzed in the accompanying tabulation. Members were present from all 7 Sections in the Pacific Coast territory (Districts 8 and 9 and the western portion of District 10), as were representatives from 12 of the 14 Student Branches in the territory. National Institute officers present included President E. B. Meyer, Newark, N. J.; vice presidents F. O. McMillan of Corvallis, Ore., and N. B. Hinson of Los Angeles, Calif.; and past-presidents H. V. Carpenter of Pullman, Wash., and R. W. Sorensen of Pasadena, Calif.

Technical Sessions

Two of the 5 general technical sessions were held Thursday, one in the morning and one in the afternoon; others were held Wednesday, Thursday, and Friday mornings. These sessions accommodated the presentation and active discussion of all 16 of the formal technical papers embraced in the detailed program of this meeting as published on page 784 of Electrical Engineering for July 1935, which program also gives reference to the pages in the April, May, June, and July issues of Electrical Engineering on which 8 of these papers were published; the 8 papers not so designated were published in the August issue. Taking advantage of the flexibility provided by the unified publication plan, the committee in charge of the technical program for the Seattle convention scheduled for presentation and discussion several papers previously presented at eastern conventions.

Dr. L. P. Sieg (right) president of the University of Washington, Seattle, welcoming E. B. Meyer, president of the A.I.E.E., to the Northwest

In addition to the regular technical papers, 3 special illustrated talks were presented:

1. Progress of the Grand Coulee Development to Date, by Alain F. Darland (A'20, M'29), Bureau of Reclamation, Coulee Dam, Wash.
2. Electrical Features of the Bonneville Project, by L. E. Kurtichanof, U.S. Army Engineering Corps, Portland, Ore.
3. Off-Peak Control of Water Heater Load, by F. M. Starr (A'30), General Electric Company, Schenectady, N. Y.

Presiding over the several technical sessions were Prof. E. A. Loew, general convention chairman, and past chairman of the Seattle Section; F. J. Bartholomew, past chairman of the Vancouver, B. C., Section; Vice President F. O. McMillan; Vice President R. W. Sorensen; and Dr. C. E. Magnusson, past chairman of the Seattle Section.

Student Technical Sessions

Consistent with the effective policy that has been followed for several years in connection with Pacific Coast conventions, 2 entire afternoon technical sessions were devoted to the presentation of 10 Student papers, the titles and authors of which were as published on page 784 of Electrical Engineering for July 1935, except for elimination of the paper scheduled to have been presented by Stephen S. Stevens.

Conference on Student Activities

In addition to these Student technical sessions, the Branch chairmen, Student counselors, vice presidents, and several others interested in Student activities attended the regular annual Student conference that was held Wednesday evening following a dinner meeting of the group. This conference was presided over by Prof. O. E. Osburn of Washington State College, Pullman, counselor-chairman for District 9 for the preceding year. In his opening remarks, Chairman Osburn sought to emphasize the importance of the responsibility that rests upon the Student Branch chairmen, and particularly upon the several Student counselors in connection with the successful development of Student activities.

The conference was given over to a thorough-going discussion of various suggestions for improving the effectiveness of activities in and among the Student Branches represented. The principal topic of discussion had to do with practical ways and means of enabling Enrolled Students to establish effective contact with the realities of their chosen profession. Vice President Hinson in brief remarks pointed out that such contact must be established sooner or later anyway, and that it was distinctly to the advantage of the young engineer to go as far as possible in that direction before graduation instead of leaving it until after graduation. It was the general consensus of opinion that 2 particularly effective channels are provided through the Stu-

dent Branches—first, the opportunity for personal participation in Institute affairs and the establishment of personal contact with practicing engineers; second, the opportunity for direct contact with, and the gradually developing understanding of, important current technical advances and broader professional problems through the use of material published by the Institute in its monthly journal ELECTRICAL ENGINEERING. Although it was suggested that more material of special interest to Students perhaps could to advantage be developed for publication, it was definitely a prevailing consensus of opinion that there is more such material being published currently than is being put to full use.

In this connection, one of the Branch chairmen said pointedly that "there is a real need in a great many instances for a proper and effective stimulation of initial Student interest, and that it was in such instances that the Branch counselors could indeed render a valuable service in assisting the Student to overcome his 'starting inertia' and in guiding the direction of the Student's initial efforts to read and understand the technical papers and discussions which his Institute affiliation brings to him through ELECTRICAL ENGINEERING." This sentiment was reflected widely in comments of other Branch chairmen, in the remarks of some of the counselors, and was emphasized by Vice President (former counselor) McMillan, who called attention frankly to the fact that responsibility for the success or failure and for the degree of effectiveness of the program of each Student Branch rests squarely upon the counselor in each case.

At the speakers' table, during the annual banquet held on Thursday evening

From left to right: Vice President F. O. McMillan, Convention Chairman E. A. Loew, President E. B. Meyer, Toastmaster Joseph Hellenthal, National Secretary H. H Henline, and Vice President N. B. Hinson

Chairman A. E. Loew (left) and Vice Chairman L. B. Robinson of the 1935 Pacific Coast convention committee

The question of Student sessions at future conventions also was discussed. Looking forward to the 1936 annual summer convention that will be held in southern California under the auspices of the Los Angeles Section, considerable attention was given to the development of preliminary plans for sessions at that convention to be devoted to Student papers.

Of the 14 Student Branches in Districts 8, 9, and the western part of 10, 12 were represented by Student chairmen or vice chairmen; and 11 out of the 14 Branch counselors also were present at the conference. Branch chairmen present included: Felix Berra, University of Arizona, Tucson; H. P. Blanchard, Stanford University, Calif.; Louis Brewer, Montana State College, Bozeman; Glenn G. Davis, University of Utah, Salt Lake City; W. A. Gish, Oregon State College, Corvallis; R. A. Greulich, University of Nevada, Reno; James H. Miller, University of Idaho, Moscow; J. T. Mullin, University of Santa Clara, Calif.; John D. Oliphant, University of Southern California, Los Angeles; Winfield Pullen, Jr., University of Washington, Seattle; Edward Simmons, California Institute of Technology, Pasadena; George L. Zimmerman, Washington State College, Pullman.

Branch counselors present were: A. L. Albert, Oregon State College, Corvallis; P. A. Biegler, University of Southern California, Los Angeles; W. A. Hillebrand, University of California, Berkeley; J. H. Johnson, University of Idaho, Moscow; O. E. Osburn, Washington State College, Pullman; E. F. Peterson, University of Santa Clara, Calif.; G. R. Shuck, University of Washington, Seattle; H. H. Skilling, Stanford University, Calif.; R. W. Sorensen, California Institute of Technology, Pasadena; A. L. Taylor, University of Utah, Salt Lake City; and J. A. Thaler, Montana State College, Bozeman.

At group conferences of the counselor-delegates, held immediately after the general conference, District Student counselor chairmen for the ensuing administration year were selected: for District 8, Prof. E. F. Peterson; for District 9, Prof. G. R. Shuck.

ENTERTAINMENT

General entertainment features opened with a reception and informal dance held Tuesday evening, August 27, in the Junior Ballroom of the Olympic Hotel; embraced a variety of features of special interest to both men and women; and with one exception closed with the annual banquet held Thursday evening in the Spanish Ballroom where 175 participants were entertained with song, dance, and orchestral numbers during the banquet. The banquet was a highly informal and thoroughly successful affair presided over by past chairman Joseph Hellenthal of the Seattle Section, featuring brief remarks from general chairman E. A. Loew of the convention committee, and President E. B. Meyer, and largely dominated by the golf committee in making its awards of a galaxy of valuable prizes.

Principal feature of the entertainment especially for women was the bridge luncheon held Thursday afternoon at the Sand Point Golf and Country Club, Seattle, and enjoyed by 49 women of whom the following were reported as prize winners: Mrs. Reinier Beeuwkes, Mrs. Charles Cross, Mrs. C. H. Hoge, Mrs. Ray Rader, Mrs C. E. Rogers, and Mrs. Wellington Rupp, all of Seattle, and Mrs. J. C. Henkle, Mrs. H. H. Schoolfield, and Mrs. V. B. Wilfley, all of Portland, Ore., and Mrs. M. H. Brewer of Belgrade, Mont. Other events included a boat trip participated in by 60 women, and a boulevard tour around the city followed by tea enjoyed by 31.

Supplementing miscellaneous inspection trips, the principal feature of the entertainment program for men was a salmon fishing contest held in Elliott Bay of Seattle Harbor, under the sponsorship of Seattle's salmon-minded "Mystic Knights of the Sea." The organizer and leader of this novel event was C. E. Rogers, past chairman of the Seattle Section. Each a guest of a Mystic Knight, some 28 Institute members attending the convention arose with the aid of a commanding telephone bell at 2:15 Wednesday morning, August 28 (after having retired at midnight or later following the reception) and gathered for breakfast promptly at 2:45 a.m. at Rippe's Cafe. By 4 o'clock, the party was afloat in 28 boats, each trolling 2 lines. Dawn revealed some 200 other boats on the same quest. A check-up of 56 Mystic Knights and guests on the dock shortly after 7 a.m. revealed that the trophy cup and claim to supremacy had been won hands down by E. L. Bettannier of Pasadena, Calif., and

J. B. Fisken (left) of Spokane, Wash., congratulates H. H. Schoolfield of Portland, Ore., upon his winning the prized Fisken golf trophy for 1935

A group of the Student Branch chairmen who attended the Pacific Coast convention at Seattle

From left to right: G. L. Zimmerman, Washington State College, Pullman; James Miller, University of Idaho, Moscow; R. M. Morton, University of British Columbia, Vancouver; Edward Simmons, California Institute of Technology, Pasadena; J. T. Mullin, University of Santa Clara, Calif; and Louis Brewer, Montana State College, Bozeman

his Mystic Knight host A. E. Cross of Seattle, who landed the only salmon caught by the party.

GOLF

The 15th annual competition for the John B. Fisken Pacific Coast A.I.E.E. golf trophy and the related competitions were held Thursday afternoon, August 29, at the Sand Point Golf and Country Club, with a field of 75 entrants. To provide the contestants with as much of an opportunity as possible, the committee had arranged 6 different competitions in addition to that for the Fisken cup, all dependent upon the tournament results. Competition was open only to members and guests officially registered at the convention. Subject to the committee's announced rule that no contestant could win more than one prize, and subject to the committee's rules for preferential selection, the winners of the several events were as follows:

1. John B. Fisken cup competition (medal play on handicap): winners, H. H. Schoolfield, Portland, Ore., 90–22–68; first runner-up, R. H. Dearborn, Corvallis, Ore., 83–14–69; second runner-up, R. W. Mastick, Seattle, Wash., 84–14–70.

2. Other winners of valuable prizes, in the order of the magnitude of their proficiency as determined by the committee were: (1) A. J. Schmitz, Seattle; (2) W. D. McDonald, Seattle; (3) E. L. Breene, Seattle; (4) W. D. Shannon, Seattle; (all winners in guest competition); (5) F. D. Carroll, Seattle; (6) C. R. Boyle, Seattle; (7) J. C. Henkle, Portland; (8) R. E. Thatcher, Seattle; (9) G. R. Murphy, San Francisco; (10) E. L. Criger, Seattle; (11) Peter Diederich, Glendale, Calif.; (12) V. B. Willey, Portland; (13) J. H. Seigfried, Kennewick, Wash.; (14) N. H. Callard, San Francisco; (15) Max Bitts (Student) Seattle; (15) J. I. Caldwell, Seattle; (16) J. G. Miles, Seattle; (17) C. H. Cutter, Seattle; and 6 or 8 others each of whom received one golf ball for each of several birdies made.

The Fisken trophy is a cup, originally donated by the Portland Section for annual competition (for members in good standing only) and named in honor of J. B. Fisken, hydroelectric pioneer of the Northwest. This year's tournament was the 15th competition for the Fisken trophy; winners are:

1920—C. L. Wernicke, Portland
1921—C. P. Osborne, Portland
1922—J. B. Fisken, Spokane
1923—S. J. Lisberger, San Francisco
1924—K. E. Van Kuran, Los Angeles
1925—W. C. Heston, San Francisco
1926—P. M. Downing, San Francisco
1927—C. E. Heath, Los Angeles
1928—G. D. Luther, Seattle
1929—E. W. Rockwell, Los Angeles
1930—W. F. Hynes, Portland
1931—M. S. Barnes, San Francisco
1932—J. E. Underhill, Vancouver, B. C.
1933—No convention
1934—H. W. Flye, San Francisco
1935—H. H. Schoolfield, Portland

COMMITTEES

Committees and committee workers responsible for the success of the Seattle convention were:

General Convention Committee—E. A. Loew, *chairman;* L. B. Robinson, G. H. Walker, A. M. Bohnert, Walter Brenton, F. J. Bartholomew, Fred Garrison, E. B. Hansen, G. L. Hoard, R. H. Hull, R. E. Kistler, F. C. Lindvall, F. O. McMillan, R. U. Muffley, E. O. Osburn, H. T. Plumb, G. E. Quinan, Wellington Rupp, C. E. Rogers, R. W. Sorensen, and J. A. Thaler.

Salmon fishing champion E. L. Bettannier of Pasadena, Calif., exhibiting the result of 232 man-hours of fishing

Meetings and Papers—G. L. Hoard, *chairman;* Reinier Beeuwkes, Joseph Hellenthal, K. L. Howe, and C. E. Rogers.

Finance—L. B. Robinson, *chairman;* C. E. Rogers and G. H. Rogers.

Publicity—R. E. Kistler, *chairman;* J. H. Kelley, A. I. Launder, C. M. Lubcke, and Ray Rader.

Hotel and Registration—E. B. Hansen, *chairman;* H. O. Blair, M. T. Crawford, E. R. Hannibal, W. S. Hill, C. A. Lund, and G. R. Shuck.

Trips and Transportation—Wellington Rupp, *chairman;* R. O. Bach, Charles Cross, W. E. Conroy, W. S. McCrea, E. L. White, and Laurence Wylie.

Golf—G. E. Quinan, *chairman;* E. L. Crider, E. J. Descamp, R. W. Mastick, and T. S. Wood

Fishing Contest—C. E. Rogers, *chairman;* G. O. Cranmer, C. A. Foley, Ray Hasselo, and C. L. Johnson.

Entertainment—R. U. Muffley, *chairman;* F. W. Carlson, E. S. Code, C. J. Hawkes, C. H. Hodge, G. Smith, and C. R. Wallis.

Ladies' Entertainment—Mrs. J. Hellenthal, *general chairman;* Mrs. R. E. Kistler, Mrs. E. A. Loew, Mrs. C. E. Rogers, and Mrs. G. H. Walker.

Engineering Examiners to Meet. The 16th annual convention of the National Council of State Boards of Engineering Examiners will be held at Columbus, Ohio, October 23–25, 1935, with headquarters at the Deshler-Wallick Hotel. The program calls for business sessions during the mornings and afternoons of Wednesday and Thursday, October 23 and 24, with committee meetings held late on Wednesday afternoon. The annual dinner, to which women are invited, will be held on Wednesday night, and the "professional engineers banquet" on Thursday night. There will be a sightseeing trip Friday morning. Business to be transacted during the convention will include reports of the following standing committees: accredited engineering schools, uniform examinations for registration, legal, National Bureau of Engineering Registration, Engineers' Council for Professional Development, constitution, and the special committee on reciprocity and certification of engineers. Perry T. Ford, who is secretary of the Ohio State board, is chairman of the convention committee.

Membership—

Mr. Institute Member:

By this time you have received our fall letter asking you to help your Section membership committee in obtaining new members by sending in the name of one person who, you feel, should be invited to join the Institute. Your individual co-operation in this activity in the past has been of the greatest helpfulness in the work and without your part in it we would not be able to return to you a substantial record of progress. If you have not yet replied to the letter, will you not do so promptly?

Ernest Fisher

Chairman National Membership Committee

Great Lakes District Meeting at Purdue

The Great Lakes District of the A.I.E.E. will hold a meeting at Purdue University, West Lafayette, Ind., on Thursday and Friday, October 24 and 25, 1935. Three technical sessions will provide an interesting variety of timely subject matter and a Student technical session will be held on Friday morning, at which 15 of the best papers selected from the various Student Branches within the District will be presented. The social and recreational features which will round out the program consist of a dinner, dance, and inspection trips to the factory of the Duncan Electric Manufacturing Company in Lafayette, and the various buildings and laboratories of the university.

It is interesting to note that Purdue University has one of the finest electrical engineering laboratories in the country. For many years they have specialized in extra high potential research, which provides a very appropriate setting for the session on high potential measurements. The majority of the technical papers for this session and the entire program except the Student session and the paper entitled "Characteristics of Luminous Tube Circuits" are published in this issue and the September issue of ELECTRICAL ENGINEERING. Copies of the latter paper may be made available by the author at the meeting. For the technical program and more complete details regarding various features of the meeting see ELECTRICAL ENGINEERING for September 1935, pages 1005–7. All meetings, with the exception of the dinner meeting, will be held in the new electrical engineering building on the North Campus, which is directly on routes 52 and 152 between Chicago and Indianapolis.

Take advantage of the opportunities which the program affords and attend this meeting on October 24 and 25. An additional feature will be the university homecoming program and football game with Carnegie Institute of Technology on Saturday.

Electrical Insulation Committee to Meet

The 8th annual meeting of the committee on electrical insulation, division of engineering and industrial research, National Research Council, will be held at Pittsfield, Mass., October 17–19, with the General Electric Company as host. The technical program is in 3 sessions in which 20 papers in the field of dielectric research and applications to the problems of electrical insulation will be presented.

Dr. J. B. Whitehead (A'00, M'08, F'12, Life Member, and junior past-president), Johns Hopkins University, Baltimore, Md., is chairman of the committee, and W. F. Davidson (A'14, F'26), Brooklyn Edison Company, Brooklyn, N. Y., is secretary.

18 Schools Request Accrediting by E.C.P.D.

Eighteen colleges and universities in the New England and Middle Atlantic States offering courses leading to an engineering degree have requested the Engineers' Council for Professional Development to consider their engineering curricula for accrediting. The group includes many of the large and important engineering schools in these 2 regions.

Engineers' Council for Professional Development is a conference of engineering bodies representing the technical, educational, and legislative interests of engineers. As part of its plan to enhance the professional status of engineers E.C.P.D. hopes to promote higher standards of education by studying engineering curricula and accrediting those worthy of recognition. A list of approved institutions will be published for the assistance of those who wish to make use of it.

As announced last June the plan, similar to that followed by the medical and legal professions, will be put in effect this fall in the New England and Middle Atlantic States, and extended later to other regions of the United States. Both qualitative and quantitative criteria will be used as a basis for accrediting. Qualitative criteria will be evaluated through visits of inspection by regional committees of qualified individuals. Quantitative criteria will be evaluated through data obtained from catalogs and by questionnaires.

The questionnaires which the committee spent over a year developing and which were tried out experimentally in a limited number of schools, are now being distributed to the institutions requesting con-

Future AIEE Meetings

Great Lakes District Meeting,
West Lafayette, Ind., Oct. 24–25, 1935

Winter Convention,
New York, N. Y., Jan. 28–31, 1936

North Eastern District Meeting,
New Haven, Conn., May 1936

Summer Convention,
Huntington Hotel, Pasadena, Calif., June 22–26, 1936

Middle Eastern District Meeting,
Akron, Ohio (date to be determined)

At the Institute's Recent Pacific Coast Convention—the Annual Banquet

A scene at the annual convention banquet held as part of the Institute's 23d Pacific Coast convention at Seattle, Wash., August 27–30, 1935. At this highly successful affair, held on Thursday evening, August 29, 175 persons were in attendance

sideration. The material thus obtained will be analyzed and studied as it is received and will be presented to the regional committees for their consideration prior to visiting the institutions.

The prompt acceptance of this plan by so many institutions is an excellent indication of the interest with which this program of E.C.P.D. is being received. A number of additional institutions expressed interest in the matter but found it necessary to defer actual requests until the return of their officers in September.

The plan being followed in the accrediting procedure was outlined in ELECTRICAL ENGINEERING for February 1935, pages 249–50; March 1935, page 343; and August 1935, page 895.

A.S.M.E. Nominates Officers. Officers of The American Society of Mechanical Engineers to serve for the year 1936 were recently nominated. W. L. Batt, president of the SKF Industries, Inc., was nominated for the office of president. Mr. Batt, a graduate of Purdue University, is also a director of the Air Preheater Corporation, and a director of the Hudson Insurance Company, New York. He is probably best known to members of the Institute for his activities on United Engineering Trustees, Inc., being at present chairman of the coordination committee of engineering societies. For his interest and activity in promoting commercial relations with Sweden, King Gustav V, of Sweden, in 1926, conferred upon Mr. Batt the Order of Vasa, and in 1933 the Royal Order of the North Star. Newly nominated vice presidents of the A.S.M.E. are Alex D. Bailey, assistant chief operating engineer of the Commonwealth Edison Company, Chicago, Ill.; J. A. Hunter, professor of mechanical engineering at the University of Colorado, Boulder; W. A. Shoudy, associate professor of mechanical engineering at Columbia University, New York, N. Y., and a practicing consulting engineer; and R. L. Sackett, dean of the school of engineering at Pennsylvania State College, State College. Newly nominated managers are W. L. Dudley, vice president and chief engineer, Western Blower Company, Seattle, Wash.; W. C. Lindemann, works manager and secretary, A. J. Lindemann and Hoverson Company, Milwaukee, Wis., and J. W. Parker, vice president and chief engineer, the Detroit (Mich.) Edison Company.

Porcelain Insulator Bodies Studied. An investigation undertaken to determine the relation and correlation between the electrical and the mechanical properties of porcelain insulator bodies furnished by manufacturers of high voltage insulators, and of similar bodies produced under laboratory conditions, has been conducted by the engineering experiment station of the University of Illinois in co-operation with the Utilities Research Commission of Chicago, Ill. Until January 1, 1936, or until the supply available for free distribution is exhausted, copies of this bulletin, No. 273, may be obtained, without charge, upon application to Engineering Experiment Station, Urbana, Ill.

Santa Fe's Mighty Diesel-Electric Locomotive

WHAT is reported to be the most powerful Diesel-electric locomotive yet constructed was recently delivered to the Atchison, Topeka, and Santa Fe Railway Company, the "Santa Fe" line. Rated 3,600 horsepower, with a weight of 240 tons and an approximate over-all length of 127 feet, this new locomotive is actually a multiple unit of 2 identical sections which can be operated either singly or together. The units are arranged for double-end operation. Motive power of each unit is supplied by 2 Winton V-type 12-cylinder high-compression 2-cycle oil engines, each rated at 900 horsepower, and weighing less than 20 pounds per horsepower. Among the many new features incorporated in the locomotive is a lightweight, compact, automatic steam generating unit for heating and air conditioning in the cars of the train. The locomotive, built by the Electro-Motive Corporation, subsidiary of General Motors Corporation, is unique in appearance, having, in addition to a streamlined exterior, an attractive handling of color scheme. Named the "Super Chief," the locomotive will be subjected to exhaustive tests; if these prove successful it will haul the road's fastest train, "The Chief," between Chicago and California on a schedule faster than at present.

Microphotography for Scientific Publication

Microphotographic, other photographic, and related methods of reproduction of printed and typewritten material have for some time been under consideration as a means of making information more widely available. The dissemination of scientific information by these methods is being studied by the documentation division of "Science Service," Washington, D. C., which points out in its document 72, dated August 16, 1935, that the first step in dissemination is publication in some manner of the research results, and the second step is the incorporation of references to published research results into usable bibliographies. This project is for the benefit of the scientific world, and in that respect differs from the major concern of "Science Service," which is an institution for the popularization of science.

The documentation division of "Science Service" states that it will first devote its energies and resources to:

1. Development of mechanisms useful in microphotographic and other photographic duplication and in bibliography.
2. Development of a method of publication for those scientific papers and monographs that cannot now secure prompt or complete issuance.
3. Co-operation with libraries in making available by photographic methods the literature of the past.
4. Investigation of the broad problem of scientific bibliography and useful mechanisms.

As one part of the plan, printed or typewritten material could be microphotographed on a 35 millimeter film which would be the master negative. For distribution, either film positives for use in reading machines, or 6 by 8 inch photographic prints suitable for reading without optical aid, could be made.

As a possibility for the future, experiments are being conducted on the publication of scientific journals by microphotography. The printing of some 200 pages of typewritten manuscripts $8^1/_2$ by 11 inches in size on a piece of film the size of a library catalog card, 3 by 5 inches, is believed to be a technical possibility, although a suitable reading machine for these microphotographs has yet to be developed. (Details of this plan are given in document 46, free from "Science Service," 2101 Constitution Avenue, Washington, D. C.)

Investigations also are under way by the documentation division upon problems connected with scientific bibliography. It is considered that photoelectric means might be used for picking out the desired subject classification from a bibliographical file, which might be a roll of film. (Detailed discussion of bibliographical procedure is contained in documents 58 and 61, free from "Science Service," 2101 Constitution Avenue, Washington, D. C.)

Standards for Large Rivets. A proposed American Standard for large rivets, $^1/_2$ inch nominal diameter and larger, has recently been completed by subcommittee No. 1 of the sectional committee on standardization of bolts, nuts, and rivet proportions. This proposed standard, a second revision, is now being distributed for criticism and comments. Copies are available upon application. All communications should be addressed to C. B. LePage, The American Society of Mechanical Engineers, 29 West 39th Street, New York, N. Y.

S.P.E.E. Elects Officers. At the recent annual meeting of the Society for the Promotion of Engineering Education, D. S. Anderson (A'01), dean, college of engineering, Tulane University, was elected president for the coming year. P. H. Daggett (A'08), dean, college of engineering, Rutgers University, and S. B. Earle, dean of engineering and director of the engineering experiment station, Clemson Agricultural College, S. C., were elected vice presidents. It was voted to hold the 1936 annual meeting of the S.P.E.E. at the University of Wisconsin, Madison.

Doctor Hotchkiss Elected Rensselaer President. Dr. William Otis Hotchkiss, who for the past 10 years has been president of Michigan College of Mining and Technology, Houghton, has been elected to the presidency of Rensselaer Polytechnic Institute, Troy, N. Y. Doctor Hotchkiss, who was born at Eau Claire, Wis., in 1878, and who studied at the University of Wisconsin, has had a long and varied career as an engineer and geologist, as well as an educator. During his 10 years at the Michigan college, he added and built up strong courses in several branches of engineering.

Wanted: Skilled Labor. A report in pamphlet form entitled "Wanted: Skilled Labor" has been prepared by the National Industrial Conference Board, Inc., which reveals information on the existing and potential shortage of skilled labor in the metal working industries. The report is based on an extensively circulated questionnaire. This 6 by 9 inch pamphlet, 37 pages in length, can be obtained from the National Industrial Conference Board, Inc., 247 Park Avenue, New York, N. Y., at a cost of $1.

Tests on Night Visibility on Highways. A paper entitled "Some Visibility Tests on Lighted and Unlighted Highways" by Parry Moon (F'34) and R. C. Waring (A'19, M'27) has been published in the *Journal* of the Franklin Institute, volume 219, March 1935, pages 285–314. The paper discusses the results of over 5,000 tests made to determine the effects of various factors on the distance at which the driver of a motor vehicle can see a pedestrian. The work was done as part of the Massachusetts Highway Accident Survey, a project of the Civil Works Administration. The principal conclusions are:

(*a*). The safety of a pedestrian walking along a highway at night can be greatly increased by the use of a small area of white (such as a handkerchief) or by reflector buttons. The visibility distance is increased approximately 50 per cent by the former and 100 per cent by the latter.

(*b*). Maximum safe speeds at night on unlighted highways are approximately 30 miles per hour when there is glare from passing cars and 40 miles per hour when there is no glare.

(*c*). Type of pavement and speed of car have little effect on visibility distance on unlighted roads.

(*d*). An increase in headlamp candle power above 32 seems advisable.

(*e*). Depressing the headlamp beams of passing cars reduces visibility distance.

(*f*). Highway lighting does not increase visibility distance appreciably unless the average luminosity of the pavement is above the chromatic threshold [order of 0.05 lumen/(foot²)].

Air Conditioning Association Moves. Headquarters of the Air Conditioning Manufacturers' Association have been moved to Washington, D. C., and offices opened in the Southern Building there.

American Engineering Council

Effects of Federal Legislation

Excerpts from the current "news letter" of the American Engineering Council follow:

In 4 months Congress will reassemble. In the interval between now and the first of January 1936, it is the task both of industry and of the federal agencies to adjust themselves to the heavy load of legislation. Both Washington and the country are reviewing with soberness the results of emergency legislation passed during the previous sessions of Congress. There are certain to be difficulties in the way of putting some of the legislation into effect.

There continues to be much confusion in Washington and, in spite of public statements to the contrary, a growing feeling on the part of those responsible for administering the legislation that there is a big difference between having new ideas and putting those new ideas into action.

The executive secretary of A.E.C. has returned from trips both to the South and to the North within the last 4 or 5 weeks. It is made evident that the "emergency" needs have passed and it is realized that what has been made possible through new legislation now has to be put into action and paid for.

Much of the new legislation, concerning as it does, natural resources, transportation, and construction, directly affects engineers and engineering development. The regulatory legislation covering utility holding companies, motor carriers, the soft coal industry, and "hot oil"; the increased powers of the T.V.A. and A.A.A., all tend to centralize authority in Washington over industrial practices and procedure.

The legislation dealing with labor, especially that trending to establish the procedure for collective bargaining by labor, as well as the "social security" system of old age pensions and unemployment reserves bring new problems to engineers and to industries employing engineers, in so far as the centralization of regulatory centralization in Washington tends to open channels for constructive study of industrial practices and procedures. There will be many opportunities within industry for men trained in engineering to apply the engineering method of analysis.

Probably in the next 10 years, many new fields of opportunity for engineers will be opened, not in the government, but in private industry, because of the need of more intensive analysis of manufacturing costs, of relation of machinery to reduction of labor costs, and of manufacturing methods. Undoubtedly also, there will be an increase in the use of power per man.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or to reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Copper and Aluminum Cable Fusing Time-Current Formulas

To the Editor:

The following formulas for calculating the time-current fusing characteristics of copper and aluminum cables for short time intervals are based upon several general assumptions but have been found to be sufficiently accurate for most purposes.

The assumption of constant current is most convenient and while most conditions in practice will involve some variation in the amount of current these cases may usually be referred to the constant current data. The time required to bring the conductor to the melting point is divided into the time required to raise the temperature to the melting point and the time required to store the heat of fusion.

The time required to reach the fusing temperature is:

Neglecting losses

$$s_1' = 2.3\,\frac{h(y+l_0)\log_{10}\dfrac{y+l_f}{y+l_0}}{I^2 r_0} \text{ (seconds)} \quad (1)$$

Including losses

$$s_1 = \frac{2.3\,kH}{I^2\dfrac{r_0 H}{y+l_0}-1}\,\log_{10}\frac{\left(\dfrac{l_f-l_0}{l_0-t_0}\right)\left(I^2\dfrac{r_0H(y+l_f)}{(y+l_f)(t-t_0)}-1\right)}{I^2\dfrac{r_0H}{l_0-t_0}-1} \text{ (seconds)} \quad (2)$$

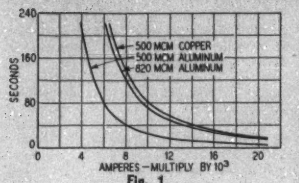


Fig. 1

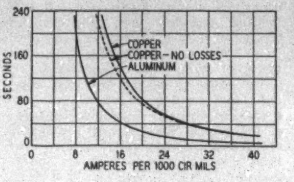


Fig. 2

The time required to store the heat of fusion is:

Neglecting losses

$$s_2' = \frac{h_f}{I^2 r_0} \frac{y + t_f}{y + t_0} \quad \text{(seconds)} \qquad (3)$$

Including losses

$$s_2 = \frac{h_f H}{(t_f - t_a)\left(I^2 \frac{r_0 H(y + t_f)}{(y + t_0)(t_f - t_a)} - 1\right)} \quad \text{(seconds)} \qquad (4)$$

The total time required to reach the molten state is the sum of s_1 and s_2.

SYMBOLS

I = current in amperes
r_0 = initial conductor resistance in ohms per foot
t_0 = initial conductor temperature in degrees centigrade
t_a = ambient temperature of surrounding medium in degrees centigrade
t_f = fusion temperature of conductor metal in degrees centigrade
h = specific heat of conductor in watt-seconds per foot of cable per degree centigrade
= 200 times pounds per foot for copper
= 418 times pounds per foot for aluminum
h_f = heat of fusion of conductor in watt-seconds per foot of cable
= 1.44×10^5 times pounds per foot for copper
= 2.63×10^5 times pounds per foot for aluminum
H = thermal resistivity of cable insulation and covering in degrees centigrade per watt per foot of cable
y = constant for conductor metal determined by temperature resistance coefficient

The curves in figures 1 and 2 were calculated for 600 volt cable using the thermal resistivity given in the table assuming that the cable covering was maintained at the ambient temperature. These values check quite closely with some of the published test values.

Table I

	Copper	Aluminum
Constants		
t_f, fusion temp., deg. C	1080	655
y, temp. constant	234	228
Electrical conductivity, %	100	61
Thermal conductivity, % (silver)	89	48
500 MCM Copper; 500 MCM Aluminum		
Current carrying capacity, %	100	61
h, specific heat, w-s/ft/°C	308	187
h_f, latent heat of fusion, w-s/ft	221×10^3	118×10^3
H, thermal res., 600 volt cable	0.952	0.952
s' (10,000 amp)	75.6	24.5
s (10,000 amp)	82.0	25.0
500 MCM Copper; 820 MCM Aluminum		
Current carrying capacity, %	100	100
h, specific heat, w-s/ft/°C	308	306
h_f, latent heat of fusion, w-s/ft	221×10^3	194×10^3
H, thermal res., 600 volt cable	0.952	0.829
s' (10,000 amp)	75.6	65.8
s (10,000 amp)	82.0	72.0

Very truly yours,

H. J. REEVES (A'30)
Paul & Reeves,
West 1030 First Ave.,
Spokane, Wash.

Titles of Engineers

To the Editor:

The article on "Structure of the Electrical Engineering Profession" by Theodore J. Hoover in ELECTRICAL ENGINEERING, July 1935, pages 695–9, outlines a problem that may well be an early one for the Engineers' Council for Professional Development to consider. That is, the determination of approved professional titles and making these titles a part of the proposed professional certification. However, it would seem that the list of professional titles should be short and carefully selected rather than permitting the compounding of titles of numerous descriptive adjectives. As admitted by Dean Hoover the use of compound titles would result in several thousand combinations and, to my mind, be almost as confusing as the present situation.

At one time it was sufficient to classify an engineer as an "electrical engineer" or a "civil engineer," etc. This is admittedly not adequate now, but for example, the title of "communication engineer" might be suitable although the individual's interest may be in any one of several branches such as acoustical, communications, sound, telegraph, telephone, or telephone equipment. The distinction between professional titles and present position titles further avoids the necessity of compound detail professional titles. The present position title often includes the engineering function or identifies the limited field of the individual's interest. This is usually a specific title established by the engineer, his firm, or the institution with which he is connected, and gives sufficient latitude for designation of restricted activity or individuality.

Any step leading to the establishment of recognized professional titles and a distinction between professional titles and position titles deserves the support of the entire engineering profession.

Very truly yours,

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Complex Hyperbolic Functions and Their Inverse

To the Editor:

The hyperbolic functions of complex variables, sinh $(X + j\theta)$, cosh $(X + j\theta)$, and tanh $(X + j\theta)$, present themselves prominently in numerous problems pertaining to long distance transmission of electrical energy, filter networks, attenuation equalizers used in communication systems, and generally in the solution of recurrent circuits both balanced and unbalanced.

In the excellent Kennelly tables of complex hyperbolic functions ("Tables of Complex Hyperbolic and Circular Functions," by A. E. Kennelly, Harvard University Press, 1914) the real member X of the complex variable is in steps of 0.05 and the j or quadrature member q is in steps of 0.05 of a quadrant, that is, in steps of 4.5 degrees for θ. A single interpolation is necessary if either the real member X or the quadrature member θ (i. e., q) is not included in the table, and a dual interpolation is needed to obtain the vector value of the desired function when the 2 members X and θ are not included. Thus the vector value of sinh (1.25 + j27 degrees), for example, may be obtained directly by using the proper table, either in the complex form $(U + jV)$ or in the polar form $r \angle \gamma$. A dual interpolation, however, is necessary to obtain the vector value of sinh (1.23 + j29 degrees) for example, because the complex quantity (1.23 + j29 degrees) is not included in the tables.

The well-known formulas

$$\sinh (X + j\theta) = \sqrt{\sinh^2 X + \sin^2\theta}\,\angle \tan^{-1}(\tan\theta/\tanh X) \quad (1)$$

$$\cosh (X + j\theta) = \sqrt{\sinh^2 X + \sin^2\theta}\,\angle \tan^{-1}(\tan\theta \cdot \tanh X) \quad (2)$$

and

$$\tanh(X + j\theta) = \frac{\sinh (X + j\theta)}{\cosh (X + j\theta)} \qquad (3)$$

afford a rapid and convenient scheme of evaluating either one of these functions by considering the numerical value of equation 1 as the hypothenuse of a right triangle whose sides are sinh X and sin θ, and the numerical value of the function cosh X, represented by the radical in equation 2 as the hypothenuse of a right triangle whose sides are sinh X and cos θ.

Applying, therefore, the trigonometric relations between the sides of a right triangle and the angle between the hypothenuse and either side, the numerical value of either sinh $(X + j\theta)$ or cosh $(X + j\theta)$ may be obtained by only 2 divisions instead of taking the square root of the sum of 2 squares. The angle associated with the numerical value of the function as a vector may be obtained by the single division (tan θ/tanh X) for the hyperbolic sine, and by the single multiplication (tanh X·tan θ) for the hyperbolic cosine. The complete vector value of either one of the 2 functions may therefore be obtained by 3 divisions. This scheme of evaluating hyperbolic functions of complex variables is the fundamental principle embodied in the Keuffel and Esser log log vector slide rule devised and described by the author in his

paper "Vector Calculating Devices" (see A.I.E.E. JOURNAL, volume 47, May 1928, pages 336–40).

The use of the Kennelly tables for the determination of the complex variable from the known vector value of the hyperbolic sine, or of hyperbolic cosine or of the hyperbolic tangent of the complex variable, consists in scanning over the columns of the proper table to locate the known vector value of the function in terms of its numerical value r and the angle γ associated with it side by side in adjacent columns, if the known function is in the polar form $r\angle\gamma$; or its 2 components (U and V) side by side in adjacent columns, if the known function is in terms of a complex number $(U + jV)$.

Thus to determine $(X + j\theta)$, when sinh $(X + j\theta)$ is equal to $1.665\angle 30.99$ degrees $= 1.427 + 0.857$, for example, we scan over the columns of the proper $r\angle\gamma$ table or the proper $(U + jV)$ table to locate the particular association of $r = 1.665$ with the angle $\gamma = 30.99$ degrees side by side in adjacent columns, or the particular association of $U = 1.477$ and $V = 0.857$ side by side in adjacent columns to determine $(X + jq) = 1.25 + j0.3$, that is $(X + j\theta) = 1.25 + j27$ degrees.

Because of the comparatively large steps in the values of X and of θ, however, the particular vector value of the function is frequently not found in the tables. It is therefore usually necessary and frequently more convenient to determine the unknown complex variable $(X + j\theta)$ from the known vector value of its hyperbolic function, either the sine, cosine, or the tangent (whichever happens to be known) by direct calculation.

EVALUATION OF $\sinh^{-1}(U_s + jV_s)$

It may be shown by a graphical method, as Kennelly has done, or by means of the hyperbolic and trigonometric relations involved, that if

$$\sinh(X + j\theta) = A\angle\alpha = U_s + jV_s,$$

where $A\angle\alpha = U_s + jV_s$ is known, the complex quantity $(X + j\theta)$ may be determined by

$$\sin\theta = \frac{\sqrt{U_s^2 + (1 + V_s)^2} - \sqrt{U_s^2 + 1 - V_s)^2}}{2} = \frac{M_s + N_s}{2} \qquad (4)$$

and

$$\sinh X = \frac{U_s}{\cos\theta}, \qquad (5)$$

where the subscript s to the quantities U, V, M, and N indicates that they pertain to a sine function.

Since the radicals in equation 4 may be thought of as hypothenuses of right triangles whose sides are U_s and $(1 + V_s)$ for one, and U_s and $(1 - V_s)$ for the other, each may be calculated by only 2 divisions instead of by the square root of the sum of 2 squares. Thus

$$\sqrt{U_s^2 + (1 + V_s)^2} = \frac{U}{\sin\rho} = M_s \qquad (6)$$

where

$$\rho = \tan^{-1}\left(\frac{U_s}{1 + V_s}\right) \qquad (7)$$

and

$$\sqrt{U_s^2 + (1 - V_s)^2} = \frac{U_s}{\sin\phi} = N_s \qquad (8)$$

where

$$\phi = \tan^{-1}\left(\frac{U_s}{1 - V_s}\right) \qquad (9)$$

A slide rule having both trigonometric and hyperbolic scales such as the Keuffel and Esser log log vector rule may therefore be used conveniently and effectively to determine directly the value of θ by carrying out the divisions indicated in the last 4 expressions, and the value of X by the division indicated in equation 5.

To illustrate the above, let

$$\sinh(X + j\theta) = 0.662\angle 68.15 \text{ degrees} = 0.246 + j0.613$$

where

$U_s = 0.246$ and $V_s = 0.613$

By equations 6 and 7 there results $M_s = 1.63$; by equations 8 and 9 there results $N_s = 0.46$; whence by equation 4 there results $\theta = 35.8$ degrees, and by equation 5, $X = 0.3$.

EVALUATION OF $\cosh^{-1}(U_c + jV_c) = (X + j\theta)$

It may be shown in a manner similar to that for the evaluation of $\sinh^{-1}(U_s + jV_s)$ that for

$$\cosh(X + j\theta) = \angle\beta = (U_c + jV_c)$$

where $B\angle\beta = U_c + jV_c$ = is known, the complex quantity $(X + j\theta)$ may be determined by

$$\cos\theta = \frac{\sqrt{V_c^2 + (1 + U_c)^2} - \sqrt{V_c^2 + (1 - U_c)^2}}{2} = \frac{M_c - N_c}{2} \qquad (10)$$

and

$$\sinh X \frac{V_c}{\sin\theta}. \qquad (11)$$

From the similarity of expressions 10 and 11 to expressions 4 and 5, respectively, it may readily be seen that the same scheme of calculation may be used to determine the complex quantity $(X + j\theta)$ when the vector value of cosh $(X + j\theta)$ is known as when the hyperbolic sine is known. Thus for

$$\cosh(X + j\theta) = 1.2\angle 25.75 \text{ degrees} = 1.081 + j0.522,$$

where $U_c = 1.081$ and $V_c = 0.522$, there results $M_c = 2.15$, and $N_c = 0.527$. Whence by equation 10 there results $\theta = 36$ degrees and by equation 11, $X = 0.802$

EVALUATION OF $\tanh^{-1}(U + jV) = (X + j\theta)$

The complex quantity $X + j\theta$ may be determined from the components U and V of the vector value of its hyperbolic tangent by the following formula obtained by graphical construction and given on page 171 of Kennelly's tables

$$X + j\theta = \frac{1}{2}\log_e\left\{\frac{\sqrt{(1 + U)^2 + V^2}}{\sqrt{(1 - U)^2 + V^2}}\right\} + j\left\{\frac{180 \text{ degrees} - \tan^{-1}[(U + 1)/V] + \tan^{-1}[(U - 1)/V]}{2}\right\}$$

The values of X and θ respectively may, however, be calculated by the following simpler and more convenient formulas obtained from the hyperbolic and trigonometric relations involved

$$\tanh 2X = \frac{2U}{1 + D^2} \qquad (12)$$

and

$$\tan\frac{2V}{1 - D^2} \qquad (13)$$

In these formulas the quantity D is magnitude of the vector value of the hyperbolic tangent of $(X + j\theta)$, U is the real component of D, and V the j or quadrature component, as indicated by the following relation

$$\tanh(X + j\theta) = D\angle\delta = (U + jV) \qquad (14)$$

To illustrate the above, let

$$\tanh(X + j\theta) = 0.876\angle 24.07 \text{ degrees} = 0.8 + j0.357$$

in which $D = 0.876$, $U = 0.8$, and $V = 0.357$.

By equation 13, there results

$$\tanh 2X = \frac{2 \times 0.8}{1 + 0.767} = 0.906$$

whence

$2X = 1.5$ and $X = 0.75$

By equation 13 there results

$$\tan 2\theta = \frac{2 \times 0.357}{1 - 0.767} = 3.064$$

whence

$2\theta = 71.9$ degrees and $\theta = 35.95$ degrees

The calculations were made by means of the Keuffel and Esser log log vector slide rule which has both trigonometric and hyperbolic scales.

Very truly yours,

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Registration of Engineers

To the Editor:

The paper entitled "Registration of Engineers" by D. B. Steinman in the August 1935 issue of ELECTRICAL ENGINEERING, pages 876–81, represents the point of view which is causing the continual extension of the field of government to the regulation of every conceivable activity of mankind. No one regulatory activity of this kind can be said to be unbearably oppressive, but in the aggregate the bureaucratic organization thus created is becoming an intolerable burden on this country.

The statement that the registration boards are made up of engineers of high standing may be true at the present time, but how long the boards will remain so constituted under the constant pressure of political influence is another matter. The writer doubts very much whether engineers with creative ability will care to serve for any length of time on such boards. Only engineers who have such ability coupled with the rare quality of good common sense should be allowed to sit in judgment on the fellow members of their profession.

The enhancement of the standing of the

profession by legal restriction may be questioned in view of the fact that such restriction has long been established for stationary engineers, marine engineers and other mechanical trades, while the greatest living American electrical engineer chooses to be called by the unregistered and unlicensed title of "professor." The only respect to which the engineering profession is entitled is that which it gains through the creative work of its members. It is in this direction that the efforts of the profession may most profitably be directed.

The reason for the registration of the medical and legal professions is that their clientele is almost entirely composed of those who have no other means of protection against the quacks and the incompetent. The services of the engineer are given almost exclusively to those who are quite as competent to evaluate them as are any of the legally constituted boards.

The insistence that engineering is one profession and that all members should be subject to the same requirements, coupled with the requirement of a written examination, indicate that the examination must be so general in character that it could be passed more easily by a recent graduate than by an engineer with many years' experience in specialized work. It would appear that in an effort to fit the profession into a Procrustean bed, many useful members might be lopped off.

The above are the personal opinions of the undersigned, and were written without consultation with members of any organization with which he is connected.

Very truly yours,

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Armature Reactions in Unloaded Single Phase Generators

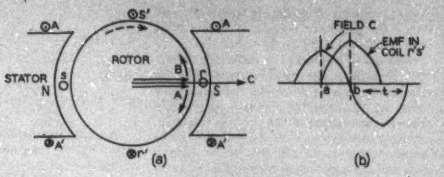
To the Editor:

This interesting study on Ferraris' theory applied to a study of armature reactions in unloaded single-phase synchronous generators, was prompted by the query of a junior electrical engineering student and it was this: Why not excite the field of a single-phase generator by alternating current and at synchronous speed take direct current from any 2 collector rings? We tried it and it did not work, but we also tried some other things which are explained in this letter.

Ferraris' theory states that a single-phase a-c field C or flux, N-S, figure 1(a), pulsating in time, can be resolved into 2 rotating fields A and B. Each is of constant magnitude and is equal to $^1/_2$ the maximum value of the pulsating field C. Field A rotates clockwise at synchronous speed with respect to C and is called the forward gliding component ($f.g.c.$) of C. Field B rotates counterclockwise at synchronous speed with respect to C and is called the backward gliding component ($b.g.c.$) of C. Evidently $A = B$.

The object of this communication is to present a physical concept of single-phase armature reactions, or flux, from Ferraris' viewpoint. It has been the writer's experience that single-phase reactions have been a stumbling block to many students from any physical viewpoint.

Fig. 1



Studies were made on 2 machines, number 1 and number 2. Generator number 1 is a 4 pole synchronous converter (a revolving armature generator). Generator number 2 is a 4 pole revolving field generator.

Each generator was directly connected to a shunt motor whose speed could be varied. In this paper both generators are assumed to have but 2 poles; this makes the synchronous speed $n = f$ the applied frequency. Each armature is assumed to have but one coil, rs, figures 1 and 2.

Instead of impressing single-phase current across the armature of number 1, or across the stator of number 2, exactly the same flux effect was produced by impressing 250-volt 25-cycle single-phase alternating current across the d-c field of number 1, or across the d-c rotor of number 2.

The first half of the paper discusses instantaneous electromotive forces (e) for generator number 1 at zero speed, for different armature positions. The discussion is unchanged for generator number 2 and is therefore omitted. The symbols and abbreviations used are as follows:

Symbols and Abbreviations

C = pulsating field or flux, in space phase with field pole axis N-S
A = clockwise or forward gliding (or rotating) component of C
B = counterclockwise or backward gliding component of C
e_{rs} = instantaneous electromotive force in armature coil in position rs
$e_{r's'}$ = instantaneous electromotive force in armature coil in position $r's'$
E = effective electromotive force
E_m = maximum cyclic electromotive force
n = synchronous speed in revolutions per second
n' = speed of rotating member in revolutions per second
f = applied frequency
α = proportional to
I_f = field current
t = time in seconds
$f.g.c.$ = forward gliding component of field C
$b.g.c.$ = backward gliding component of field C

(a). At Instant a, Figure 1(b)

In this case, 25 cycle field current I_f produces field C; C pulsates back and forth along field axis 25 times a second ($n = 25$), no matter what speed n' may be. C also pulsates along horizontal axis in space 25 times a second, no matter what n' may be, because the field is always at rest. Pulsating flux $C = +$ maximum at instant a, figure 1(b); $+$ flux is assumed to be from left toward right in figure 1(a). Field current I_f is also $+$ maximum and is in time phase with C (this neglects hysteretic lag). The 2 rotating fluxes A and B are in space phase with C at instant a and $A = B = {}^1/_2C$.

First. Assume armature coil to be in position rs. Conductor r is cut clockwise by A, this induces an instantaneous electromotive force *into* the paper; conductor r is cut counterclockwise by B, this induces an instantaneous electromotive force *out* of the paper; total instantaneous electromotive force in conductor r is 0; similarly total instantaneous electromotive force in conductor s is 0. Therefore total instantaneous electromotive force in coil rs (e_{rs}) = 0.

Second. By hand, move armature coil clockwise into position $r's'$. Conductors r' and s' are cutting 0 flux since A and B are in horizontal position, at instant a. Therefore, total instantaneous electromotive force in coil $r's'$, i. e., $e_{r's'} = 0$.

(b). At Instant b, Figure 1(b)

Third. By hand, move armature coil back into position rs. Conductors r and s are cutting zero flux because A and B are in vertical position. Therefore total instantaneous electromotive force in coil rs, i. e., $e_{rs} = 0$.

Fourth. By hand, move armature coil clockwise into position $r's'$. Conductor r' is cut clockwise by arrow *heads* of A, this induces an instantaneous electromotive force *into* the paper and at instant b, it has a maximum value; conductor r' is cut counterclockwise by arrow *tails* of B, this induces an instantaneous electromotive force *into* the paper, it has a maximum value. Therefore total instantaneous electromotive force in conductor r', i. e., $e_{r'}$ = sum of these 2 electromotive forces, and $e_{r'}$ = maximum value; similarly $e_{s'}$ = maximum value. Therefore, total instantaneous electromotive force in coil $r's'$, i. e., $e_{r's'}$ = $+$ maximum at instant b ($= E_{r's'}$).

Conclusion

1. Instantaneous electromotive force in coil rs, i. e., $e_{rs} = 0$, at instant a. Instantaneous electromotive force in armature coil = 0 in any position of armature at instant a. Instantaneous electromotive force in coils rs, i. e., $e_{rs} = 0$, at instant b. Instantaneous electromotive force in coil $r's'$, i. e., $e^{r's'}$ = $+$ maximum at instant b, or instantaneous electromotive force in armature due to field C = 90 degrees behind C in time, figure 1(b).

2. From the viewpoint of transformer action, (a) and (b) above may be stated thus:

(a). With armature coil in position rs the primary and secondary axes are at right angles and $e_{rs} = 0$ at all times; $E_{eff.} = 0$ at all times.

(b). With coil in position $r's'$ the primary and secondary axes coincide and $e_{r's'} = E_m$ at instant b: $E_{r's'eff.}$ = maximum at all times.

The second half of this paper deals only with effective values of electromotive force (E).

The observations used to substantiate the theory were obtained by connecting in parallel, to any 2 collector rings of generator number 1 or to any 2 terminals of generator number 2: (a) a 0-0.25, 0-center d-c voltmeter; (b) an a-c voltmeter of suitable

range; and (*e*) an oscilloscope. In this manner single-phase observations were made on 2 polyphase generators.

Each generator was studied when: (*a*) rotor speed $n' = 0$; (*b*) $n' = n$; (*c*) $0 < n' < n$; (*d*) $n' = 2n$; and (*e*) $n < n' < 2n$.

Generator Number 1 With Revolving Armature, Figure 1

Case (*a*), $n' = 0$. Armature is at rest. See conclusion 2 above.

Observations: (1) armature coil in horizontal position *rs*.

(*a*). $E_{d-e} = 0$; needle does not vibrate.
(*b*). $E_{g-e} = 0$.
(*c*). Oscilloscope shows nothing.

Observations: (2). Armature coil in vertical position $r's'$.

(*a*). $E_{d-e} = 0$; needle vibrates 25 times a second.
(*b*). $E_{g-e} = 3$ volts $\alpha (A + B)n \ \alpha \ (A + B)25$. See (*b*) "*fourth*," above.
(*c*). Oscilloscope showed 25 cycle stationary wave; length of 1 cycle = 4 inches.

Observations: (3). Armature coil moved by hand from position *rs* to $r's'$ back to *rs*.

(*a*). E_{d-e} reads to left of zero, then to right of zero (due to higher rate of cutting by *B* than by *A* and *vice versa*). Its magnitude and rapidity of reversal vary with the speed by which the coil is moved back and forth.

(*b*). E_{g-e} reads 0 to 3 back to 0 volts (from zero transformer action, to maximum, back to zero). Time required to move pointer from 0 to 3 = time required to move coil from position *rs* to position $r's'$.

(*c*). Oscilloscope shows nothing, then a 25 cycle stationary wave, then nothing. Time required to change from nothing to stationary wave = time required to move coil from position *rs* to position $r's'$.

Case (*b*), $n' = n$. Armature is driven clockwise at synchronous speed.

E_1 (due to *f.g.c.* *A*) $\alpha \ (n - n')\ A = 0$. Therefore $E_{d-e} = 0$; see "third" final conclusion.

E_2 (due to *b.g.c.* *B*) $\alpha \ (n + n')B \ \alpha \ B \times 50$. *F.g.c.* *A* is at rest with respect to armature; *b.g.c.* *B* passes surface of armature at speed $n + n'$.

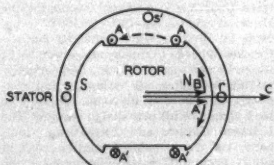


Fig. 2

Observations:

(*a*). $E_{d-e} = 0$; needle vibrates 50 times a second (due to speed $n + n'$ of *b.g.c.* *B*).
(*b*). E_{g-e} (= 3 volts), $\alpha \ B \times 50$, but $B \times 50 = (A + B)\ 25$; see observation 3(*b*) above.
(*c*). Oscilloscope shows a 50 cycle stationary wave; length of 1 cycle = 2 inches.

Case (*c*), $n' < n$

Observations:

(*a*). E_{d-e}: needle goes to right and to left of zero and more slowly as n' approaches n. This is due to the decreasing relative speed of field *A* and coil *rs*. Needle vibrates $(n + n')$ or < 50 times per second.
(*b*). $E_{g-e} = 3$–4 volts; E_{g-e} is made up of $E_1 \ \alpha \ A \times (n - n')$ and $E_2 \ \alpha \ B \times (n + n')$, and $E_{g-e} = \sqrt{E_1^2 + E_2^2}$. (See "Principles of Alternating Currents," first edition, page 84, McGraw-Hill Book Co.)
(*c*). Oscilloscope shows a moving wave of constantly changing amplitude and frequency as n' varies from 0 to n and as frequency varies from 25 to 50; 1 cycle of wavelength changes from 4 inches ($n' = 0$) to 2 inches ($n' = n$).

Case (*d*), $n' = 2n$. Armature is driven clockwise at 2 times synchronous speed.

E_1 due to *f.g.c.* $A \ \alpha \ (n' - n)A \ \alpha \ 25 \times A$; $f = 50 - 25 = 25$ cycles.

E_2 due to *b.g.c.* $B \ \alpha \ (n' + n)B \ \alpha \ 75 \times B$; $f = 50 + 25 = 75$ cycles.

Observations:

(*a*). $E_{d-e} = 0$; needle vibrates 75 times per second due to *B* and pulsates 3 times per second due to the 75 cycle field *B* being superimposed on the 25 cycle field *A*.

(*b*). E_{g-e} = about 6 volts; $E = \sqrt{E_1^2 + E_2^2}$.
(*c*). Oscilloscope shows a 75 cycle stationary wave; length of 1 cycle = 4/3 inch (= 4 inches × 25/75); this wave is superimposed on a 25 cycle wave; if oscilloscope is synchronized for 25 cycles, than at $n' = 2n$ the 75 cycle wave is stationary, as well as the 25 cycle wave, and it is superimposed on the 25 cycle wave; see case (*d*), observation (*a*).

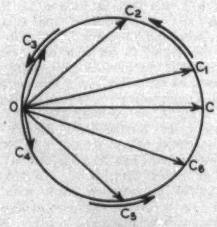


Fig. 3

Case (*e*), $n < n' < 2n$.

Observations:

(*a*). $E_{d-e} = 0$; needle moves back and forth slowly on either side of zero as n' increases from n. This is due to the relative speed of field *A* and coil *rs*. Needle vibrates $(n + n')$ times a second due to speed of *b.g.c.* *B* relative to coil *rs*; and $(n' - n)$ times a second due to speed of *f.g.c.* *A*.
(*b*). $E_{g-e} = 3$–6 volts. Compare with observation (*b*) case (*d*).
(*c*). Oscilloscope, when $n' = 49$, shows a 74 cycle wave $(49 + 25)$ due to *b.g.c.* *B* superimposed on a 24 cycle wave $(49-25)$ due to *f.g.c.* *A*. Since oscilloscope is synchronized for 25 cycles, the resultant 74 cycle wave moves 1 cycle per second, of 25 cycle wave length, to left and moves up and down, because its axis is the 24 cycle wave which is not in synchronism with the oscilloscope.

General Observations:

First. Oscilloscope shows stationary wave at $n' = 0$, $n' = 12^1/_2$, $n' = 25$, and $n' = 50$ and length of 1 cycle is 4 inches, 3 inches, 2 inches, and 4/3 inch, respectively.
Second. When n' increases, wave moves forward; when n' decreases, wave moves backward and in each case these waves become stationary at the frequencies stated in the first general observation.

Generator Number 2 With Revolving Field, Figure 2

Case (*a*), $n' = 0$. (See Figure 2).

In this case, 25 cycle field current, I_f produces field *C*; *C* pulsates back and forth along field axis 25 times a second, no matter what speed n' may be; *C* pulsates along horizontal axis in space 25 times a second, only when $n' = 0$; see [(*a*) at instant *a*].

Number 2 generator is identical throughout cases (*b*), (*c*), (*d*), and (*e*), with number 1 generator except where $E_{a-e} = 3$ volts for number 1, $E_{a-e} = 16.5$ volts for number 2. This is due to the fact that *C* is larger in generator number 2 and so are *A* and *B*.

Final Conclusions

First. In number 1 generator, figure 1.

(*a*). Field *C* pulsates along field axis, no matter what n' may be.
(*b*). Field *C* pulsates along horizontal axis in space no matter what n' may be.
(*c*). *F.g.c.* *A* glides clockwise past field at speed n, no matter what n' may be.
(*d*). *F.g.c.* *A* glides clockwise in space at speed n, no matter what n' may be.
(*e*). *B.g.c.* *B* glides counterclockwise past field at speed n, no matter what n' may be.
(*f*). *B.g.c.* *B* glides counterclockwise in space at speed n, no matter what n' may be.

Second. In number 2 generator, figure 2.

(*a*). Field *C* pulsates along field axis, no matter what n' may be.
(*b*). Field *C* pulsates along horizontal axis in space only when $n' = 0$.
(*c*). *F.g.c.* *A* glides clockwise past field at speed n, no matter what n' may be.
(*d*). *F.g.c.* *A* is at rest in space, when $n' = n$.
(*e*). *B.g.c.* *B* glides counterclockwise past field at speed n, no matter what n' may be.
(*f*). *B.g.c.* *B* glides counterclockwise in space at speed $2n(= n + n)$, when $n' = n$.

If *A* is at rest in space at $n' = n$ see (*d*) above and *B* glides counterclockwise in space at speed $2n$ see (*f*) above the resultant of a stationary vector A + a rotating vector *B* gives a resultant *C* in space shown in figure 3.

The resultant *C* follows, in a counterclockwise direction, the locus of a circle and at $n' = n$ assumes successively the values OC, OC_1, OC_2, OC_3, OC_4, OC_5, OC_6, back to OC, 50 times each second in space, but only 25 times a second with respect to the rotor.

In number 1 generator, resultant *C* pulsates back and forth along a horizontal axis in space, 25 times a second. This is the big difference between the armature reactions in the 2 unloaded generators.

They both pulsate, back and forth along their respective field axes, 25 times a second.

Third. About obtaining direct current or when $f = 0$: only when $n' = n$ is frequency of $A = 0$ $(f = n - n')$, but then *f.g.c.* *A* has zero rate of cutting and therefore $E_{d-e} = 0$; see generator number 1, case (*b*) $n' = n$.

Fourth. It can easily be shown that if the generator has 3 windings 120 degrees apart, the 3 *f.g.c.* fields *A* coincide, producing 3 times the magnitude of field *A*, discussed in this paper, and the 3 *b.g.c.* fields *B* cancel each other and do not exist in the fundamental wave. This is a frequently used method of studying armature reactions in 3-phase generators.

Fifth. This same Ferraris' theory could be used in a similar manner in studying single-phase synchronous motors.

Sixth. Ferraris' theory is often used as an easy though somewhat unsatisfactory method of studying single-phase induction motors.

Seventh. This study of armature reactions could have been made using transformer (or pulsational) electromotive forces and rotational electromotive forces. Such a method is to be preferred in studying what takes place in single-phase induction motors.

Very truly yours,

J. L. Beaver (A'14, F'26)
Professor of Elec. Engg.,
Lehigh University, Bethlehem, Pa.

Personal Items

E. B. Meyer (A'05, F'27, and president) chief engineer, Public Service Electric and Gas Company, Newark, N. J., has been appointed chairman of the Institute's executive committee for the year 1935–36. Mr. Meyer, who was born at Newark in 1882, is a graduate of Pratt Institute, Brooklyn, N. Y., completing the electrical engineering course in 1903. In that year he entered the employ of the Public Service Corporation of New Jersey as engineering assistant, and was promoted through successive positions to become assistant chief engineer in 1919. Three years later he was appointed chief engineer of the Public Service Production Company at its formation, and in 1929 was made a vice president. With the merger the following year of this company and United Engineers and Constructors, Inc., Mr. Meyer was appointed a vice president of the latter in the capacity of executive and engineering head of the Newark office. Recently he was appointed chief engineer of the Public Service Electric and Gas Company. Mr. Meyer has served on many Institute committees in the past, and was a director 1928–31, and a vice president 1932–34. He is now a member of the Edison medal committee, and is Institute representative on the American Engineering Council and the Charles A. Coffin fellowship and research fund committee. Other societies of which he is a member include The American Society of Mechanical Engineers, the New York Electrical Society, Inc., and the American Transit Association. Mr. Meyer is the author of a number of technical articles, and the book "Underground Transmission and Distribution."

J. B. Whitehead (A'00, F'12, Life Member, and junior past-president) dean of the school of engineering, The Johns Hopkins University, Baltimore, Md., has been appointed chairman of the committee on Institute policy for the year 1935–36. Doctor Whitehead, who was born at Norfolk, Va., August 18, 1872, studied at The Johns Hopkins University, from which he received the degrees of electrical engineer (1893), bachelor of arts (1898), and doctor of philosophy (1902). He first was employed by the Westinghouse Electric and Manufacturing Company, and for a short time was with the Niagara Falls Power Company and the Pittsburgh Reduction Company. In 1898 he returned to the university as an instructor in electrical engineering, and became associate professor of applied electricity in 1905. He became professor in 1919, and since 1925 has been dean. In addition to teaching he has carried on a large consulting practice. He is well known for his work on high voltage insulation, and has presented a number of papers on this subject before the Institute. Doctor Whitehead has been active in the work of the Institute, and was a manager 1924–28 and president 1933–34. In addition to his present appointment as committee chairman he is a member of the executive, electrophysics, and Edison medal committees, and is a representative on the John Fritz medal board of award, and on the division of engineering and industrial research of the National Research Council. Among other committees on which he has served are electrochemistry and electrometallurgy, of which he was a member 1924–33, and research, of which he was a member 1920–33, and chairman 1922–27.

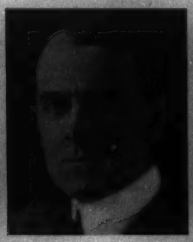
W. R. Smith (M'18, F'30) transmission construction engineer, Public Service Electric and Gas Company, Newark, N. J., has been appointed chairman of the Institute's committees on technical program and award of Institute prizes for the year 1935–36. Mr. Smith was born at Charleston, S. C., in 1885 and was graduated from Clemson Agricultural and Mechanical College in 1906 with the degree of bachelor of science in electrical and mechanical engineering. He remained at the college for a year as secretary and engineering assistant to the department head before entering the apprentice course of the Westinghouse Electric and Manufacturing Company, and from 1908 to 1913 was with the Hartford Suspension Company at Jersey City, N. J. In 1914 he engaged in construction work with the Public Service Electric Company at Newark, and was made field engineer in 1917. When the Public Service Construction Company was formed in 1922 he was made superintendent of the electrical construction department, becoming managing electrical engineer in charge of the electrical engineering department 2 years later. From 1927 until recently he was assistant chief engineer of United Engineers and Constructors, Inc., Newark. Mr. Smith has been a member of the Institute's board of examiners since 1930, and has served as chairman since 1934. He is also serving on the committees on publication and co-ordination of Institute activities. Mr. Smith is a member also of the Illuminating Engineering Society and the Edison Electric Institute.

O. W. Eshbach (A'17, M'30) special assistant, personnel department, American Telephone and Telegraph Company, New York, N. Y., has been appointed chairman of the Institute's committees on education and Student Branches for the year 1935–36. Mr. Eshbach was born at Pennsburg, Pa., April 13, 1893. He is a graduate of Lehigh University, from which he received the degrees of electrical engineer (1915) and master of science (1920). During the year 1916–17 he was an instructor in electrical engineering at the university, then entered the U.S. Army, subsequently being commissioned a lieutenant in the Signal Corps. In 1919 he returned to the university as an instructor, and the following year was made assistant professor. In 1923 he was made assistant engineer with the Bell Telephone Company of Pennsylvania, his work being associated with the employment and training of engineering graduates. He accepted his present position in 1925, his duties involving educational and employment work, and is nonresident instructor in electrical engineering at Massachusetts Institute of Technology and instructor in the graduate night school at Brooklyn Polytechnic Institute. Mr. Eshbach has been a member of the Institute's committee on education since 1931, and is now a member of the committees on technical program, publication, and Sections. He is a member of the Society for the Promotion of Engineering Education and other organizations, and in 1932 was director of the survey of adult technical education in the New York industrial area, on which subject he presented a paper before the Institute.

A. M. MacCutcheon (A'12, F'26, and past director) engineering vice president, The Reliance Electric and Engineering Company, Cleveland, Ohio, has been appointed chairman of the Institute's committee on the Lamme medal for the year 1935–36. Mr. MacCutcheon was born at Stockport, N. Y., December 31, 1881, and taught mathematics and science in high schools for 3 years following his graduation from Albany State Normal School in 1901. He then entered Columbia University, completing the electrical engineering course in 1908. From 1909 to 1914 he was employed by the Crocker-Wheeler Company at Ampere, N. J., where he was successively in charge of engineering estimates, all estimates and proposals, and the drafting room. In 1914 he took charge of all new design work for The Reliance Electric and Engineering Company, and was appointed chief engineer in 1917. From 1917 to 1919 he served in the U.S. Navy, becoming lieutenant in charge of fire control on the U. S. S. Louisiana. A

E. B. MEYER

J. B. WHITEHEAD



A. M. MAC CUTCHEON

W. R. SMITH

O. W. ESHBACH

R. N. CONWELL

year after his return to civil life he was elected a director of the company, and in 1923 was appointed vice president in charge of engineering. Mr. MacCutcheon has prepared many technical papers, and is recognized as an authority on motor applications for steel mill auxiliaries. He is also a member of the Institute's standards committee, on which he has served since 1922, and of which he was chairman 1931–34, and is Institute representative on both the electrical standards committee and the council of the American Standards Association. Mr. MacCutcheon has served on a number of other committees, including general power applications, of which he was chairman 1925–28, electrical machinery, applications to iron and steel production and meetings and papers (now technical program), and was representative on the U.S. national committee of the International Electrotechnical Commission 1931–35. He has also been active in the Association of Iron and Steel Electrical Engineers and other organizations of which he is a member.

R. N. Conwell (A'15, F'31) transmission and substation engineer, Public Service Electric and Gas Company, Newark, N. J., has been appointed chairman of the Institute's committee on constitution and by-laws for the year 1935–36. Mr. Conwell, who was born at Anderson, Ind., February 10, 1885, is a graduate of Purdue University and George Washington University. In 1911, following a year as engineer in charge of acceptance tests for the sewer department of Washington, D. C., he was employed as a cadet engineer by the Public Service Electric Company at Newark, later becoming laboratory assistant and chief of the materials division of the testing laboratory. He was appointed assistant engineer in the engineering department, with charge of station and substation design and system protection in 1917, and in 1922 was appointed transmission engineer in the distribution department with charge of transmission design and system load forecasting and planning. While in this capacity he redesigned and reconstructed the transmission system of the company. Since 1925 he has held his present position. Many technical papers have been prepared by him, and he is the holder of a number of patents, including that of a type of inverse current relay. Mr. Conwell has also served the Institute on many other committees, and is now a member of the committees on technical program and award of Institute prizes, having been chairman of both during 1933–35, publication, power transmission and distribution, and co-ordination of Institute activities, and is representative on the Alfred Noble prize committee and the American committee on marking of obstructions to air navigation. In addition to serving on many of the Institute's committees, Mr. Conwell has been a member of committees of the former National Electric Light Association (now Edison Electric Institute), American Standards Association, American Committee on Inductive Co-ordination, National Fire Protection Association, and Association of Edison Illuminating Companies.

D. W. Roper (A'93, F'14, and member for life) assistant electrical engineer, Commonwealth Edison Company, Chicago, Ill., retired recently. Mr. Roper was born at Grafton, Ill., and received the degree of mechanical engineer at Cornell University in 1893. Following experience in the student course of the General Electric Company and with the Missouri Edison Electric Company, St. Louis, Mr. Roper in 1903 entered the engineering department of the Chicago Edison Company, a company later consolidated into the present Commonwealth Edison Company. In 1904 he was made assistant to chief operating engineer, and had charge of engineering, construction, and operation of underground cables. In 1911 overhead systems were added to his responsibilities. From 1915 to 1933 he was superintendent of the street lighting department, being appointed assistant electrical engineer in charge of the research division of the engineering department. Mr. Roper is a well-known authority on underground cables, and has presented a number of papers to the Institute on this subject. He has been a member of the Institute's committee on research since 1924, and other committees on which he has served include power transmission and distribution, 1917–35, and U.S. National Committee of the International Electrotechnical Commission, 1923–30.

M. S. Coover (A'16, M'32) former professor of electrical engineering at the University of Colorado, Boulder, has been appointed professor and head of the department of electrical engineering at Iowa State College, Ames, where he succeeds F. E. Johnson (A'13, F'31). Professor Coover was born at Shippensburg, Pa., and was graduated from Rensselaer Polytechnic Institute in 1914 with the degree of electrical engineer. Following graduation he was in the employ of the New York Central Railroad and in 1915 went with the Montana Power Company until the outbreak of the World War. Shortly after his release from army service (1919) he was appointed instructor in electrical engineering at the University of Colorado. The following year he was appointed assistant professor, and 2 years later became associate professor. He was appointed professor in 1930. Professor Coover served on the automatic stations committee of the Institute, 1927–29, and was secretary of the North Central District 1929–33. He is also a member of the Society for the Promotion of Engineering Education and served on the electrical engineering committee 1933–34. During summer vacations at Colorado his activities as a consultant and investigator on electrical engineering problems have taken him to widely separated parts of the United States.

I. E. Moultrop (A'10, F'29, and past vice president) chief engineer and superintendent of the construction bureau of The Edison Electric Illuminating Company of Boston, Mass., has retired from active service after 43 years with the company. Mr. Moultrop was born at Marlboro, Mass., in 1865 and became an apprentice with the Whitter Machine Company in 1882. He became head draftsman of this company, which was a pioneer in the manufacture of electric elevators, and resigned in 1892 to become chief draftsman of The Edison Electric Illuminating Company of Boston. In 1897 he was appointed mechanical engineer, serving in that capacity until 1913 when he was appointed assistant superintendent of the construction bureau. His appointment to chief engineer was made in 1926, the supervision of the construction bureau being added subsequently. Throughout his period of service he has had a prominent part in all the construction work of the company, both mechanical and electrical, including also transmission and distribution. Mr. Moultrop's work has been recognized by the award of the Elliott Cresson medal by the Franklin Institute and the honorary degree of mechanical engineer by Stevens Institute of Technology. Recently he was appointed chairman of the Boston area committee in the drive to raise funds for Engineering Index, Inc. A past chairman of the Boston Section, he has been very active in the affairs of the Institute, and was a director 1926–30 and a vice president 1930–32. He is the author of several Institute papers, and has been a member of the power generation committee since 1916 and of the automatic stations committee since 1930, serving also on others. Mr. Moultrop is a member and past officer of The American Society of Mechanical Engineers, and is president of the Engineers' Club of Boston.

F. P. Cox (A'01, F'13) manager of the West Lynn, Mass., works of the General Electric Company, retired on September 1, 1935. Mr. Cox graduated from Rose Polytechnic Institute, Terre Haute, Ind., in 1887, and since 1889 has been with the General

Electric Company and its predecessors, having charge of meter and instrument design and development from 1894 to 1920, when he was appointed manager. A number of patents were granted to him for his work, which included prepayment and rate meters. Mr. Cox was a member of the Institute's standards committee 1915–22 and 1923–28, and served also on the instruments and measurements committee, 1917–24, and on a joint power factor committee 1919–20.

F. E. Johnson (A'13, F'31) who has been head of the department of electrical engineering of Iowa State College, Ames, has accepted the position of dean of the college of engineering at the University of Missouri, Columbia. Dean Johnson was born at Le Roy, Mich., and is a graduate of the University of Michigan, having received the degrees of bachelor of arts, in 1906 and of electrical engineer in 1909. Following some experience in electrical construction work he became an instructor at Rice Institute, Houston, Tex., in 1912 and 3 years later went to the University of Kansas, Lawrence, where he was successively assistant professor, associate professor, and professor, being appointed head of the department of electrical engineering in 1928. In 1930 he resigned to become head of the department at Iowa State College. During the period 1933–35 Dean Johnson served as a member of the Institute's commmittee on education.

J. T. Mountain (A'04, F'20) Chicago, Ill., has retired from the Commonwealth Edison Company after 36 years with the company. Mr. Mountain entered the employ of the Chicago Edison Company following his graduation from the electrical engineering course at the University of Michigan in 1899. He served as load dispatcher and chief load dispatcher from 1904 to 1910, when he was made assistant to the chief operating engineer. He held this position until recently, when he was appointed assistant service manager. In addition to his general interest in operating affairs he concerned himself especially with lamp matters and policies, and was a member of the lamp committee of the Association of Edison Illuminating Companies.

R. H. Tapscott (A'18, F'29, and vice president) vice president of the New York Edison Company, New York, N. Y., has been elected to the board of the New York Edison Company and to the executive committee of the United Electric Light and Power Company. Mr. Tapscott, in addition to serving the Institute as a vice president, is also chairman of the finance committee and a member of executive, headquarters, and co-ordination of Institute activities committees.

J. D. Ross (A'08, F'12) superintendent of lighting, City of Seattle, Wash., has been appointed a member for a 5 year term of the Securities and Exchange Commission by President Roosevelt. Mr. Ross was born at Chatham, Ont., Can., and was educated in Canada. For a short time he was engaged in mining, and in 1903 was employed on the design, construction, and operation of the municipal electric plant at Seattle, engaging also in other consulting and supervising work. Since that time Mr. Ross has been superintendent of the system. Recently he was appointed chief consulting engineer of the power division just organized by the Public Works Administration. He was a member of the Institute's committee on power stations (now power generation) 1918–19 and 1920–21.

R. C. Hummel (A'29) equipment engineer, West Coast Telephone Company, Everett, Wash., has been awarded the 1934 A. I. E. E. North West District prize for best paper for his paper "The Design and Operation of an Automatic All Relay Telephone

R. C. HUMMEL

Switching System for Small Communities." Mr. Hummel was born at Lopez Island, Wash., and has been engaged in telephone work since 1918, when he was employed at switchboard maintenance by the Puget Sound Telephone Company, predecessor of the West Coast Telephone Company. During the year 1923–24 he was design and production engineer with the North Electric Manufacturing Company, Galion, Ohio, where he worked on the design of the first magneto machine switching telephone exchange placed in commercial service and on power supervisory equipment of various types. In 1924 Mr Hummel assumed his present duties as equipment engineer.

A. H. Kehoe (A'12, F'25) vice president, New York Edison Company, New York, N. Y., has been elected to the board of the United Electric Light and Power Company, New York. Mr. Kehoe is a member of the Institute's committee on standards, and was recently elected second vice president of the New York Electrical Society to serve for the year 1935–36.

N. J. Darling (M'34) who is manager of the River Works of the General Electric Company at Lynn, Mass., has also assumed management of the works at West Lynn following the retirement of F. P. Cox (A'01, F'13). Mr. Darling graduated from Cornell University in 1907, and was entered in the student course of the General Electric Company at Schenectady, N. Y., until 1909. He returned to the company at Erie, Pa., in 1915, and 3 years later was appointed assistant works manager there. Since 1922 he has been manager of the River Works at Lynn. Mr. Darling was first elected to membership in the Institute in 1922, and was a member of the committee on education during 1926–28.

W. B. Jackson (A'97, F'13, past vice president and Life Member) rate engineer of the New York Edison Company, New York, N. Y., since 1920, has been made rate consultant. Colonel Jackson graduated from Pennsylvania State College in 1890, and was engaged by several companies prior to his becoming a member of the consulting firm of D. C. and W. B. Jackson in Chicago, Ill. He was made rate engineer of the New York Edison Company in 1920, shortly after his return from service in the army. Colonel Jackson was a manager of the Institute, 1912–15, and a vice president 1918–19, and is now an Institute representative on the commission of the Washington award. He is a member and past officer of a number of organizations.

L. S. Keith (A'06) consulting engineer, Chicago, Ill., has been elected secretary of the Western Society of Engineers. Mr. Keith, who graduated from Massachusetts Institute of Technology in 1900, has been a consultant on public utility and industrial matters since 1922, and has been connected with the Cook Electric Company, Chicago, as vice president and director. Recently he was a member of the staff of the administrator of the work and rehabilitation division of the Illinois Emergency Relief Commission, resigning to assume his position with the Western Society of Engineers, which he already has served as treasurer and vice president.

F. M. Terry (A'22, M'28) executive assistant, New York Edison Company, New York, N. Y., has been appointed rate engineer to succeed W. B. Jackson (A'97, F'13, past vice president and Life Member). Mr. Terry, who was graduated from Union College in 1920, was employed in the test department of the New York Edison Company in 1921, following a year with the General Electric Company at Schenectady, N. Y. In 1923 he was appointed assistant to the rate engineer, and became chief assistant in 1927. Since 1932 he has been executive assistant.

G. E. McCarn (M'22) Denver Colo., has retired as chief engineer of The Mountain States Telephone and Telegraph Company. Mr. McCarn was born at Plattsville, Wis., and was employed in the engineering department of The Colorado Telephone Company in 1899, becoming assistant chief engineer of the company 4 years later. In 1911 he became general plant superintendent in charge of the engineering department of its successor, The Mountain States Telephone and Telegraph Company, and in 1921 was appointed chief engineer.

Russell Hastings (A'14) electrical engineer, Boston, Mass., who for the past 15 years has been engaged in public utility rate work, has joined the staff of the Edison Electric Illuminating Company of Boston as rate engineer. Mr. Hastings, a graduate of Massachusetts Institute of Technology, was employed by the Westinghouse Electric and Manufacturing Company and the Boston Elevated Railway Company before he engaged in his present line of activity; in this work he has been in association with A. S. Knight, through whose offices he has been closely identified with The Edison Electric Illuminating Company.

W. J. Canada (A'20, M'20) formerly head of the engineering department of the National Electrical Manufacturers' Association, New York, N. Y., has entered upon a new activity as special engineering representative with offices at New York for the Chase-Shawmut Company and the Wiremold Company. Mr. Canada, who has given special attention to safety work, has previously been connected with the National Fire Protection Association, Rocky Mountain Fire Underwriters' Association, and Bureau of Standards, and was a member of the Institute's committee on safety codes from 1924 to 1928.

J. T. Nichols (M'30) former manager of the research laboratory of the American Sheet and Tin Plate Company, Pittsburgh, Pa., has been appointed special representative for the company, and is now in San Francisco, Calif. Mr. Nichols, in connection with his past work, developed an automatic optical pyrometer for measuring the temperature of glowing objects. He is a member of the American Society of Refrigerating Engineers, the Engineers Society of Western Pennsylvania, and other organizations, and is the author of several technical papers.

G. T. Shoemaker (M'20) vice president and electrical engineer, United Light and Power Engineering and Construction Company, Davenport, Ia., has assumed the duties of vice president of the Kansas City (Mo.) Power and Light Company. Mr. Shoemaker, a graduate of Purdue University became electrical engineer for the United company in 1913, and since then has been engaged in the engineering of various steam power and hydraulic plants, as well as transmission lines and distribution systems.

Magnus Bjorndal (A'25, M'34) former chief engineer of The Daven Company, Newark, N. J., is the founder and president of Tech Laboratories, Jersey City, N. J., a new company which will specialize in the manufacture of precision electrical resistance instruments and allied products. Mr. Bjorndal, before joining The Daven Company recently, was chief engineer of Hardwick, Hindle Incorporated, Newark, where he was in charge of the design and production of various electrical equipment.

C. E. Wilson (A'16) vice president of the General Electric Company, Schenectady, N. Y., has been made chairman of the board of Houses, Incorporated. Houses, Incorporated, is a company newly organized by the General Electric Company to cooperate with others in the development of houses of any type which seems worthy and promising, to conduct research work, and to assist in the management and financing of such enterprises, being concerned primarily with the interior mechanism of the house.

H. V. Putman (A'23, M'32) since 1931 manager of the transformer engineering department of the Westinghouse Electric and Manufacturing Company at Sharon, Pa., is now manager of the switchgear management unit of the company at East Pittsburgh, Pa. Mr. Putman is the author of a number of Institute papers, and has been appointed a member of the power transmission and distribution committee for the year 1935–36. He served as a member of the electrical machinery committee 1931–35.

Matthew Luckiesh (A'11, M'15) director, lighting research laboratory, General Electric Company, Cleveland, Ohio, has had the honorary degree of doctor of engineering conferred upon him by Purdue University, which has conferred this degree only 6 times in 61 years. The citation in regard to Doctor Luckiesh is "whose skillful moulding of the candles of science has furnished new light for the darkened places where men live."

Elihu Thomson (A'84, F'13, HM'28, past-president and member for life) consulting engineer, General Electric Company, and director, Thomson Research Laboratory, Lynn, Mass., was elected an honorary president oft he International Electrotechnical Commission at the meeting in Brussels. Recently Doctor Thomson received the award of the V. D. I. medal of honor (Electrical Engineering, May 1935, page 574).

O. E. Allende (A'25, M'31) electrical engineer and assistant to the general manager, Electric Company of Costa Rica, (Delaware) and local manager, Compania Electrica de Turrialba, Cartago, Costa Rica, C. A., has been appointed by the Chilean government civil attaché to the Chilean Legation for all the Central American nations, this appointment being in addition to his regular position.

F. A. Merrick (A'07) president, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been decorated with the Order of the Rising Sun, third class, by Emperor Hirohito of Japan in appreciation of technical assistance rendered to that country's electrical industry and railway lines. The presentation was made by Communications Minister Tokonami.

J. C. Burkholder (M'30) former partner of the firm of Burkholder and Kelley, Toronto, Ont., Can., is now vice president and chief engineer of Burlec Limited, a company newly formed at Scarboro Junction, Ont., for the manufacture of line and special telephone and telegraph apparatus. Mr. Burkholder was at one time engaged with the Canadian National Railways in developing a method of telephoning from a moving train.

Sidney Hosmer (A'97, F'12, and member for life) vice president and general manager, The Edison Electric Illuminating Company of Boston, Mass., has assumed the duties of acting head of the construction bureau, following the retirement of I. E. Moultrop (A'10, F'29, and past vice president). Mr. Hosmer has been a vice president of the company since 1926, and was appointed general manager in 1932.

J. W. Barker (M'26, F'30) dean, school of engineering, Columbia University, New York, N. Y., is serving as New York area chairman in the drive to raise funds for Engineering Index, Inc. Dean Barker has been serving on the Institute's committees on education, technical program, publication, and production and application of light, having been chairman of the latter since 1933.

William Spraragen (A'17, M'26) president, Spraragen Engineering Corporation, New York, N. Y., and former secretary of the National Research Council, has been appointed a member of the welding research committee sponsored by Engineering Foundation. Mr. Spraragen has served on the Institute's committee on electric welding since 1927.

G. M. Armbrust (A'11, F'33) assistant electrical engineer, Commonwealth Edison Company, Chicago, Ill., has been given charge of the new plant engineering division of the company, formed from the combination of the design and field engineering divisions. Mr. Armbrust was recently appointed a member of the Institute's power transmission and distribution committee.

H. C. Wolf (A'16, M'23) formerly vice president of the Consolidated Gas and Electric Company, New York, N. Y., has become president of the Central Indiana Gas Company, Muncie, the operations of which cover gas, electric, and water properties in the central and southern portions of the state. Mr. Wolf is a former director of the Institute's Baltimore Section.

W. E. Wyss (A'35) who has been in the test department of the General Electric Company at Schenectady, N. Y., has been sent to Washington, D. C., as a student patent attorney in the patent department of the company. He is co-author of a paper on induction motor starting which is scheduled for presentation at the coming Great Lakes District meeting of the Institute.

N. M. DuChemin (A'29) formerly general superintendent of the West Lynn, Mass., works of the General Electric Company, has assumed the duties of assistant manager in charge of operations. He was educated at London University, and graduated from the General Electric engineering school in 1917. He was made general superintendent at West Lynn in 1924.

E. E. Turkington (A'08) electrical engineer, Associated Factory Mutual Fire Insurance Companies, Boston, Mass., has been appointed chairman of a newly formed subcommittee of the electrical committee of the National Fire Protection Association, the subcommittee being concerned with the subject of small circuit breakers.

C. H. Champlain (A'28) general works manager, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been forced to retire by illness. He had been with the company for many years, becoming manager of the plant at Sharon, Pa., in 1922 and general works manager at East Pittsburgh more recently.

W. J. Mahan (A'25) electrical inspector in the building department of the city of New Haven, Conn., has been appointed chairman of a newly formed subcommittee of the electrical committee of the National Fire Protection Association, the new subcommittee being concerned with the subject of fuses.

R. H. Combs (A' 13, M'18) president and general manager, Prest-O-Lite Storage Battery Company, Ltd., Toronto, Ont., Can., has been elected a member of the council of the Association of Professional Engineers of Ontario, representing the mechanical branch, and also has been elected a member of the executive council of the association.

H. M. Hobart (A'94, F'12, and member for life) consulting engineer, Schenectady, N. Y., has been appointed a member of the welding research committee sponsored by Engineering Foundation. Mr. Hobart is chairman of the Institute's committee on electric welding, and a member of the technical program committee.

J. P. Barton (A'30) former sales engineer in the electrical sheet division of the Empire Sheet and Tin Plate Company, Mansfield, Ohio, has accepted a similar position with the American Sheet and Tin Plate Company, Pittsburgh, Pa. Mr. Barton, a member of several other organizations, is the author of 2 Institute papers.

J. C. Langdell (A'07) meter engineer, Commonwealth and Southern Corporation, Jackson, Mich., has been appointed a member of the new subcommittee on small circuit breakers formed under the electrical committee of the National Fire Protection Association.

H. N. Pye (A'15, M'27) chief engineer, Southeastern Underwriters Association, Atlanta, Ga., has been appointed a member of the new subcommittee on small circuit breakers formed under the electrical committee of the National Fire Protection Association.

R. B. Shepard (A'25, M'26) electrical engineer, Underwriters' Laboratories, Inc., New York, N. Y., has been appointed a member of the new subcommittee on small circuit breakers formed under the electrical committee of the National Fire Protection Association.

A. D. Stoddard (A'16) chief engineer, Haliburton Oil Well Cementing Company, Duncan, Okla., has been made a vice president of the company. Mr. Stoddard, who has been with the company for several years, will be in charge of manufacturing and engineering.

C. A. Adams (A'94, F'13, past-president and member for life) Lawrence professor of engineering, Harvard University, Cambridge, Mass., has been appointed chairman of Engineering Foundation's welding research committee. He is also a member of the Institute's committee on electric welding.

S. M. Kintner (A'02, M'03) vice president in charge of research, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been appointed chairman of the Pittsburgh area committee in the drive to raise funds for Engineering Index, Inc. Mr. Kintner has been a member of several Institute committees.

C. F. Scott (A'92, F'25, HM'29, past-president and member for life) professor of electrical engineering emeritus, Yale University, New Haven, Conn., has been appointed a member of the board which will supervise registration and examination of all types of engineers in Connecticut.

E. G. Cullwick (A'26, M'33) who for a short period was with the electrical engineering branch of the Military College of Science at London, England, has returned to Vancouver, B. C., Can., as associate professor of electrical engineering at the University of British Columbia.

J. E. Yarmack (A'35) has joined the Diehl Manufacturing Company, the electrical division of the Singer Manufacturing Company, at Elizabethport, N. J., as research and development engineer in charge of the laboratory, development, and experimental shops.

A. F. Darland (A'20, M'29) former superintendent of electrical construction and design in the department of public utilities, Tacoma, Wash., is now field engineer with the Department of Interior reclamation service on the Grand Coulee (Wash.) Columbia River project.

W. J. Lewis (A'33) has resigned as assistant electrical engineer with the Cincinnati (Ohio) Street Railway Company to take a position as engineer with R. Roy Holden, Inc., Chicago, Ill., manufacturers of overhead equipment for trackless trolley lines.

E. A. Moyle (A'26) who has been distribution engineer for the Texas Power and Light Company at Tyler, is now consulting and chief engineer of the S. W. Scales electric Company, distributor at Greenville, Texas, in which Mr. Moyle has a part interest.

C. A. Tudbury (A'35) is now a junior electrical engineer with the New England Power Engineering and Service Corporation, Worcester, Mass. A paper by him recently received a prize in a technical paper contest between the Lynn and Boston Sections.

W. D. Cassin (A'23) Philadelphia, Pa., former sales engineer with the Westinghouse Electric and Manufacuring Company, is now in the engineering department of the Pennsylvania State Public Service Commission, Philadelphia.

D. S. Jacobus (A'03, and member for life) advisory engineer, Babcock and Wilcox Company, New York, N. Y., has been appointed a member of the welding research committee sponsored by Engineering Foundation.

M. M. Brandon (A'34) associate electrical engineer, Underwriters' Laboratories, Inc., New York, N. Y., has been appointed a member of the new subcommittee on fuses formed under the electrical committee of the National Fire Protection Association.

L. W. Going (A'19) chief electrical inspector for the city of Portland, Ore., has been appointed a member of the new subcommittee on fuses formed under the electrical committee of the National Fire Protection Association.

C. F. Himes (A'34) formerly in the Mound Valley School at Hominy, Okla., is now with the Eagle Mills at Edmond, Okla., as engineer. Mr. Himes received the A.I.E.E. South West District prize for Branch paper in 1933.

S. K. Waldorf (A'27) who has been a fellow at The Johns Hopkins University, Baltimore, Md., is now with the Pennsylvania Water and Power Company, Baltimore. Mr. Waldorf has presented several papers to the Institute.

Alex Dow (A'93, F'13, and member for life) president, Detroit Edison Company, Detroit, Mich., has received the honorary doctor of science degree from the University of Detroit. He is the author of a 1934 Institute paper on the schooling of engineers.

L. E. Messinger (A'30) president and managing director, Canadian Line Materials Limited, Scarboro Junction, Ont., Can., is president of the newly formed Burlec Limited, a manufacturing company at Scarboro Junction.

Sidney Simpson (A'12, M'27) formerly deputy electrical locomotive superintendent, Eastern Bengal Railroad, Kanchrapara, Bengal, India, is now chief electrical engineer of the North Western Railway, Lahore, Punjab.

Raymond Rugge (A'30) formerly in the engineering department of the Curtiss Wright Airplane Company, Robertson, Mo., is now municipal engineer and superintendent of the electric light plant at Larned, Kan.

P. M. Ross (A'34) formerly in the commercial engineering department of the

Frigidaire Corporation, Dayton, Ohio, is now laboratory engineer with the insulator division of the Ohio Brass Company at Barberton.

H. B. Dates (A'98, F'32, and member for life) professor of electrical engineering, Case School of Applied Science, Cleveland, Ohio, has been elected vice president of the Illuminating Engineering Society to serve a 2 year term.

S. W. Stoddard (A'28, M'30) who has been superintendent of the northeastern division of the New England Power Association at Lawrence, Mass., is now central division superintendent at Worcester, Mass.

Peter Fries, Jr. (A'34) New York, N. Y., has been appointed associate editor of The Justinian, legal newspaper of Brooklyn Law School of St. Lawrence University, for the year 1935–36.

W. A. F. Zarth (A'23) who was formerly employed by Southern Dairies, Inc., Washington, D. C., has become affiliated with Dictograph Products Company, Inc., Jamaica, N. Y., as production engineer.

Samuel Ferguson (A'02) president and chairman of the board of directors, Hartford Electric Light Company, Hartford, Conn., has been re-elected as a trustee of the Edison Electric Institute.

N. A. Rollins (M'27) station installation engineer, Commonwealth Edison Company, Chicago, Ill., has been given supervision of the line installation and service investigation sections.

J. W. Keeney (A'22) who has been superintendent of the southern division of the New England Power Association at Providence, R. I., is now superintendent of the northeastern division at Lawrence, Mass.

L. H. Hendrixson (A'32) formerly with the Southern California Telephone Company, Los Angeles, is now connected with the bureau of power and light of the City of Los Angeles.

W. L. Abbott (A'01, F'13, and member for life) chief engineer, Commonwealth Edison Company, Chicago, Ill., is serving as area chairman in Chicago in the drive to raise funds for Engineering Index, Inc.

J. H. Herron (M'35) president, James H. Herron Company, Cleveland, Ohio, is sponsoring a committee in Cleveland in the drive to raise funds for Engineering Index, Inc.

Chester Stevens (A'32) former plant superintendent for the Producers Cold Storage Company, Shelbina, Mo., is now plant manager for the Independence Produce Company, Independence, Iowa.

C. G. Grimes (A'33) lieutenant, U.S. Navy, who has been electrical officer of the U. S. S. New Mexico, been has transferred to the bureau of engineering of the Navy Department at Washington, D. C.

R. Y. Miner (A'35) former engineer with Calibron Products, Inc., West Orange, N. J., has accepted a position as design engineer with Arma Engineering Company, Inc., Brooklyn, N. Y.

E. J. Withers (A'34) formerly employed by the Shell Petroleum Company, East Chicago, Ind., has taken a position as switchboard operator with the Inland Steel Company at East Chicago.

William Waterman (A'31) former chief engineer, Lang Radio Corporation, Brooklyn, N. Y., is now a radio engineer with the Victor division of the R.C.A. Manufacturing Company at Camden, N. J.

E. C. Morse (A'07, M'13) former manager, co-operative merchandising department, American Bemberg Corporation, New York, N. Y., is now general director for Associated Wool Industries, N. Y.

R. H. Hughes (A'20, M'30) assistant vice president, New York (N. Y.) Telephone Company, has been elected president of the New York Electrical Society to serve for the year 1935–36.

G. F. Fowler (A'29) member of technical staff, Bell Telephone Laboratories, Inc., New York, N. Y., has been elected treasurer of the New York Electrical Society to serve for the year 1935–36.

W. F. Oliver (A'23) who has been foreign wire relations supervisor with the Southern Bell Telephone and Telegraph Company at Atlanta, Ga., has been transferred to Baton Rouge, La.

W. G. Kelley (A'08, F'26) plant design engineer, Commonwealth Edison Company, Chicago, Ill., has been given supervision of the drafting and equipment sections.

E. A. Loew (A'08, M'13) professor of electrical engineering at the University of Washington, Seattle, was recently appointed acting dean of the college of engineering.

J. H. Hunt (A'07, M'13) patent section, General Motors Corporation, Detroit, Mich., has been elected president of the Detroit Engineering Society.

C. T. Mess (A'27, M'29) former electrical engineer of the California Railroad Commission, San Francisco, has been appointed valuation engineer for the commission.

J. P. E. Arberry (A'30) is now connected with the Pittsburgh Plate Glass Company, Pittsburgh, Pa., as assistant electrical engineer.

A. H. Lane (A'27) who is employed by the American Telephone and Telegraph Company, has been transferred from New Haven, Conn., to New York, N. Y.

J. P. Schroeder (A'31) Oakland, Calif., is now employed in the engineering department of the Yuba Manufacturing Company, Benicia.

Paul Boodberg (A'30) junior engineer, Pennsylvania Power and Light Company, has been transferred from Pottsville, Pa., to Hazleton.

H. M. Duphorne (A'29) toll plant extension engineer, Southwestern Bell Telephone Company, has been transferred from Oklahoma City, Okla., to Little Rock, Ark.

F. C. Moak (A'29) professional engineer of Saugerties, N. Y., is now connected with the Arma Manufacturing Company, Brooklyn, N. Y.

J. R. McCaa (A'34) is now employed in the mechanical engineering department of the York Ice Machinery Corporation, York, Pa.

W. T. White (A'33) assistant, U.S. Coast and Geodetic Survey, who has been at Corpus Christi, Texas, is now at Burlington, N. J.

J. J. Rose (A'33) electrical draftsman, New York and Queens Electric Light and Power Company, Flushing, N. Y., has been appointed chief draftsman.

J. G. Pleasants (A'32) production foreman, Proctor and Gamble Company, who has been at Cincinnati, Ohio, is now at Staten Island, N. Y.

P. J. Boesen (A'23) is now with the Public Service Commission of West Virginia at Charleston.

W. A. Stelzer (A'34) is now employed in the U.S. Engineer Department at Fort Peck, Mont.

L. R. Rockholt (A'33) is now junior electrical engineer with the Bowie Switch Company, San Francisco, Calif.

A. N. Budden (A'26) of Montreal, Que., Can., is now with the Dominion Engineering Company, Limited, Toronto, Ont.

G. H. Ulrich, Jr. (A'34) is now a draftsman in the engineering department of the Link Belt Company, Chicago, Ill.

D. F. Hild (A'33) is now area manager at Edmore for the Central West Public Service Company of North Dakota.

H. R. Anderson (A'27) of Huron, S. D., is now connected with the U.S. Engineers at Fort Peck, Mont.

T. C. Dearlove (A'25) is now employed by the Cemco Electrical Manufacturing Company in Vancouver, B. C., Can.

E. O. Lunn (A'32) is now employed as mechanic and electrician at Bradian Mines Limited, Bralorne, B. C., Can.

T. T. Woodson (A'33) is now in the test department of the General Electric Company at Schenectady, N. Y.

F. L. Ost (A'29) who has been at Vesteras, Sweden, is now employed by the Svenska Elektriska Aktiebolaget at Ludvika.

W. P. Stevens (A'28) has engaged in consulting engineering in Palestine, Texas.

Obituary

William Charles Gotshall (A'01, M'02, and Life Member) consulting and constructing engineer, New York, N. Y., and former president and chief engineer of the New York and Port Chester Railroad, died August 20, 1935. Mr. Gotshall was born at St. Louis, Mo., May 9, 1870. Following studies at Washington University he was employed by the St. Louis and Eastern Railroad Company and the Missouri Power and Light Company, and subsequently rebuilt and operated a number of electric railways. As chief engineer of the Union Railway Company, St. Louis, he undertook the rehabilitation of the system, which involved the first introduction of the 3 wire system on railways. In 1897 he was in charge of the rebuilding of the Second Avenue Railway in New York, which was converted from horsepower to a conduit system. Following this he became president and chief engineer of the New York and Port Chester Railroad, which he designed and constructed. This was the first high speed electric railway in the United States built entirely on its own right of way without grade crossings, which involved the introduction of many improvements in high speed electric traction. This work was completed in 1912, and subsequently Mr. Gotshall was engaged in other railroad work in the United States, Europe, and Africa. He also took part in several archaeological expeditions and was the author of a number of articles on electric railways, as well as a book on their economics. He was a member of the American Society of Civil Engineers, the American Association for the Advancement of Science, and other organizations.

Otto Wallace Walter (A'21, M'29) assistant professor of electrical engineering, College of the City of New York, N. Y., was killed in an automobile accident July 7, 1935. He was born at Beatrice, Neb., December 28, 1892, and received the degrees of bachelor of arts (1920), bachelor of science (1921), and electrical engineer (1926) at the University of Oklahoma, Norman, where he was an instructor and assistant professor from 1919 to 1926. During the year 1926–27 he was an instructor at Massachusetts Institute of Technology, Cambridge, where he received the degree of master of science in electrical engineering. The following year he returned to the University of Oklahoma as associate professor of electrical engineering, and in 1928 accepted the position of assistant chief engineer with the Hall Electric Heating Company, Inc., Philadelphia, Pa. He resigned as research engineer of the company in 1931 to resume teaching as assistant professor at The College of the City of New York.

Jay Houghton Hall (A'05, M'12) assistant chief engineer, Electric Controller and Manufacturing Company, Cleveland, Ohio, died in August 1935 while on a vacation trip. Mr. Hall was born at Momence, Ill., April 9, 1875, and studied electrical engineering at Rose Polytechnic Institute, from which he received the degree of bachelor of science in 1893. Subsequently he received the degrees of master of science in 1906 and electrical engineer in 1908. His first position was in charge of an isolated light plant, following which, in 1899, he became a draftsman in electrical department of the Carnegie Steel Company at Munhall, Pa. For a short time in 1901 he was in charge of the electric signal system of the Chicago and Eastern Illinois Railroad Company, and from 1901 to 1904 was chief draftsman and assistant superintendent for the Youngstown Engineering Company, Youngstown, Ohio. In 1904 he became chief draftsman for the Electric Controller and Manufacturing Company, and since then had held successively the positions of assistant engineer, sales engineer, manager of the New York sales office, assistant to the president, and electrical engineer, with the exception of the period 1915–17, when he was at Morganton, N. C. Mr. Hall received a number of patents on motor controlling apparatus, and was a member of the institute's committee of applications to iron and steel production in 1926–27.

Carl Borgmann (A'24) manual telephone equipment engineer, Bell Telephone Laboratories, Inc., New York, N. Y., died suddenly August 20, 1935. He was born at Christiania, Norway, January 31, 1881, and graduated from the Technical College there in 1900. Until 1902 he was in charge of telephone equipment design with a manufacturing company, then came to the United States and was employed by the Mark Manufacturing Company at Evanston, Ill. In 1903 he became a supervisor in the drafting department of the Western Electric Company, Chicago, Ill., and in 1907 became inspector of installation. From 1909 to 1919 he was equipment engineer and since 1919 had been manuel telephone equipment engineer at New York; in 1925 the laboratories of this company became the Bell Telephone Laborabories, Inc. In 1930 he was a member of the group of engineers sent abroad to study European communications.

Charles Martin Clark (A'96, and member for life) director of many utility companies and former president of The Bradstreet Company, New York, N. Y., died July 24, 1935. Mr. Clark was born at Boston, Mass., November 5, 1873, and received the degree of electrical engineer from the Columbia School of Mines in 1897. From 1904 to 1926 he was treasurer of The Bradstreet Company, becoming president in 1926. Among the many companies of which he was a director were American Power and Light Company, Electric Power and Light Company, United Gas Corporation, The Washington Water Power Company, Florida Power and Light, and Dun and Bradstreet, Inc.

Mortimer Dickinson Gould (M'25) Buffalo, N. Y., died on June 8, 1935. He was born at Buffalo, February 28, 1879, and was graduated from Stevens Institute of Technology in 1905. Until 1907 he was engaged in construction work with the Niagara, Lockport and Ontario Power Company, and then entered the engineering department of the Rochester (N. Y.) Gas and Electric Company. From 1911 to 1917 he was in charge of engineering, construction and operation for the Livingston Niagara Power Company at Avon, N. Y., and in 1917 joined the Westinghouse Electric and Manufacturing Company, becoming manager of the engineering division of the Buffalo office of the company, which position he held until recently.

Edward K. Shelton (A'12) designing engineer, General Electric Company, Pittsfield, Mass., died on August 31, 1935. He was born at Manhattan, Kan., January 7, 1890, and graduated from the electrical engineering course at the University of Washington in the class of 1910 with the degree of bachelor of science in electrical engineering. In that year he entered the employ of the General Electric Company in the testing department at Schenectady, N. Y. In 1913 he was transferred to the lightning arrester department in the Pittsfield works, and since 1920 had been in charge of the design and development of capacitors.

Aldis H. Wurts (A'21) attorney with Cotton, Franklin, Wright, and Gordon, New York, N. Y., died August 2, 1935. He was born at Chatham, Ohio, August 9, 1890, and received the degrees of bachelor of arts at Western Reserve University in 1913, bachelor of science in electrical engineering at University of California in 1914, and bachelor of laws at Harvard University in 1917. Following military service he engaged in the practice of law with M. B. and H. H. Johnson in Cleveland, Ohio, and in 1922 became associated with the firm of Cotton and Franklin in New York.

Joseph Hugh McHugh (A'31) electrical inspector, City of St. Paul, Minn., died in January 1935 according to word recently received at Institute headquarters. He was born at Minneapolis, May 24, 1884, and was engaged in electrical construction work from 1900 to 1908, and as a theatrical electrician from 1908 to 1918. Since that year he had been an electrical inspector.

Harley C. Schulze (A'24) results engineer, The Ohio Power Company, Philo, Ohio, died March 21, 1935, according to word just received at Institute headquaters. Mr. Schulze was born at Hubbard, Ia.,

September 25, 1899, and was a graduate of Iowa State College, from which he received the degree of bachelor of science in electrical engineering. In 1921 he entered the testing department of the General Electric Company at Schenectady, N. Y., where he was employed until he became efficiency engineer at the Philo plant of the Ohio Power Company in 1926.

Membership

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before Oct. 31, 1935, or Nov. 30, 1935, if the applicant resides outside of the United States or Canada.

Angell, C. H., Westinghouse Elec. & Mfg. Co. St. Louis, Mo.
Baker, A. W. (Member), Am. Transit Assoc., New York, N. Y.
Bell, F. B. (Member), T.V.A., Joe Wheeler Dam, Ala.
Bertolet, W. B., Metropolitan Edison Co., Easton, Pa.
Briner, J. F., Jr., Federal Pwr. Comm., Washington, D. C.
Brooking, J. M. (Member), Am. Tel. & Tel. Co., New York, N. Y.
Counts, R. E. L., Federal Pwr. Comm., Washington, D. C.
Cross, G. F., Hudson Bay Mining & Smelting Co., Flin Flon, Manitoba, Can.
Dawson, J. W. (Member), Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Edgar, C. K., Dept. of Water & Pwr., City of Los Angeles, Calif.
Eslick, E. (Member), Federal Pwr. Comm., Washington, D. C.
Gray, L. A., Simplex Wire & Cable Co., Cambridge, Mass.
Hansen, A., Pacific Tel. & Tel. Co., Seattle, Wash.
Harrison, P. W. (Member), Am. Tel. & Tel. Co., New York, N. Y.
Heitman, C. E. Jr. (Member), Edward G. Budd Mfg. Co., Philadelphia, Pa.
Henkel, L. C. (Member), 220 West 7th St., Hanford, Calif.
Hiscox, W. L. (Member), Am. Tel. & Tel. Co., New York, N. Y.
Howe, C. D., Pacific Tel. & Tel. Co., Seattle, Wash.
Jones, G. G. (Member), Am. Tel. & Tel. Co., St. Louis, Mo.
Logan, J. T., Ga. Pwr Co., Atlanta.
Maddock, G. F. (Member), Federal Pwr. Comm., Washington, D. C.
Masters, M. H., Ford Motor Co., Somerville, Mass.
McClure, F. J., 9332 N.E. Skidmore St., Portland, Ore.
Millard, F. P. (Member), Am. Tel. & Tel. Co., New York, N. Y.
Morris, M., N. Y. Edison Co., Inc., New York, N. Y.
Morrow, B. E. (Fellow), Consumers Pwr. Co., Jackson, Mich.
Oklund, A. L., Milwaukee Sch. of Engg., Milwaukee, Wis.
Perkinpine, R. W. (Member), Am. Tel. & Tel. Co., New York, N. Y.
Pollard, E. I., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Richardson, A. F., Jr. (Member), Am. Tel. & Tel. Co., New York, N. Y.
Richardson, G. E., Am. Steel & Wire Co., Worcester, Mass.
Rosene, V. E., Bell Tel. Lab., New York, N. Y.
Smith, G. R. (Member), Am. Tel. & Tel. Co., New York, N. Y.
Smith, L. A. (Member), Western Union Tel. Co., New York, N. Y.
Sprague, C. H., Intl. Corresp. Schools, Scranton, Pa.
Stockhus, C. R., Union Elec. Lt. & Pwr. Co., St. Louis, Mo.
Tenney, G. C., "Electrical West," San Francisco, Calif.
Thompson, S. H., Federal Pwr. Comm., Washington, D. C.
Thomson, J. L., Independent Subway System, New York, N. Y.
Vaile, R. B., Jr., Iowa State College, Ames.
Weston, P. O., St. Louis Rockbestos Products Corp., St. Louis, Mo.

41 Domestic

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as it now appears on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Bock, F. S., 1642 W. Broad St., Richmond, Va.
Bruse, Otto, 214 White St., Waverly, Mass.
Chiofalo, J., 203 Graham Ave., Brooklyn, N. Y.
Cole, Fred H., 1116 Washington Blvd., Oak Park, Ill.
Crite, Mitchel, 32 E. 126th St., New York, N. Y.
Ghosh, K. C., c/o Compagnia Generale Di Elettricita, 34 Via Borgognone, Milan, Italy.
Golikoff, A., Main F. O. Gen. Del., Moscow, U.S.S.R.
Greene, F. M., 656—50th St., Brooklyn, N. Y.
Kimball, Gordon S., 154 Elmer Ave., Schenectady, N. Y.
Nelson, Charles J., 1515 N. Lotus Ave., Chicago, Ill.
Roselle, P. M., 2018 Chestnut St., Harrisburg, Pa.
Schelberg, Kenneth O., 411 5—51st St., S., Seattle, Wash.
Spiegel, William F., 7 Stegman Court, Jersey City, N. J.
Vance, Paul E., c/o Marietta Mfg. Co., Point Pleasant, W. Va.
Walker, Jas. E. L., 773 N. Jefferson St., Milwaukee, Wis.
Whittemore, Geo. W., 151 Ridgewood Ave., Glenwood, N. J.
Williams, Ellis Richard, 97 W. 8th St., Wyoming, Pa.

17 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

COMBUSTION ENGINE FUELS and HEAT, $1.75; STATIONARY DIESEL ENGINES, $1.75; DIESEL ENGINE DETAILS and MANAGEMENT, $2.00. By J. Vanderdoes, L. H. Morrison and C. T. Baker. Scranton, Pa., International Textbook Co., 1935. Illus., diagrs., charts, tables, 8x5 in., lea. The first discusses the nature of heat, its effects, thermodynamics, heat and work, combustion, liquid and gaseous fuels, and the principles of the internal-combustion engine. The second describes the various types and their construction. The third describes the parts of these engines and their auxiliaries, and explains the operation, maintenance, and repair.

FACTORY ORGANIZATION and ADMINISTRATION. By H. Diemer. 5 ed. New York and London, McGraw-Hill Book Co., 1935. 412 p., illus., diagrs., charts, tables, 9x6 in., cloth, $4. A standard text revised to include the advances made during the past decade. Covers everything from factory location and building to department organization.

NATIONAL PHYSICAL LABORATORY, REPORT for the YEAR 1934. London, Dept. of Sci. and Ind. Res. His Majesty's Stationery Office, 1935. 260 p., illus., diagrs., charts, tables, 11x8 in., paper, 13s. A concise report on the work done in the fields of physics, electricity, radio, metrology, engineering, metallurgy, aerodynamics, and hydrodynamics. A list of papers published by the laboratory is included.

RISE of MODERN PHYSICS. By H. Crew. 2 ed. Baltimore, Williams & Wilkins Co., 1935. 434 p., illus., diagrs., tables, 8x5 in., cloth, $4. Makes no requirements of technical knowledge upon the reader. Intended for undergraduates, but will be equally useful to all those interested in the history of science. Three new chapters, dealing with the inertia of electricity, the rise of modern spectroscopy, and restricted relativity have been added.

SMITH'S COLLEGE CHEMISTRY. By J. Kendall. 3rd rev. ed. New York and London, D. Appleton-Century Co., 1935. 753 p., illus., diagrs., charts, tables, 9x6 in., cloth, $3.75. The new edition of this textbook of general chemistry exhibits few important changes from the preceding one, the chief being in the treatment of ionization and the discussion of recent advances in our knowledge of the atom.

STEAM TURBINES. By. E. F. Church. 2 ed. New York and London, McGraw-Hill Book Co., 1935. 327 p., illus., diagrs., charts, tables, 9x6 in., cloth, $3. For students in engineering colleges. The form and characteristics of turbines are presented, and thermodynamic principles are applied to the calculation of the flow of steam, and to the various factors that effect efficiency.

STRUCTURE of CRYSTALS, Supplement for 1930–34 to 2nd Ed. By R. W. G. Wyckoff. (Amer. Chem. Soc. Monograph Series No. 19-A). New York, Reinhold Publ. Corp., 1935. 240 p., diagrs., charts, tables, 9x6 in., cloth, $6. Brings up to date the second edition by reviewing the X ray determinations of structure which have been published during the last 4 years. The bibliography contains over 2,000 references.

IMPREGNATED PAPER INSULATION, the Inherent Electrical Properties. By J. B. Whitehead. N. Y., John Wiley & Sons, 1935. 221 p., illus., 9x6 in., cloth, $4.00. A comprehensive survey of researches at the Johns Hopkins University, the fourth of the series of monographs issued by the committee on electrical insulation of the National Research Council. While much of the content has appeared previously in periodicals, it is here united into a connected account.

INTRODUCTION to PHYSICAL SCIENCE. By C. W. Miller, 2 ed. N. Y., John Wiley & Sons, 1935. 409 p., illus., 9x6 in., cloth, $3.00. An introductory text using only common mathematics, and including late discoveries in nuclear physics.

PRINCIPLES of ELECTRIC POWER TRANSMISSION by Alternating Currents. By H. Waddicor. 3 ed. N. Y., John Wiley & Sons, 1935. 449 p., illus., 9x6 in., lea., $6.00. A text for students and also a handbook for designers and operators, supplying a systematic exposition of the principles that underlie the electrical design of transmission lines.

SIX-PLACE TABLES, with Explanatory Notes. By E. S. Allen. 5 ed. N. Y. and Lond., McGraw-Hill Book Co., 1935. 175 p. 7x4 in., lea., $1.50. A collection of tables, cubes, square and cube roots, circumferences and areas of circles, fifth roots and powers, common logarithms of numbers and trigonometric functions, natural trigonometric functions and logarithms, radians and degrees, and exponential, hyperbolic and gamma functions.

SPEKTROSKOPIE (Sammlung Göschen 1051). By K. W. Meissner. Berlin and Leipzig, Walter de Gruyter & Co., 1935. 180 p., illus., 6x4 in., cloth, 1.62 rm. A concise yet comprehensive introduction to spectroscopy.

THIS MODERN WORLD and the ENGINEER. Edinburgh, Royal Scottish Society of Arts, 1934. 140 p., illus., 9x6 in., cloth, 5s. Lectures discussing the achievements and problems of modern engineering in the fields of physics, civil, mechanical, electrical, and chemical engineering, and in mining.

Engineering Societies Library

29 West 39th Street, New York, N. Y.

MAINTAINED as a public reference library of engineering and the allied sciences, this library is a cooperative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

Industrial Notes

New Name for Fansteel.—The Fansteel Products Co., North Chicago, Ill., has changed its name to the Fansteel Metallurgical Corporation. The new corporate name more clearly defines the nature of the business, that of refining rare metals such as tantalum, tungsten, molybdenum, electrical contacts, etc., and fabricating them to a wide variety of industrial uses.

Westinghouse Promotes T. I. Phillips.—Appointment of T. I. Phillips, as general works manager of the Westinghouse Electric & Mfg. Co., has been announced. In his new position Mr. Phillips will serve as central authority for all manufacturing operations of the company. He succeeds C. H. Champlain, who has been forced by prolonged illness to relinquish his activities with the company. Mr. Phillips has been with Westinghouse since 1915.

Steel and Tubes Transfers Personnel.—Due to increased business activity in the territory served from Philadelphia, Steel and Tubes, Inc., Cleveland, has recently created a new sales district, headed by C. J. Boyd, formerly of the Brooklyn, N. Y., sales organization. J. F. Keeler, formerly of the sales promotion department in Cleveland, has been transferred to the Brooklyn office, and J. S. Anderson, formerly of Detroit, has been transferred to the new Philadelphia office. J. D. Benfield and Robert Turrell, formerly with the electrical division of Steel and Tubes, have formed their own organization, with headquarters at Detroit, and are representing Electrunite Steeltubes and Fretz-Moon conduit products in the Michigan territory.

New Heating Element.—A new electrical resistance alloy, "Kanthal," with operating temperature of better than 2460° is being produced by the C. O. Jelliff Mfg. Corp., Southport, Conn. According to the manufacturer it not only operates at higher temperatures than other base metal or alloy without protective gases but also possesses remarkable oxidation resisting qualities. Three grades are available: maximum 2462° for electric furnaces; 2372° for domestic appliances; 1150° for most purposes where nickel chrome is now used. It also has the advantage of lower cost and longer life.

New Angle Clamp.—The Ohio Brass Co., Mansfield, O., has developed a new angle clamp designed to simplify angle construction in farm line design. According to the manufacturer, any angle from 30 to 120° can be turned with this clamp without the necessity of dead-ending the conductors and using jumpers. The new clamp, No. 80431, is $4^{3}/_{16}$ inches long and the radius of its seat curvature is 3 inches, enough to take conductors up to 2/0 A.C.S.R. The special "U"-bolt practise as incorporated in the design, permits the clamp to be attached directly to a 6-inch suspension unit, without the use of intermediate fittings, and it will fit 41 different sizes and types of conductors.

Underground Cable Mole.—The Burndy Mole or insulated multiple connector has been designed to provide a simple method of making joints in underground secondary distribution systems. The manufacturer, Burndy Engineering Co., Inc., 305 E. 45th St., New York, claims that it is especially advantageous for connections between rubber-leaded and rubber-covered cables to paper-insulated, oil-impregnated cables; also, with the Mole, an effective stop joint on oil-impregnated cables can readily be made, eliminating entirely the need for a stub joint. Cables are clamped by simple solderless devices which in turn are attached to a copper, rubber-insulated body. Each connector can accommodate a range of cable sizes, and combinations for various arrangements of mains and feeders can be easily made.

Trade Literature

Voltage Regulator.—Bulletin 2204, 8 pp. Describes new type BFR, low cost, automatic branch feeder voltage regulator, available in all standard commercial voltages from 2400 to 13,200, single and three phase. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Pole Anchoring.—Bulletin, 24 pp., "Correct Anchoring." A comprehensive, illustrated study of pole anchoring and guying by means of various types of patented anchors. Tables on anchor holding powers in different soils are included, as well as a chapter on figuring strains on guys. Chance Company, Centralia, Mo.

Synthetic Rubber.—Bulletin, 12 pp., "Koroseal." Describes a new synthetic rubber-like material, known as Koroseal. The properties of the product, the forms in which it is available and the uses to which it has been successfully adapted, are listed. B. F. Goodrich Co., Mechanical Rubber Goods Div., Akron, O.

Output Switching Panel.—Bulletin, 8 pp. Describes a new output switching panel, 271A, for speech input equipment. It provides facilities for dispatching programs from as many as 6 amplifier channels over 4 output circuits to line amplifiers. Western Electric Co., 195 Broadway, New York.

Fire Extinguishing System.—Bulletin, 12 pp., "Smothering Fire in Power Plants." Describes the Lux carbon dioxide system of protecting electrical equipment from fires. The gas is stored in cylinders and in case of fire is released, either by manual or automatic control. The principal advantage in the use of this system is its freedom from damaging after-effects. Walter Kidde & Co., Inc., 140 Cedar St., New York.

Thermostatic Metals.—Bulletin, 32 pp. A comprehensive review of specifications, properties and methods of application of modern thermostatic bi-metals. Ten full-page charts show deflection and force characteristics, along with design formulae, providing up-to-date engineering data for bi-metal applications in the field of temperature indication and thermal control. H. A. Wilson Co., 105 Chestnut St., Newark, N. J.

Phenolic Insulation.—Catalog, 48 pp. Describes "Dilecto," a laminated plastic, developed to meet the demands for a waterproof insulating material with great mechanical strength and adaptability to all machining operations. The material is supplied in sheet, tube and rod form, or is fabricated to specifications. Process of manufacture is outlined and illustrated, applications set forth and a table compares the properties of hard rubber, vulcanized fibre, etc. and Dilecto. Continental-Diamond Fibre Co., Newark, Del.

Transformer Protector.—Bulletin, 8 pp., "How Do You Forestall Faults?" Describes the Kidde transformer protector, a mechanical device for the protection of conservator type transformers. It warns of the occurrence of minor faults and in the case of major faults it disconnects the transformer from the line. The principle upon which the protector operates is based upon the fact that gases are given off when any fault occurs in a transformer. These gases actuate the protector. Walter Kidde & Co., Inc., 140 Cedar St., New York.

Time Switches.—Bulletin GEA-1427D, 8 pp. Describes general-purpose automatic time switches. Type T-17 will control almost any electric circuit on a schedule related to the time of day. It will perform any practical number of operations per day and skip a day or more if desired. Standard switches are designed for a-c circuits, 115 and 230 volts, 40 amperes per contact. This switch can be furnished with either a plain dial (for fixed-time settings) or astronomic dial (for sun schedules) and certain combinations of both. Type T-27 switch is similar to the T-17 except that it is only for indoor service and is not equipped with an omitting device for day cutouts. In both types, drive is direct from Telechron motor, through a compact spur-gear train. General Electric Co., Schenectady, N. Y.

Motor Maintenance Equipment.—Catalog, 64 pp. Lists a wide variety of motor maintenance devices, including commutator and slip-ring resurfacers, grinders, truing tools, undercutters, slotters, blowers, sprayers, etc. Detailed information on care and servicing of commutators and slip-rings is presented; chapters cover definitions of electrical terms; tables on current carrying capacities of wires; fusing, wiring and full load current data for all types of motors; formula for determining amperes, horsepower, kilowatts and kva; for calculating electric current, etc. Among new products listed are improved precision grinders, a complete line of electric cleaners, a new industrial thermometer, an improved coil winding head and new sizes of thread-on, solderless wire connectors and lugs. Ideal Commutator Dresser Co., Sycamore, Ill.

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Fortification Hill as seen from the Nevada shore of Black Canyon reservoir above Boulder Dam. Photo courtesy U.S. Bureau of Reclamation

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In This Issue—

HEATING by electricity is a subject of ever-increasing interest. Two types of electric heating are described in this issue. One involves induction heating of iron parts at low temperature. It is useful in such operations as baking paint or rapidly drying wet metal parts (*pages 1210–2*). The other is an electric furnace in which a carbon electrode raised to a very high temperature is used in metallurgical operations (*pages 1195–9*).

MATHEMATICAL ANALYSIS of electric circuits and machinery is featured in 3 papers in this issue: One embraces certain extensions to Heaviside's operational methods (*pages 1222–7*); one presents an analysis of an inverter circuit (*pages 1227–35*); one gives a method for analyzing the performance of capacitor motors (*pages 1235–9*).

THE electrical control scheme adopted for a Diesel electric train of the light weight streamlined type which was placed in operation a few months ago, enables the greatest possible use to be made of the available engine power (*pages 1240–5*).

KNOWLEDGE of the resistivity of the earth's crust and the relation it bears to geological structure is useful in several types of electrical calculations. Data on this subject obtained through numerous experiments are available. (*pages 1153–61*).

COMMUTATION by means of harmonically vibrating contacts actuated by a "rotating" electromagnetic field is the principal novel feature of a method of converting alternating to direct current described in this issue (*pages 1213–21*).

ARC FURNACES are highly desirable loads for electric power companies, but may disturb other customers unless certain precautions are observed in connecting such loads to power systems (*pages 1173–8*).

PILOT wire schemes for relay protection of transmission lines have recently undergone changes which enhance the advantages of this type of protection considerably (*pages 1262–9*).

TWO immense projects on the Columbia River, Bonneville, and Grand Coulee, have been made the subject of an interesting group of photographs taken early in September (*pages 1272–3*).

DISCUSSIONS have been omitted from this issue to provide additional space for papers to be presented at the forthcoming 1936 A.I.E.E. winter convention.

FERROMAGNETISM has resisted the attack of theorists for many years. Recent advances in this field are summarized in this issue (*pages 1251–61*).

LOAD RATINGS for underground electric power cables may be computed by applying the method of harmonic analysis of load cycles (*pages 1166–72*).

WELDING research shows that a stable arc cannot be maintained in highly purified argon gas under ordinary welding conditions (*page 1144–9*).

PHOTOELECTRIC cells of the dry disk type have characteristics which make them desirable for use in many applications (*pages 1186–90*).

1936 TRANSACTIONS

The A.I.E.E. TRANSACTIONS for 1936 will be produced only for those having subscription cards on file at A.I.E.E. headquarters not later than Friday, December 20, 1935. Present production methods require determination, in advance of the printing of the January 1936 issue of ELECTRICAL ENGINEERING of the exact number of TRANSACTIONS volumes to be provided for. For the convenience of members desiring to maintain in this permanent form a file of A.I.E.E. papers and discussions, important additional information and a convenient order blank are provided on page 10 of the advertising section of this issue.

Opportunity and the Young Engineer

—*A Message From the President*

COLLEGE STUDENTS and young engineers have been confronted during the past few years with the perplexing problem "What opportunities are there in the engineering profession?"

In my opinion, there are greater opportunities in the engineering field today than have ever existed before. Perhaps more than at any previous time in the last few decades industry has been marking time while scientific development has advanced at an ever-increasing rate, leaving a vast field open to the application of science's discoveries and to modernization. Furthermore, I also believe that no matter what specific line of activity offers itself or may be decided upon for a life work, the young engineer will find that his engineering training has furnished the best possible foundation, whether he becomes a scientist, professional engineer, educator, businessman, lawyer, or banker.

It is true that the present economic disorder has afforded limited opportunity for useful employment, but this is only a temporary condition, and the young engineer has had extra time in which to strengthen his life equipment.

A man's education is not completed when he receives his degree at graduation. Many men in the business world consider that it only begins at that time. Graduation is just the beginning of an engineering career, the college course being the foundation for the superstructure which is to follow.

The most that can be expected of any engineering course is that it teaches the student to think. Training for the practice of engineering is similar to the training of a law student. The law student does not have to know all of the law, but he does learn where he can find the principles, and must be able to reason from these principles to particular cases.

After graduation, the engineer does not have to remember all of his analytical geometry, or his thermodynamics, or his calculus, but he will be expected to know what principles to apply and how to apply them in attempting the solution of a particular problem. If he knows these 2 things he need never hesitate to tackle any engineering problem presented to him.

The words "successful career" have been variously defined. Some measure success by the ratio of money received to the time and effort spent; others think that success is measured by the kind of service rendered and the degree of its benefit to mankind. The young engineer has a choice. It has been said that to achieve what the world calls success a man must attend strictly to business and keep a little in advance of the times. In any event, success has never been handed out to man, but has had to be earned by perseverance, hard work, energy, patience, and singleness of purpose.

The pages of history are filled with the names of persons who have attained renown through some distinguished service contributing to the welfare of mankind. These are the Isaac Newtons, Robert Fultons, James Watts, and many others. Throughout the whole of history we read also of those who have used their talents to break down and destroy civilization—the Caesars and Napoleons who disrupted the natural progress of the world to satisfy their personal ambitions and selfish desires. Both groups have received the plaudits of the multitude. They worked for a cause—creation, preservation, or destruction.

Another group includes the Benjamin Franklins and Thomas A. Edisons who rose to fame through the fields of invention. They were purely individualists who assumed their tasks, not in response to popular demand, but inspired only by their own visions. They had the conviction that there was some specific object which they could accomplish, and they carried their work to a successful conclusion without outside advice or assistance.

In general, engineering education and training have effectively developed a man's power of observation, his analytical ability, and his desire and capacity to learn, but all too frequently have failed to develop in the engineer an ability to express himself effectively. The highest measure of engineering success often is won by the man who possesses, in addition to his technical knowledge, the ability to deal with people and to "sell" himself and his ideas. Leadership must first express itself in speech. One must know how to ask for things, how to explain things, and how to speak persuasively enough to win the active support of others. Doing business is chiefly talking business. Engineering is a business and one of the most remarkable things about it is that there is scarcely a region of the world's activity into which the engineer's direct interest does not extend.

The American Institute of Electrical Engineers through its many Sections and Student Branches presents an excellent means to all young electrical engineers to take an active part in the discussions of current engineering problems. This feature aids the engineer materially in developing the essential qualities of clear thought and effective speech. This is but one of the many benefits derived from membership in the Institute.

The question of opportunity for the young engineer is simply the question of his scientific training, plus initiative, aggressiveness, character, and personality. Good men are needed now as they always will be.

Arc Welding in Argon Gas

During the course of the extensive research in arc welding being conducted at Lehigh University under joint sponsorship of the A.I.E.E. and several other organizations, apparatus for experimental welding at atmospheric pressure in controlled pure gas atmospheres has been designed and constructed. Tests in argon gas reveal 3 phenomena not previously associated with the welding arc: (1) the impossibility of maintaining a stable arc in highly purified argon under ordinary conditions; (2) the absence of all crater formation under pure iron in pure argon; and (3) the absence of all observable "pinch effect" accompanying the detachment of the globules from the electrode wire.

By
GILBERT E. DOAN

WILLIAM C. SCHULTE*

Both of
Lehigh University,
Bethlehem, Pa

AN EXTENSIVE PROGRAM of investigation is being carried out at Lehigh University in the study of arcs and arc welds of pure iron. These studies have been sponsored by A.I.E.E. and aided by The Engineering Foundation. Several reports on the progress of these studies have been issued previously.[1–4] The present report discloses the design and construction of an apparatus for experimental welding at atmospheric pressure in controlled pure gas atmospheres, using automatic feeds for both electrode and work piece. Auxiliary apparatus is provided for purifying the gases and for analyzing them, both before welding begins and after it is completed. This apparatus design may be useful to other investigators in the study of welding atmospheres.

Briefly summarized, the more important results obtained so far are as follows:

1. Stable welding arcs cannot be maintained in argon of 99.5 per cent purity, when the electrode is clean, unless the open-circuit voltage is greater than 62 volts and the short-circuit current greater than 110 amperes. In air or in impurer argon stable arcs form readily at currents and voltages far less than these minima.

2. No crater is formed under the iron arc in argon. This condition results in complete lack of penetration into the base metal, and thus renders welding impossible.

3. The globules at the end of the electrode grow gradually to about $^1/_4$ inch in diameter and detach under no apparent force except that of gravitation.

4. The melting rates per kilowatt-hour in argon and in air are approximately equal.

Among the most important metallurgical aspects of the investigation are the high ductility of the pure iron welds made in argon: 90 per cent reduction of area and 30 per cent elongation. For pure iron welds made in air the reduction of area was only 3.5 per cent instead of 90, and the elongation only 4 per cent instead of 30. These results indicate the great effect of air in lowering the ductility of the metal obtained in the arc welding operation. The strength of the pure iron welds on the contrary was 40,000 pounds per square inch for those made in argon and rose to 65,000 for those made in air. The effect of the air thus is to raise the strength of the weld greatly. Some experiments made with cellulose coating on the electrode gave results intermediate with respect to those in argon and those in air. Other purely metallurgical aspects of the investigation are to be reported elsewhere.

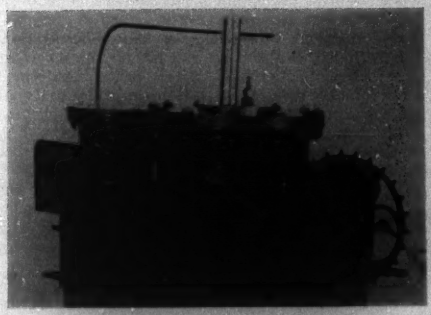


Fig. 1. Exterior view of chamber for experimental welding in pure gases

Material Used

The rods and plates used in this program were of carbonyl iron which had been treated in a stream of undried hydrogen for 72 hours at 1,375 to 1,420 degrees centigrade, by a co-operating laboratory, that of the General Electric Company at Schenectady, N. Y. The wire was 4 millimeters ($^5/_{32}$ inch) in diameter and the base metal plates were 6 and 2 millimeters thick. These plates were used to line a 45 degree V groove between 2 $^1/_2$ inch steel plates, the plates serving as backing to prevent the

A research progress report written especially for Electrical Engineering. Manuscript submitted March 22, 1935; released for publication July 25, 1935.

* Formerly Engineering Foundation Fellow at Lehigh University, Bethlehem, Pa.; now with Lukens Steel Company, Coatesville, Pa.

1. For all numbered references see list at end of article.

arc from melting through the pure iron "liners" and from "blowing" magnetically. This arrangement is shown at V in figure 3. The chemical analysis of the carbonyl iron after hydrogen treatment was as follows:

Carbon	0.009	Sulphur	0.005
Manganese	0.046	Nitrogen	0.002
Silicon	0.002	Oxygen	0.002
Phosphorus	0.01	Hydrogen	0.0002

The analyses were supplied by another co-operating laboratory, that of the American Rolling Mill Company; all values given are percentages.

Most of the tests were made using bare wire. In a few instances, the wire was coated to produce a "shielded arc" such as has recently yielded commercially a weld metal of markedly improved properties. The coating contained cellulose with sodium silicate as a binder and some titanium oxide to reduce porosity and act as an arc stabilizer. These rods were coated by courtesy of the welding research laboratory of the A. O. Smith Corporation.

The argon used was supplied by the incandescent lamp department of the General Electric Company. As received, the gas contained approximately 1 per cent nitrogen. All carbonaceous gas impurities were less than 30 parts per million. The argon was given final purification after being admitted to the welding chamber and when analyzed just before using, it showed a purity of 99.3 to 99.6 per cent argon.

Description of Apparatus

Figure 1 shows the chamber in which the tests in pure argon were made. Figures 2 and 3 show the main details of construction. The welding chamber is built of copper tubing $7^1/_2$ inches in diameter and $^3/_{32}$ inch thick to provide good heat conduction. It consists of a vertical tube A 6 inches high cut to fit into a horizontal half cylinder B 15 inches long. The bottom and ends of the horizontal part are made from copper plates. The top of the vertical tube is fitted with a flat cover plate C $^1/_2$ inch thick. The cover plate can be bolted securely to the top of the vertical tube with a rubber gasket between to prevent leakage. A suitable window is provided for viewing the welding operation.

Specimens to be welded are placed on a movable table D on the bottom of the chamber. The table is moved by a lead-screw E which is driven through a stuffing box F by a $^1/_4$-horsepower variable-speed motor.

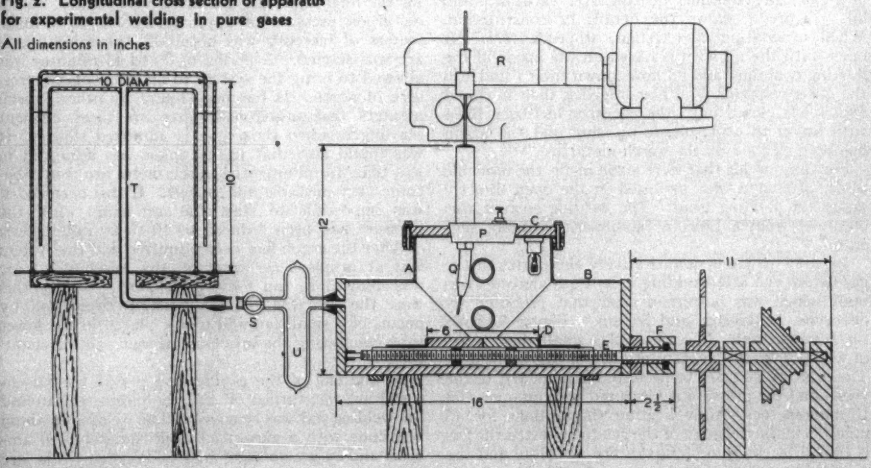
An auxiliary chamber 4 inches in diameter and 6 inches high is connected to the rear of the welding chamber with 2 horizontal tubes G each 1 inch in diameter. This auxiliary chamber contains a "misch-metal arc" (H–I), a glow discharge between an iron anode (I) and a "misch-metal" cathode (H). ("Misch metal" is a pyrophoric alloy containing about 65 per cent of rare earth metals, such as cerium and lanthanum, the balance being iron.) Such a discharge activates the cathode so that it combines with any chemically active gas surrounding it, thus purifying the inert atmosphere used in these experiments. The connection to the argon tank and the vacuum pump is made to the top of this auxiliary chamber so that all the argon admitted is made to pass the misch-metal arc before passing into the welding chamber.

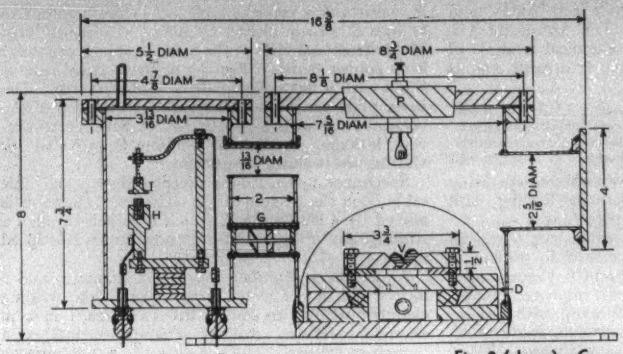
Figure 4 shows the seal that allows the welding rod to pass into the chamber and yet not allow air to leak in or argon to leak out. Two soft rubber washers J are compressed between parts K and L by turning K. The soft rubber fits tightly around the rod and against the walls of the tube M.

To evacuate the system tube N is sealed to the

Fig. 2. Longitudinal cross section of apparatus for experimental welding in pure gases

All dimensions in inches





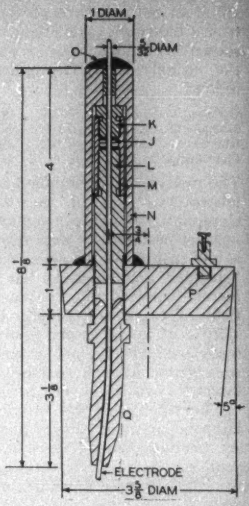


Fig. 3 (above). Cross-sectional view of welding chamber

Fig. 4 (right). Cross-sectional view of welding electrode seal

All dimensions in inches

copper plug P. A split collar O fits tightly around the rod and into the small hole on the top of the tube N. This joint is entirely sealed with "picein," a black wax commonly used in high vacuum work for sealing joints in the apparatus. After argon has been admitted and is up to atmospheric pressure, the picein and split collar are removed and the rod thoroughly cleaned of picein with ether.

The copper plug P fits into a tapered hole in the cover plate of the main arc chamber, and the tapered joint is sealed with stopcock grease. The rod passes through this copper plug $^3/_4$ inch off center, thus providing a means for shifting the electrode from one side to another.

The current pick-up nozzle Q is fitted to the bottom of the tapered copper plug. The rod is fed into the chamber with an automatic welding head R.

During welding, the argon expands considerably because of the heat of the arc. To accommodate this expansion, a gas reservoir was built which consists of a gas tight container floating over vacuum pump oil. Figure 2 shows the details of construction. When evacuating the system, stopcock S is left open until the oil level is raised on the inside of the floating container and oil flows down tube T and into the glass reservoir U. The stopcock then is closed and is left closed until the chamber has been filled with argon to atmospheric pressure and the argon has been cleaned by the misch-metal arc.

For those welds that were made in air, the movable table, of course, was mounted in the open directly under the welding head. The welding current was obtained from a Lincoln "stable-arc" welding generator.

In order to know quantitatively the purity of the gas before and after welding in it, a gas analyzer was built which was patterned after that proposed by Severyns, Wilkinson, and Schum.[5] Figure 5 shows the construction. It consists of a small glass vessel in which a small quantity of lithium can be heated. The mixture of gases to be tested is admitted to the vessel and the pressure is measured with an open-end U manometer. After heating the lithium for 45 minutes in the presence of the gas to be tested the gas is cooled to the same temperature as before and the pressure measured again. The percentage of impurity is expressed as:

$$\frac{P_1 - P_2}{P_1} \times 100 = \text{per cent impurity}$$

where P_1 is the pressure before heating and P_2 is the pressure after heating.

Method of Welding

After the system has been evacuated, it was flushed once with argon and again evacuated. The argon for the final filling was admitted very slowly. After an argon pressure of approximately 2 to 4 millimeters of mercury was obtained, the misch-metal arc was started. A period of 30 to 45 minutes was allowed to bring the system to an atmospheric pressure of argon. It has been found by other experimenters that misch-metal arcs are more efficient scavangers when the argon is admitted slowly. It was found also that if the argon was admitted in less than 15 minutes the misch-metal arc would become very unstable and go out. If this occurred it was impossible to start the arc again until the pressure had been reduced to 10 to 20 millimeters.

After the argon had been admitted and the system was at atmospheric pressure, the misch-metal arc was allowed to run for 6 to 8 hours. During this time the gas was given a positive circulation by means of a small fan and motor placed in the lower tube connecting the misch-metal and welding chambers.

At the end of the purification period the misch-metal arc was turned off and the picein seal around the welding rod was removed. The welding in argon was done with a current of approximately 180 amperes and an arc voltage of 10 to 12 volts. The arc

length could be controlled very closely and was kept at approximately $^1/_8$ to $^3/_{16}$ inch at all times by means of the automatic feed of the welding head. For the welds made in air with the bare pure iron electrodes a current of 150 amperes was used with an arc of 15 to 17 volts. When welding with the heavily coated pure iron electrode 130 to 140 amperes was used with 25 to 28 volts. These conditions were the necessary ones for each type of weld in order to obtain sound nonporous welds.

Welding Characteristics Observed in Argon

Deposition of metal in an atmosphere of argon is strikingly different in appearance, for both pure iron and steel, from what it is in air. While the melting rates in argon and in air are similar (argon 0.922 pound per kilowatt-hour, air 0.895 pound), yet the transfer of metal in argon takes the form of very large globules approximately $^7/_{32}$ inch in diameter at the rate of about 1 every 3 seconds, whereas in air the globules are quite small and fall at the rate of about 10 to 15 per second. The globules in argon cross the arc calmly and under no apparent force except that of gravitation. Quite frequently they grow so large as to bridge the arc and then they free themselves from the electrode quite rapidly. The so-called "pinch effect," proposed by Carl Hering and studied by E. F. Northrup, is not manifest in promoting globule detachment in the iron arc in argon, even when the drops grow to a very large size before detaching. The arc is quiet, with a complete absence of the steady sharp crackling sound that is characteristic of a good welding arc in air. When viewed through the dark yellowish-green welding glass, the arc core appears bright yellow with successive sheaths of greenish-blue, black, and orange.

Another striking and significant difference when welding in argon is the complete absence of the crater in the liquefied base metal or previous weld bead that is so important for welding in air. This results, of course, in a complete lack of penetration into the parts. Figure 6 shows the appearance of the welding arc in argon and the lack of crater formation. Figure 7 is a macrograph of a section of a multipass weld of ordinary steel made in pure argon. The lack of penetration is clearly evident since the contour of each individual layer easily can be traced.

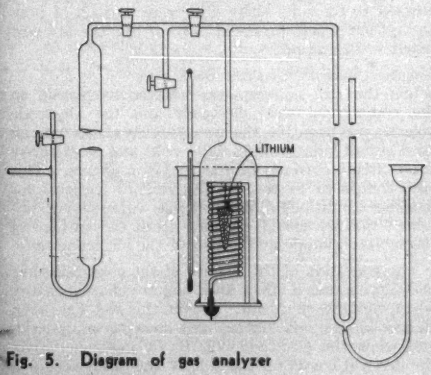


Fig. 5. Diagram of gas analyzer

Thus one of the most basic and essential features of the commercial arc welding process, namely, penetration and crater formation, is not an inherent characteristic of the iron arc, but, fortunately for the engineer, it is one that appears when arc welds are made in air. This absence of crater formation is of peculiar interest since numerous theories have been advanced to explain the nature of the force in the arc that creates this crater, and yet none of these theories considered the atmosphere as an important factor. One theory, proposed by P. P. Alexander and G. Donath, is that a pressure within the arc is created by a gas or electron steam and that this pressure blows the liquid metal outward from the center of the molten puddle toward its edges. One of the authors in an earlier study[6] has attributed the forces of crater formation partially to the differences of surface tension of the molten metal at the center of the puddle from that at the edges. Neither of these theories would account for the lack of crater formation found for iron arcs in argon.

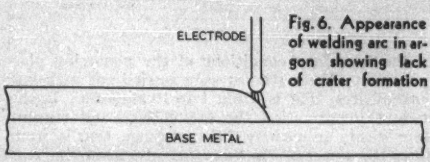


Fig. 6. Appearance of welding arc in argon showing lack of crater formation

An attempt was made to find out what percentage admixture of air was necessary in the argon in order to obtain penetration and fusion. When welding in 50 per cent air and 50 per cent argon, the penetration was about equal to that obtained in air. Welds then were made in 90 per cent argon and 10 per cent air. Figure 8 is a macrograph of a section of such a weld. A slight amount of penetration can be noted, and there was a very shallow crater at the end of the weld bead. Hence it can be seen that crater formation is dependent on the presence of air and that very little air is required to produce penetration and crater formation. The experiments in penetration were carried out by an expert in experimental arc welding, and every possible combination of current, voltage, arc length, and rate of travel was tried until the best result achievable was obtained in each gas mixture. Figures 7 and 8 show a single cross section of the results. They are, however, entirely representative of the welds as a whole.

Unstable Arcs in Argon

One of the authors and J. Leland Myer have reported[2] that an arc discharge could not be obtained under ordinary conditions in pure argon gas. Further studies with Albert M. Thorne[5] have confirmed this fact for other inert gases and have yielded knowledge

Table I—Results of Welding Tests in 99.3 to 99.5 Per Cent Pure Argon Gas

Rod material: commercial steel wire *E*-No. 1-*A* $^1/_8$ inch in diameter

Weld No. and Pass	Welding Current Amperes	Welding Volts	Open-Circuit Volts	Short-Circuit Amperes	Rod Polarity	Rod Surface	Stability of Arc
14–1	40–60	26	58–60	110–120	−	Clean	Fairly stable
14–2	40–60	26	58–60	110–120	−	Clean	Unstable
14–3	40–60	26	58–60	110–120	−	Clean	Unstable
14–4	40–60	26	58–60	110–120	−	Clean	Unstable
14–5	40–60	26	62–64	110–120	−	Clean	2 to 10 seconds
14–6	40–60	26	62–64	110–120	−	Clean	2 to 10 seconds
15–1	70	14	60	110–120	+	Clean	Unstable
15–2	70	14	60	110–120	+	Clean	Unstable
15–3	70	14	65	110–120	+	Clean	5 to 10 seconds
15–4	70	20	80	110–120	+	Clean	Stable
15–5	50–70	14–17	58–60	110–120	−	Clean	Unstable
15–6	120–160	24–30	63	200	−	Clean	Stable
15–7	70	14	60	110–120	−	Sull	Stable
15–8	70	14	60	110–120	−	Sull	Stable
15–9	120	18	63	200	−	Sull	Stable

of the boundary conditions of the nonarcing phenomenon. These studies were carried out with low current arcs, that is, from 1 to 10 amperes. In the present investigation the arc voltage and current were within an entirely different range, that is, from 40 to 180 amperes. In this range also nonarcing was observed under certain conditions both with commercial steel wire and with pure iron wire.

Negative Electrode Coating Removed

When welding with commercial steel wire of $^1/_8$ inch diameter with the "sull" coating (the light sulphate coating left on the wire after pickling in sulphuric acid) removed, and with a welding current of 40 to 60 amperes and an arc voltage of 26 volts, after the arc had been maintained for a short time (30 to 50 seconds) it became very unstable. The electrode would be fed down by the automatic device, make contact with the plate, and then be drawn away. When the contact with the plate was broken a flash of an arc would occur lasting for only a fraction of a second and then would go out. The welding head automatically would move the electrode down again and the same process would be repeated. This would occur 8 or 10 times until finally an arc could be struck that would last for a few seconds, and when it went out the same cycle would be repeated. This took place when the open circuit voltage of the welding generator was 58 to 60 volts with momentary short-circuit currents of 110 to 120 amperes and the polarity of the electrode negative. The instability was not attributable to the commonly observed magnetic effect encountered at the ends of the plate, for it would take place in the center portion of the weld as well as toward the ends. When the open circuit voltage was increased slightly above 60 volts (62 to 64) the arc would last for several seconds before going out. When making the test welds in argon this unstable range was avoided by increasing the open circuit voltage of the generator to 65 volts or more and by increasing the welding current.

Fig. 7. Cross section of multipass weld of ordinary steel in pure argon gas. Note lack of penetration into plate and into early deposits

Fig. 8. Same welding conditions as figure 7, but in a mixture of 90 per cent argon and 10 per cent air. Note slight but definite penetration into plate

Positive Electrode Coating Removed

When the polarity was reversed, that is, with the electrode positive (and cleaned of all drawing compound as before), the arc was again slightly unstable with open circuit voltages of 58 to 60 volts and momentary short-circuit currents of 110 to 120 amperes. During the short welding periods the arc voltage was 17 volts with a welding current of 50 to 70 amperes. When the open circuit voltage was increased to 65 volts there still were periods of nonarcing, but when increased beyond this the arc persisted until stopped.

Negative Electrode Coating Remaining

When the sull coating was allowed to remain on the commercial steel electrode and the electrode polarity was negative, the arc was fairly stable with an open circuit voltage of 58 to 60 volts and momentary short-circuit currents of 110 to 120 amperes. This gave values of 14 to 17 volts and 70 amperes for welding conditions. When these values were obtained the arc would emanate from the surface of the molten globule at the end of the electrode only.

The condition of the surface of the electrode thus had a pronounced effect upon the arc characteristics when welding in argon. When the rod has been cleaned of its sull coating and drawing compound, and when the electrode polarity is made negative, the arc will travel up the side of the electrode for a

distance of $^1/_2$ to $^3/_4$ of an inch. This behavior made welding very difficult, for while the arc would be emanating from the side of the electrode, the arc voltage would be high and the welding head automatically would feed the rod down to lower the voltage, until finally the end of the rod would ram into the base metal and cause a complete short circuit. However, this same phenomenon did not take place when the electrode polarity was positive, but the arc then would jump around on the plate in a very erratic manner. When the electrode was negative and the sull coating remained on the rod, the arc emanated steadily from the end of the electrode only. Evidently the cathode is unstable, whether it be formed of the wire or the plate, unless the wire is coated. In this event the cathode is stable. Results of these tests are summarized in table I.

These observations on lack of penetration and crater formation and lack of arc stability indicate that intrinsically the high current arc is something quite different from that with which we have become acquainted by observing only the arc between steel electrodes in air. Other purely metallurgical aspects of the investigation are to be reported elsewhere.

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Bridge Measurement of Electromagnetic Forces

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A simple impedance bridge may be used to measure the variation of inductance of a disconnecting switch of practical dimensions as the switch blade is displaced by slight amounts from the closed position. The electromagnetic force tending to open the switch blade, calculated from the observed variation of inductance, checks the theoretical value obtained from Dwight's formula. The bridge may be used to determine the electromagnetic forces acting on current carrying members the configuration of which is such as to make accurate theoretical calculation impossible.

CONSIDERABLE work has been done in the mathematical treatment of electromagnetic forces between members of an electric circuit. The actual measurement of these forces has received comparatively little attention; and as far as the authors could ascertain, with the exception of torque measurements in electrical instruments,[1] all such measurements have been direct physical measurements of the forces involved.

It is well known from fundamental electromagnetic theory that the electromagnetic force in any given direction on a member of an electric circuit is proportional to the square of the current flowing through that member and the rate of change of self-inductance with respect to the deformation of the circuit in that direction. This can be expressed as

$$F = \frac{1}{2} I^2 \frac{dL}{dS} \tag{1}$$

The form of this equation immediately suggests a very obvious method of measurement of electromagnetic force, namely, the determination of the self-inductance as a function of the desired deformation. Indeed, several writers, Dwight,[2] Hague,[3] Karapetoff,[4] and others, have suggested this measurement of inductance as a function of deformation as being the most convenient means of determining electromagnetic forces.

The forces under consideration here are those existing in simple types of circuits, such as bus bars, switches, and circuit breakers. To make direct measurements of these forces involves heavy currents and means of measuring the actual resulting forces. A method of measuring such forces in this manner is described in a paper by J. Walter Roper[5] in which he has investigated forces in a circular and

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1. For all numbered references see list at end of paper.

a rectangular circuit. If the values of self-inductance be plotted versus the deformation in the direction of the force to be measured, the slope of the resulting curve at the point of zero deformation gives the quantity $\Delta L/\Delta S$, from which the force in that direction can be calculated.

Since the force on a member is proportional to the derivative of self-inductance with respect to deformation, it is not necessary to determine the absolute value of the self-inductance of that member, but only small increments of inductance of the system including the member. This peculiar advantage enables one to use a bridge with "impure" arms so long as the portions of the arms that must be changed, to balance the bridge as the circuit is deformed, are sufficiently "pure." In view of the fact that the changes of inductance in circuit members of practical interest are extremely minute, this is a very important consideration.

Strangely enough the authors have not been able to find in technical literature any report of the measurement of the variation of self-inductance for the purpose of determining electromagnetic forces on circuit members of the types mentioned in the beginning of this paper. The purpose of this paper is to show that it is entirely feasible to measure such electromagnetic forces by means of an impedance bridge. Briefly:

1. An impedance bridge is described that measures the change of inductance in a disconnecting switch of practical dimensions; measurements made with this bridge check the theoretical value computed from Dwight's formula.

2. The bridge method actually measures the $\Delta L/\Delta S$ of the structure being studied and thereby makes possible the calculation of electromagnetic forces prevailing under actual operating conditions with ample accuracy for design purposes.

3. The bridge method does not measure physical forces and therefore requires only that the structure being studied carry currents of magnitude sufficient to obtain adequate bridge sensitivity.

Disconnecting Switch

A circuit was chosen of simple configuration so as to be readily amenable to mathematical analysis in order to have a check between theoretical and measured values. For this purpose a disconnecting switch was constructed similar to the one described by Dwight, for which he calculated the force at the break jaw tending to open the blade.[2] A diagram of the switch is shown in figure 1. To complete the circuit, a parallel return conductor was added and placed adjacent to the connecting leads of the switch, as shown. The return conductor circuit was opened at one point and connected to the bridge with a pair of twisted leads.

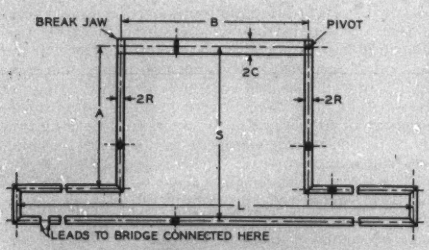


Fig. 1. Diagram of disconnecting switch

A = 30.48 cm (12.00 in.) R = 0.794 cm (0.3125 in.)
B = 40.64 cm (16.00 in.) S = 35.56 cm (14.00 in.)
C = 1.587 cm (0.625 in.) L = 208.3 cm (82.0 in.)

Dwight's formula assumes connecting leads and a return conductor of infinite length. By placing the return conductor comparatively close to the connecting leads of the switch (see figure 1), the value of $\Delta L/\Delta S$ can be made to approach the ideal value to a fair degree of approximation without involving excessively large circuit dimensions. The actual values of the dimensions indicated in figure 1 are given in the caption, the symbols corresponding to those used in Dwight's formula.

The force at the break jaw tending to open this switch as developed by Dwight is as follows:

$$F = \frac{I^2}{4.45 \times 10^7}\left[2.3026 \log_{10}\left(\frac{2A}{R}\right) - \frac{2}{3} - \frac{1}{2}\frac{A}{B} - \frac{1}{6}\frac{C^2}{A^2} + \frac{3}{20}\frac{R^2}{A^2} + \frac{1}{24}\frac{A^2}{B^2} + \frac{1}{24}\frac{AC^2}{B^3} + \frac{B}{S}\right] \text{ pounds} \qquad (2)$$

The current is expressed in amperes. Substituting the dimensions of the switch in figure 1 in equation 2,

$$F = \frac{I^2}{4.45 \times 10^7}\left[2.3026 \log_{10}\left(\frac{2 \times 12.00}{0.3125}\right) - \frac{2}{3} - \frac{12.00}{2 \times 16.00} - \frac{1}{6}\left(\frac{0.625}{12.00}\right)^2 + \frac{3}{20}\left(\frac{0.3125}{12.00}\right)^2 + \frac{1}{24}\left(\frac{12.00}{16.00}\right)^2 + \frac{12.00 \times (0.625)^2}{24 \times (16.00)^2} + \frac{16.00}{14.00}\right] \text{ pounds}$$

giving

$$F = 1.002 \times 10^{-7} I^2 \text{ pounds} = 4.54 \times 10^{-6} I^2 \text{ kilograms}$$

Substituting this value of force into equation 1, the change of inductance with distance should be

$$\frac{\Delta L}{\Delta S} = \frac{2F}{I^2} = 8.92 \text{ abhenries per centimeter} \qquad (3)$$

The Impedance Bridge

The bridge method of measuring these forces presents several advantages. It is necessary to pass only a small current through the switch circuit, sufficient to give adequate bridge sensitivity. No special connecting devices are needed inasmuch as it is not necessary to open the switch blade beyond a point at which a satisfactory friction contact can be maintained at the break jaw. The configuration of the circuit, whether or not it is susceptible to mathematical analysis, is immaterial to the operation of the bridge.

It was necessary to develop a bridge that could detect a change in inductance of 1×10^{-9} henry. A Maxwell bridge was chosen to measure this change in inductance. As explained before, the problem does not involve the measurement of the absolute values of the impedances in any of the bridge arms; this simplifies matters considerably. The complete bridge circuit is shown in figure 2.

The resistances in the various arms were equal (15 ohms), with the exception of a small increment of resistance added to R_2 to balance the resistance of the switch circuit. To secure a final resistance balance a 0.1-ohm constant-inductance slide-wire was employed in series with R_3. Blocks of high grade mica capacitors were connected in parallel with a variable air capacitor to balance out the residuals of the bridge and of the switch circuit. A precision type of variable air capacitor of 1,500 micromicrofarads maximum capacitance was used for the final reactance balance. The change of resistance occasioned by the maximum opening of the switch blade necessitated only a very small change in the slide-wire setting (less than 0.002 ohm). Because of this small change in resistance and also because the resistances in the remaining arms were not disturbed and were small in value, it was not necessary to shield the members of the bridge electrostatically from each other. The switch was removed from the immediate vicinity of the bridge to minimize any mutual effects. The entire bridge was enclosed in a metallic screen, and a frequency of 56 cycles was used to eliminate disturbing effects of 60 cycle circuits in the laboratory. All bridge connections were made with heavy bus bar, with the exception of the twisted leads connecting the switch to the bridge; these were enclosed in a small pipe for purposes of rigidity.

To secure phase selectivity of balance a moving-coil a-c galvanometer was used as a null detector. This instrument had a sensitivity of 1.3×10^{-9} ampere per millimeter. The resistance of the moving coil was 20 ohms, thus affording a good impedance match with the impedance of the bridge circuit at the galvanometer terminals.

To prevent a negligibly small resistance unbalance from affecting the reactive balance, it was necessary to keep the phase of the galvanometer field very closely along the quadrature component. Instead of carefully shifting the phase of the galvanometer field from one component to another with a single phase-shifting transformer, it was found to be more convenient to use 2 phase-shifting transformers; one was set permanently for the reactive balance, and the other for the resistance balance. These were connected alternately to the galvanometer field by means of a double-pole double-throw switch as indicated in figure 2.

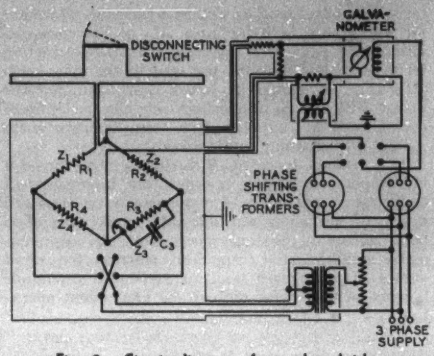


Fig. 2. Circuit diagram of complete bridge

Analysis of Bridge Circuit

In developing the expression for the increase of inductance of the switch circuit, it is necessary to consider the effect of residual inductance in each resistance element. The impedances of the several arms are then as follows:

$$Z_1 = R_1 + j\omega L_1$$
$$Z_2 = R_2 + j\omega L_2 \qquad Z_3 = \frac{R_3 + j\omega L_3}{1 - \omega^2 C_3 L_3 + j\omega R_3 C_3}$$
$$Z_4 = R_4 + j\omega L_4$$

Here the R's are the resistances of the various arms, C_3 is the shunt capacitance, L_2, L_3, and L_4 are the residual inductances of the corresponding resistances, and L_1 is the residual inductance of R_1 plus the inductance of the switch circuit in the closed position. At balance,

$$\frac{(R_1 + j\omega L_1)(R_3 + j\omega L_3)}{1 - \omega^2 C_3 L_3 + j\omega R_3 C_3} = (R_2 + j\omega L_2)(R_4 + j\omega L_4) \tag{4}$$

Equating quadrature components and solving for L_1,

$$L_1 = C_3 R_3 R_4 - C_3\omega^2 L_2 L_4 + \frac{R_3(L_2 R_4 + L_4 R_2) - L_3(R_2 R_4 - \omega^2 L_2 L_4)}{R_3^2 + \omega^2 L_3^2} \tag{5}$$

Here the first term is the normal balance condition for inductance in a "pure" Maxwell bridge, and the remaining terms are corrections engendered by the residual inductances of the resistances.

When the blade of the switch is opened by a slight amount, the impedance in the Z_1 arm changes from $R_1 + j\omega L_1$ to $(R_1 + \Delta R_1) + j\omega(L_1 + \Delta L_1)$. This small change in impedance is balanced by changing C_3 to $(C_3 + \Delta C_3)$ and the constant-inductance slide-wire from $R_3 + j\omega L_3$ to $(R_3 + \Delta R_3) + j\omega(L_3 + \Delta L_3)$. Since the slide-wire undergoes only a minute change, the denominator of 2 of the correction terms may be written

$$(R_3 + \Delta R_3)^2 + \omega^2(L_3 + \Delta L_3)^2 \cong R_3^2$$

The expression for inductance change of the switch circuit then becomes

$$\Delta L_1 \cong \Delta C_3 R_3 R_4 - \Delta C_3\omega^2 L_2 L_4 + \frac{\Delta R_3(L_2 R_4 + L_4 R_2) - \Delta L_3(R_2 R_4 - \omega^2 L_2 L_4)}{R_3^2} \tag{6}$$

The resistances of all arms being maintained substantially equal, the following substitution may be made in the correction terms:

$$R = R_2 = R_3 = R_4$$

and then obtain, upon neglecting $(\omega^2 L_2 L_4)/R_3^2$ in comparison with unity,

$$\Delta L_1 \cong \Delta C_3(R_3 R_4 - \omega^2 L_2 L_4) + \frac{\Delta R_3}{R}(L_2 + L_4) - \Delta L_3 \tag{7}$$

Consideration of the residual inductances of the

resistance boxes used as well as a generous allowance for the change in inductance ΔL_3 of the constant-inductance slide-wire revealed that the correction terms were less than 0.1 per cent of the main term $\Delta C_3 R_3 R_4$. It should be noted that balancing the bridge with the Z_3 arm brings only the variation of capacitance ΔC_3 into the main term, the resistances R_3 and R_4 remaining undisturbed.

The product term $\Delta C_3 R_3 R_4$ dictates the use of a low impedance bridge in order that increments of capacitance may be read conveniently on standard types of precision variable air capacitors. Too large values of resistances necessitate an inconveniently small variable capacitor, whereas too small values of resistances tend to make the resistance balance of the bridge difficult for convenient operation.

Results

A typical set of measurements on the disconnecting switch shown in figure 1 is given in table I. The increments of inductance ΔL are plotted against increments of displacement ΔS in figure 3. The points approximate a straight line of slope 9.10 abhenries per centimeter. An idea of the consistency of performance of the bridge may be obtained from a series of such measurements. The resultant slopes obtained are:

Test number	1	2	3	4	Mean
Slope of line (abhenries per centimeter)	9.28	9.19	9.10	9.31	9.22

The spread between maximum and minimum values expressed as a percentage of the mean is 2.3 per cent. The chief factor contributing to this spread is believed to be the difficulty of obtaining a resistance balance because of variation of contact resistance in the constant-inductance slide-wire.

Although the increment of resistance ΔR_3 appears only in a correction term in the expression for ΔL_1 the variation of contact resistance prevented as accurate a resistance balance as was maintained for the inductance component. However, considering the magnitude of the inductance measured, the accuracy of the bridge is ample for the determination of forces in current carrying members found in practice.

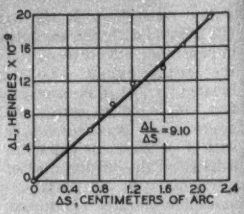
Table I—Typical Measurements on Switch Shown in Figure 1

Bridge input current = 0.50 ampere
Frequency = 56 cycles per second
$C_2 = 11.965 \times 10^{-9}$ farad (switch closed)
$R_1 = R_4 = 15.0$ ohms
$R_2 = 15.2$ ohms
$R_3 = 15.018$ ohms*

ΔS** Centimeters	ΔC_3 Micromicrofarads	ΔL Abhenries
0.00	0.0	0.0
0.96	40.8	9.3
1.58	59.4	13.5
2.17	85.8	19.6
0.69	27.6	6.3
1.83	71.4	16.3
1.20	51.6	11.8

* For balance the resistance change throughout a run was too small to be read on the scale of the 0.1-ohm slide-wire.
** ΔS was measured with a cathetometer along the arc passing through the center of the break jaw.

Fig. 3. Variation of inductance with displacement, plotted from data of table I



In every measurement listed in this paper, the value of $\Delta L/\Delta S$ exceeded the theoretical value computed from Dwight's formula by about 3 per cent. The mean of the observed values, 9.22, exceeds the theoretical value, 8.92, by 3.25 per cent. There are several differences between conditions as measured and those assumed by the formula. The switch, as measured, was connected to leads and return conductor of finite length with end connections as shown in figure 1, whereas the formula is developed on the basis of infinite leads and return conductor. There is also a possibility of discrepancy caused by the assumptions in the contribution to inductance of the switch blade within the jaws and, to some extent, in the limit of integration for current flow when calculating the effect of the jaw member. On page 1343 in Dwight's paper[2] it is stated that: "Now the flux in the jaw does not produce the full amount of mechanical force on the blade, because the current in the blade tapers off gradually from the full value to zero in the distance $2R$ in the jaw." Further, on pages 1339 and 1340: "The current in the arm, which tapers off gradually for the distance $2C$ at the jaw, may be assumed to be full strength as far as the middle of the blade."

It is difficult to see how any other assumptions could be made, while keeping the analysis within reasonable limits of practical calculation. However, it is obvious that as the switch blade is withdrawn from the closed position, these assumptions are modified continuously. Dwight states also that in the usual case, the contribution of the switch blade within the jaw constitutes about 8 per cent of the total mechanical force. Thus whatever be the nature of current flow at the jaw, the attempt to reconcile theoretical with observed values would concern only a small fraction of the total force.

The authors hope that engineers will find the method presented in this paper useful for determining forces on current carrying members of various kinds, the configuration of which is such as to preclude mathematical analysis.

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Earth Resistivity and Geological Structure

The relation which the resistivity of the earth's crust bears to the geological structure has been studied with the aid of many experimentally obtained data. Although the resistivity is found to vary between wide limits, and not always to be the same even for the same types of rock formation in different locations, it has been found that the variation for any particular material is within more narrow limits, and that the older materials generally have the higher resistivities. The results of the studies are of value in several types of electrical calculations.

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In connection with inductive coordination problems it is frequently necessary to estimate low-frequency ground-return mutual impedances between power and communication lines. Where both lines are in place the mutual impedance can usually be measured; however, even in such cases preliminary estimates are often wanted. If one of the lines has not been constructed estimates alone must be relied upon.

The distribution of currents in the earth—the extent and character of the spreading of the current filaments downward and outward—is a major factor in the determination of these impedances. This distribution is controlled by the resistivities of the component parts of the earth's crust and the arrangement of these parts. In impedance formulas that are customarily used the effect of the earth is taken care of by the inclusion of a single parameter; the earth resistivity. For a homogeneous earth this would be the actual resistivity of the material composing it. But the crust is nowhere homogeneous; hence, the resistivity used in such formulas is always of the nature of an average of the resistivities of the several parts of the crust—it is termed the effective earth resistivity.

The effective earth resistivities for fundamental power-system frequencies derived from mutual impedance measurements made in many parts of the world, as given in published papers,[1-9] range from 2 to 10,000 meter-ohms. (The unit of resistivity used herein is the meter-ohm. The resistivity of a particular material, expressed in terms of this unit, is equal to the resistance in ohms between opposite faces of a one meter cube of that material. Earth resistivity in meter-ohms may be converted to earth conductivity in abmhos per centimeter by multiplying its reciprocal by 10^{-11}.) Recent information indicates that values considerably above 10,000 meter-ohms may be encountered in exceptional cases. With such a range to contend with, it is to be expected that estimates of ground-return mutual impedances for situations in areas where no earth resistivity data are available may be in error by large factors.

Previous Studies

In an effort to improve upon the accuracy of such estimates a study was begun several years ago of the relation between effective earth resistivity and geology. Consideration was at that time given only to areal geology, the geology of the strata of the crust lying immediately below the soil and other loose surface materials. Earth resistivity data from 25 or 30 tests at different points in the United States were then available.

From this preliminary work, it appeared that the resistivities in areas of very old rocks were high and that, in a general way, decreasing resistivity corresponded to decreasing age of the rocks. There were, however, a number of outstanding discrepancies that could not be satisfactorily explained. Further studies of this character made as additional test data became available provided information of value but the discrepancies were still unexplained.

It then became apparent that consideration of the areal geology alone was not sufficient; instead, that the earth's structure to considerable depths must be taken into account. Data on this stucture and the effective resistivities indicated by mutual impedance measurements at a large number of test sites have now been assembled. Analysis of these data shows a more or less consistent relation between the resistivity at any given point and the age and physical characteristics of the geological formations involved. This relation is such that, in general, decreasing effective resistivity corresponds roughly to decreasing age of the formations, as the earlier study seemed to indicate. However, there are certain exceptions to this rule.

The literature on this subject includes papers giving the results of effective resistivity determinations at various points in Japan[3,4] and Europe.[5-9] These papers include data on the geology of the test sites but these data are in most instances confined to the principal materials composing the uppermost strata or to the geological periods of these strata. None of the published papers giving the results of effective

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1. For all numbered references, see list at end of paper.

resistivity determinations within the United States has included geological information.

Usefulness of the Data

The principal field of usefulness of the data to be presented is in the preliminary estimating of mutual impedances between ground return circuits and in the calculation of the self-impedances of such circuits, where only the order of magnitude of the earth resistivity is required. Where more accurate values of mutual impedance are necessary the type of data presented is useful in planning the character, extent, and arrangements of the needed field tests.

Certain of the data may be also found useful for other purposes, such as the calculation of impedances of lines at higher frequencies, estimating the character and difficulty of obtaining artificial grounds, and in connection with studies of natural earth currents, attenuation of radio signals, the behavior of traveling waves on lines, and potential gradients in the earth resulting from lightning discharges.

It must be recognized, however, that except where the earth's structure is known to be essentially uniform, estimated resistivities based upon these data must be used with especial caution in problems involving the higher frequencies or those concerned with mutual impedances of lines whose end ground connections are so situated that "ground potentials" are of importance.

The prediction of effective resistivities with a high degree of accuracy, even for low frequencies, is not possible. However, with the aid of correlation data such as those to be presented, the accuracy of these predictions can be increased materially. Giving no consideration to such data, estimates of effective resistivity varying over a range of 5,000 or more to 1 might be made for any particular area, whereas, with the information now available, it seems possible to narrow this range to 500 or 1,000 to 1 in areas of highly complicated structure and to much lower ratios under more favorable conditions. In fact there are many areas in which estimates can be made with a fair degree of assurance within a range of 10 or 20 to 1.

Summary of Principal Results

The effective resistivities indicated by the tests included in the study range from 2 to 10,000 meter-ohms, about 10 per cent of the values lying between 2 and 10 meter-ohms, 70 per cent between 11 and 1,000 meter-ohms, and the remaining 20 per cent above 1,000 meter-ohms.

The principal correlation data are summarized in the following tabulation. This is the result of grouping the tests in accordance with the geological periods to which the principal strata comprising the structure in each case belong and noting the ranges within which the resistivities determined by the greater part of the tests of each group lie.

Pre-Cambrian and combinations of pre-Cambrian and Cambrian	1,000–10,000 meter-ohms
Cambrian and Ordovician combinations	100–1,000 meter-ohms
Ordovician to Devonian, inclusive, and combinations of these periods	50–600 meter-ohms
Carboniferous, Triassic, and combinations of Carboniferous and earlier periods	10–300 meter-ohms
Cretaceous, Tertiary, Quaternary and combinations of these periods	2–30 meter-ohms

It would be well to examine briefly the meaning of this summary and to consider its limitations. The geologists tell us that underlying the entire continent of North America are extremely old rocks, extending downward to great depths. Little is known of the relative ages of different parts of this underlying structure. They are here grouped under the general term pre-Cambrian. In some areas pre-Cambrian rocks appear at or near the surface, the only covering being clays, soils, and other loose materials. In other areas they are overlain by rocks and sediments formed during later periods, the total thickness of which ranges up to many thousands of feet. The ages, arrangement, and characteristics of these upper strata are much better known. They are assigned by geologists to various periods in accordance with the ages during which they were formed. These periods appear in the tabulation in order from the oldest to the youngest.

In the case of tests made in areas where the pre-Cambrian rocks are overlain by younger strata it becomes necessary to consider just what portion of the structure probably influenced the test results. For instance, at the test sites included in the second group of the summary the upper part of the structure consists of Ordovician rocks. These are underlain by Cambrian strata which, in turn, lie on the pre-Cambrian base. The question arises whether the results were influenced by the Ordovician strata alone, by both the Ordovician and Cambrian, or by the Ordovician, Cambrian, and pre-Cambrian. The method of approach to this problem is discussed in the appendix. Application of this method discloses that probably only the Ordovician and Cambrian strata were involved to any important extent. The tests in the other groups have been treated in a similar manner.

In the cases considered above, the measurements were apparently influenced largely by strata of a single period or of 2 or more periods of about the same age. The problem is not always as simple as this. For instance, in some areas combinations of very old and very young strata occur. Areas in which the oldest rocks, the pre-Cambrian, lie directly under comparatively thin sediments of the latest periods—the Quaternary, Tertiary, and Cretaceous— are not uncommon. The effective resistivities shown by the tests in such areas range between very wide limits and the tabulation should not be taken as indicative of the values which may prevail under such conditions.

The effects of soils, glacial drift, alluvial deposits along the courses of streams, and other surface materials may also in some instances be such as to result in effective resistivities differing widely from those that would be indicated by the tabulation. However, in the cases included in the study, except in a few instances where alluvial deposits are present, these effects have not been such as to throw the resistivities

outside the ranges given. The effect of local alluvial deposits, where they overlie the older rock strata, is to lower very materially the effective resistivity that would be expected were the deposits not present.

Another limitation which must be considered is concerned with the presence of rocks formed by volcanic action. Apparently such rocks usually have a high resistivity and where they occur in a comparatively young structure, the effective resistivity may be much higher than the tabulation would indicate.

Principles of Correlation

It seems logical that there should be some correlation between earth resistivity and geological structure when the natural processes of formation of the earth's crust and the nature of its materials are considered.

The strata of the earth's crust that are of principal concern in this work are those formed by the deposition in lowlands, seas, and inland lakes of material eroded from strata at higher elevations, and by the accumulation of shells and organic materials on the bottoms of the deeper bodies of water. These materials when first deposited are loosely consolidated; the deposits may later undergo chemical changes or be subjected to great pressure; by these and other means the loose materials may be consolidated to form rocks and the metamorphosis may continue until these rocks become dense crystalline structures. The crust is, however, constantly in a state of flux, and the simple structure formed by sedimentation may, as time goes on, be folded and faulted or the strata tilted. Also, this structure may be elevated by crustal movements and in turn undergo erosion, later to again be lowered relative to the surrounding land and to receive additional sediments.

During the process of formation of sedimentary strata, or after formation, molten rock may be forced up through the structure by volcanic action, thence to spread out over the surface or to be forced between the strata in the form of great sheets. The "igneous" rock thus formed may, when first cooled, be more or less crystalline, the extent of crystallization depending, among other factors, upon the rate of cooling. As with the sedimentary rocks, those formed by volcanic action may later be extensively metamorphosed.

The dry minerals composing rocks and sediments, with the exception of certain ores, are of such high resistivity that they may be considered as complete nonconductors. According to Sundberg,[10] the resistivities of these materials as they occur in nature are determined by the waters contained in them; the waters within the particles of the material and, to a much greater extent, in the pores between particles. For materials below the water table, where the pores are completely filled, the resistivity depends upon the pore volume, the shape and arrangement of the particles, and the composition of the impregnating waters. For soils and other materials above the water table, the pores may be only partly filled with water, thus introducing another variable.

When sediments are first deposited the pore volume is great. As time goes on and they are consolidated and metamorphosed, the pore volume gradually decreases to very low values. Representative values of pore volumes, as given by Meinzer,[11] are 35 to 53 per cent of the total volume for clays and unconsolidated sands, 4 to 16 per cent for sandstones, shales, slates, and limestones, and 0.02 to 1.85 per cent for very old crystalline rocks.

Since the younger rocks and sediments are of comparatively large pore volume, they might be of either low or high resistivity so far as this factor alone is concerned. However, these materials are usually comparatively soluble and the salts dissolved from them form good electrolytes; hence they are usually of low resistivity. Exceptions to this are sands and gravels. They are relatively insoluble and where they are so situated that they do not receive conducting waters from other strata, as where they form the upper portions of structures, they may be of very high resistivity. Old crystalline rocks are not only of low pore volume but they are relatively insoluble and impervious. Consequently, they neither provide salts to form electrolytes nor receive conducting waters from other strata. Hence they are necessarily of high resistivity.

Individual strata of the crust at any point cannot be considered independently. In the case of the more pervious materials an intermingling of the impregnating waters of adjacent strata may take place; also these waters may flow along the strata. Hence the resistivity of a particular stratum may be dependent not only upon its own characteristics but also upon the surrounding conditions, and strata of the same age and of apparently similar materials in different localities may have different resistivities.

Young formations are usually simple in physical structure, and, since they are relatively pervious, the flow of waters between strata should tend to make the structure appear even simpler from a resistivity standpoint. Hence, where such formations prevail it is to be expected that effective resistivities determined from mutual impedances measured between wires at different separations or at different points within the same locality will be comparatively uniform. Very old structures are likely to be complicated by much faulting, crumpling, and folding of the strata, and inclusions of igneous rocks. Very little flow of waters between the parts of such structures is to be expected; hence the resistivities of the several parts may be quite different. Also, where effective resistivities are high the structure to depths of several thousand feet will be involved if the frequency is low; thus the chances for structural irregularities to affect the resistivities are great. Because of these factors wide and erratic variations in effective resistivities are likely to be encountered in regions where high resistivity rocks prevail.

Methods of Determining Earth Resistivities

The greater part of the resistivity data used in the study was derived from measurements of the mutual impedances of existing lines, usually a power transmission line and a telephone line. In certain cases

the measurements were confined to a single section, in others they were made both in the over-all section and in a number of subsections. In some instances either an existing line or a long wire supported in a temporary manner was energized as a ground return circuit and several comparatively short wires, gener-

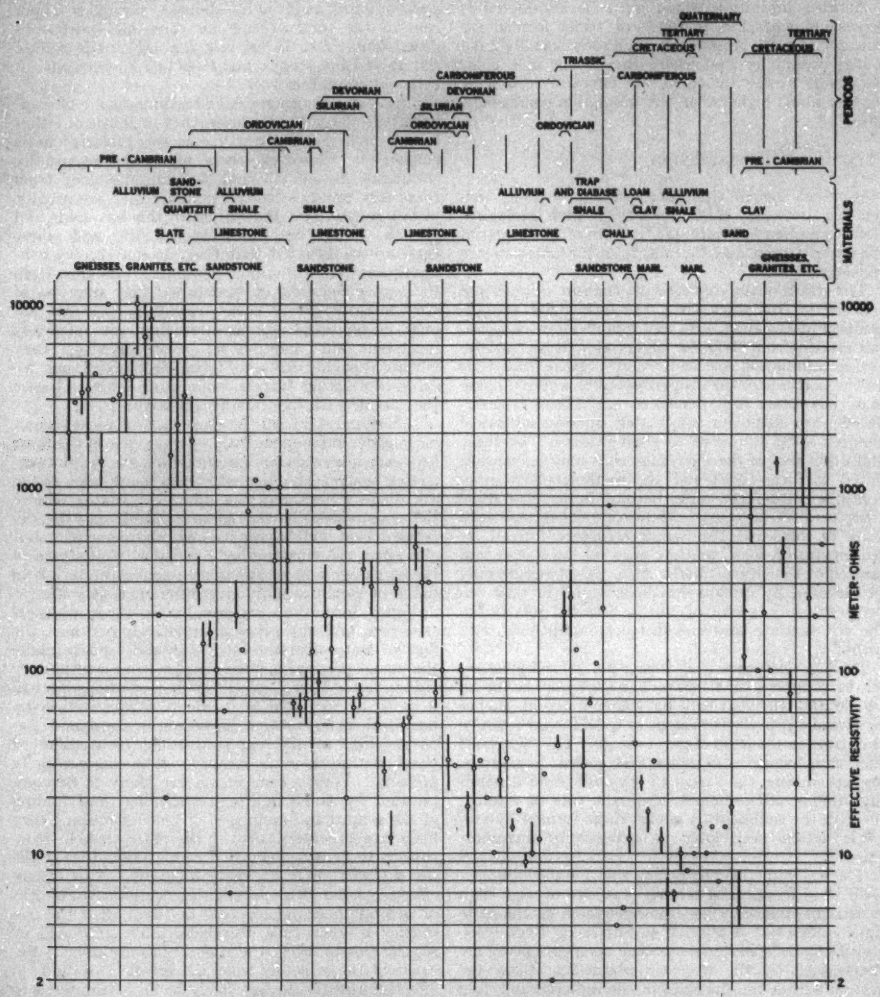


Fig. 1. Correlation of effective resistivities with geological periods and materials

The heavy lines indicate the range of effective resistivities for tests in which measurements were made in several subsections or exploring wires; the mean effective resistivities are indicated by circles. Isolated circles indicate effective resistivities where only one measurement was made

The sequence in which the various types of materials are listed is not necessarily the time sequence in which these materials occur in the geological structures, although the oldest materials are, in general, on the left

The overburden is not indicated except in a few cases where material thicknesses of alluvium are present

"Limestone" as used in connection with silurian and earlier formations includes, in many cases, dolomites as well

ally termed exploring wires, were placed at various separations from the energized circuit and parallel to it. Measurements were then made of the mutual impedance of the energized circuit and each of the exploring wires in turn. With few exceptions the measurements were made at a frequency of 60 cycles. Methods of making such measurements and of deriving from them the effective resistivities have been discussed in published papers.[1,5,6,8,9]

In most cases the resistivities indicated by the measurements in various exploring wires or subsections vary over a considerable range. Where the measurements were made in consecutive subsections the term "mean effective resistivity" is here applied to the value corresponding to the over-all mutual impedance. Where exploring wires were used, this term is applied in most instances to the geometric mean of the maximum and minimum values.

A second method of measurement which has been employed in a few instances involves the exploration of the field between the end electrodes of a ground return circuit energized with direct current. This method is similar to those frequently used in such work as geophysical prospecting, one of which has been described as Gish and Rooney.[12]

General Correlation Data

The basic data included in the study are summarized in figure 1 in a manner to facilitate comparison of the resistivities derived from the results of the several tests with the geological periods and types of rocks involved in each case. For those cases in which only one measurement of mutual impedance was made, the effective resistivities are indicated in this figure by isolated circles. Where measurements were made in several sections of lines or in several exploring wires, the mean effective resistivities are indicated by circles and the range of individual values by the vertical lines drawn through these circles. For any particular test the principal materials composing the structure and the geological periods of the principal strata are indicated by the brackets directly above the resistivity data. From left to right the tests are included in the figure in order of the ages of the predominant strata composing the structures, from the oldest to the youngest, so far as it has been practicable to do so.

This figure shows in striking manner the tendency for effective resistivities to decrease with decreasing age of structure but at the same time it emphasizes the irregularity of this relation.

It does not seem unreasonable that this irregularity should exist when it is considered that each geological period covers a very wide range in age, that the strata of any given period are composed of many different types of materials, and that the impregnating waters of the strata of one period may be affected by neighboring strata of other periods. Where strata of the same period have been deposited in widely separated areas, these factors have a greater opportunity to cause variations in resistivities. The test results confirm this; they indicate that the effective resistivities of structures of given periods within certain large geographical regions are markedly different from those of structures of the same periods in other large regions. Within any one of such regions, excluding areas where igneous and highly metamorphosed sedimentary rocks are involved, the effective resistivities of structures of the same period are encompassed within a comparatively narrow band. This effect is illustrated by figure 2. As

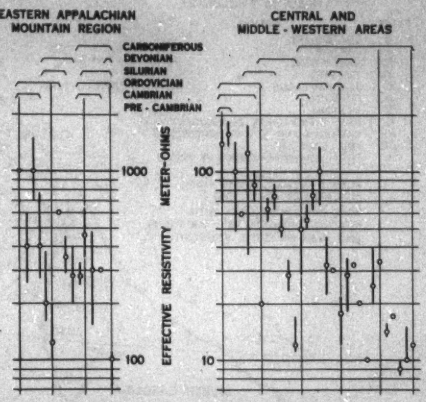


Fig. 2. Correlation of effective resistivities and geological periods—Paleozoic areas

shown by this figure the effective resistivities in the eastern Appalachian Mountain region are higher by ratios of 5 or 10 to 1 than those determined for structures of corresponding periods farther to the west.

Not only is the variation between the effective resistivities at more or less widely separated localities of interest, but also the variation in the resistivities corresponding to mutual impedances for different separations at particular points, or to mutual impedances of consecutive sections of 2 lines, the separation between which may be constant or may vary if an irregular manner. In each of the tests in areas of the older rocks, the pre-Cambrian and combinations of pre-Cambrian and Cambrian, in connection with which measurements were made in several sections or exploring wires, the variations in resistivities were very erratic and in several instances were quite wide, in one case nearly 20 to 1. Such variations are in accord with the expectations for the behavior of these older structures as outlined above.

Considering the tests involving structures composed principally of strata of Cambrian or later periods, it will be noted from figure 1 that the range of variation indicated for any particular test is comparatively narrow; in general, 2 or 3 to 1. The structures in most of these cases are composed of fairly uniform layers, horizontal or inclined at low angles. However, even where these simpler structures are involved there may be considerable vari-

ation in the stratification at different points along the test lines. In the case of some of the tests involving strata of intermediate age, the Cambrian, Ordovician, Silurian, and Devonian, the structures are complicated by faulting, folding, and tilting of the strata. The uniformity of the results shown by individual tests where such structural variations are encountered is perhaps explained, at least in part, by the tendency for the resistivities of the several parts of structures composed of the more pervious materials to merge due to the intermingling of the impregnating waters.

On the right-hand side of figure 1 are shown the data for several tests involving structures composed of materials of 2 of the latest periods, the Cretaceous and Tertiary, directly underlain by pre-Cambrian strata. The upper strata are composed mostly of low resistivity materials and the pre-Cambrian strata are of high resistivity. There is a distinct layer effect in such cases and the effective resistivities may range from the resistivity of the upper materials, where these are very thick, to values approaching the resistivity of the pre-Cambrian rocks as the thickness of the upper strata decreases. As will be noted the mean effective resistivities indicated by these tests range from 24 to 1,800 meter-ohms.

The foregoing discussion has been confined almost entirely to the relation between the effective resistivities of structures and the periods to which the component parts of these structures are assigned. The relation between these resistivities and the various types of rocks, the granites, limestones, sandstones, etc., must also receive consideration.

Where recently deposited sedimentary materials, such as clays, sands, marls, and chalks, predominate, the effective resistivities range from 2 to 32 meter-ohms. Such materials are consolidated in time to form shales, slates, sandstones, limestones, and similar rocks, which in various stages of induration will be found principally in structures ranging in age from the Cretaceous to the Cambrian, inclusive. The range in effective resistivities where these rocks prevail is from 10 to 1,000 meter-ohms. The pre-Cambrian rocks consist mostly of schists, gneisses, granites, quartzites, and other dense, hard varieties. Similar rocks are present in some Cambrian structures, and very hard rocks, such as granites, have been formed by volcanic action in even later periods. The effective resistivities where these types prevail range from 1,000 to 10,000 meter-ohms.

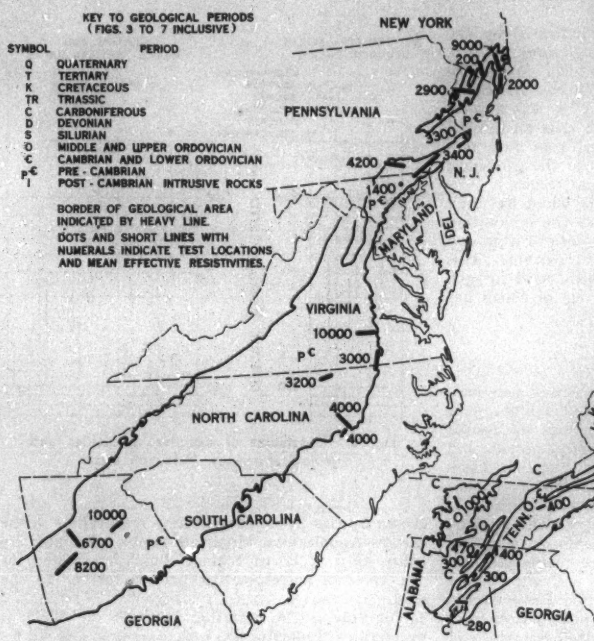
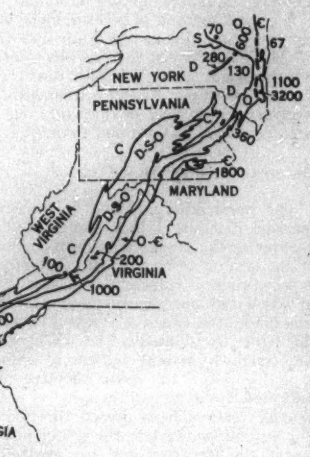


Fig. 3 (left). Areal geology and effective resistivities—pre-Cambrian areas

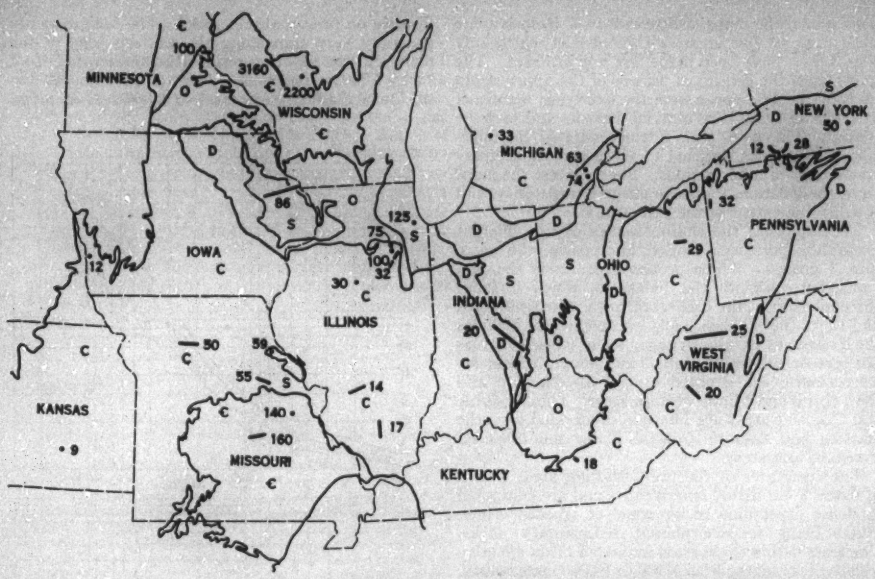
Fig. 4 (below). Areal geology and effective resistivities—Appalachian Paleozoic areas

Refer to key on figure 3



Correlation Data for Specific Areas

To give a general picture of the resistivity characteristics of different areas within which tests have



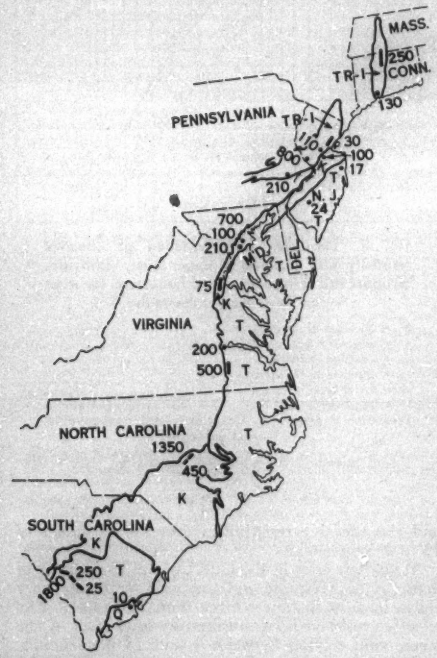


Fig. 5 (above). Areal geology and effective resistivities—Central and Middlewestern Paleozoic areas

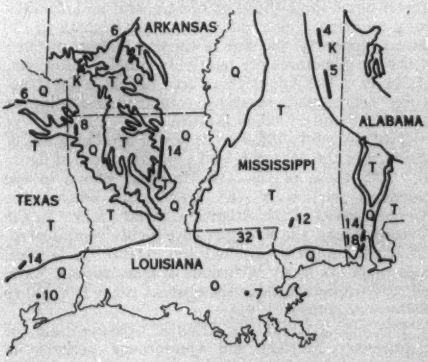
Refer to key on figure 3

Fig. 6 (left). Areal geology and effective resistivities—Eastern and Atlantic Coastal Plain Mesozoic and Cenozoic areas

Refer to key on figure 3

Fig. 7 (below). Areal geology and effective resistivities—Gulf Coastal Plain Mesozoic and Cenozoic areas

Refer to key on figure 3



been made, the maps of figures 3 to 7, inclusive, are presented. A few areas, within each of which only 1 or 2 tests have been made, are not included. The maps show the geological periods of the upper strata as they would appear were the overlying mantle of soil, glacial drift, local alluvial deposits and such removed. The small scale has necessitated the omission within areas assigned to given periods of many small areas of other periods. For each test the maps show the location, the mean effective resistivity, and roughly the extent of the test section.

To emphasize the characteristics of the different areas they have been divided, in preparing the maps, into 3 groups. These groups are: first, the pre-Cambrian; second, the Paleozoic, which includes the periods from the Cambrian to the Carboniferous; and third, the Mesozoic and Cenozoic, which includes the Triassic to the Quaternary. The Paleozoic areas are further subdivided into 2 subgroups, which, for convenience, are denoted as the Appalachian and the Central and Middlewestern areas. The Mesozoic and Cenozoic areas are likewise subdivided into the Eastern and Atlantic Coastal Plain, and the Gulf Coastal Plain areas.

The structures of the pre-Cambrian areas shown in figure 3 are highly complicated and are composed of dense crystalline rocks, some of igneous origin, others being metamorphosed sedimentary rocks. The tests within these areas indicated mean effective resistivities ranging from 1,400 to 10,000 meter-ohms, the only exception being one test in New York from which a value of 200 meter-ohms was derived. The rocks at the latter test site are partly covered with alluvium.

A wide variety of structures is involved in the tests in the Paleozoic areas shown in figures 4 and 5. Likewise the effective resistivities varied widely, the mean values ranging from 67 to 3,200 meter-ohms. Values above 1,000 meter-ohms were indicated only at points where pre-Cambrian rocks are involved or where rocks of the earlier Paleozoic periods have been partly or wholly metamorphosed and greatly disturbed by crustal movements.

The remaining tests of the Paleozoic group may be divided into 2 classifications; those in the Appalachian areas, which indicated values from 67 to 1,000 meter-ohms, and those in the Central and Middlewestern areas, which indicated values from 12 to 160 meter-ohms. At the sites of the greater part of these tests the structures are relatively simple. However, at many of the Appalachian area test sites the structures are characterized by complicated folding of the strata and by many faults.

Two distinctly different types of structure are of concern in the Mesozoic and Cenozoic areas of figure 6; first, those of the Triassic areas shown in the northern portion of the figure, and second, the younger areas of the Atlantic Coastal Plain. In the Triassic areas, the structures are highly complicated. The strata have been tilted and extensively faulted, and there are many intrusions of igneous rock. The effective resistivities in these areas range from 30 to 800 meter-ohms.

The sediments of the Atlantic Coastal Plain, of Cretaceous, Tertiary and Quaternary periods, lie directly on pre-Cambrian rocks. The sediments are generally very thin along the western edge of the plain and the effective resistivities there range from 75 to 1,800 meter-ohms. Toward the coastline the thickness gradually increases to 2,000 feet or more,

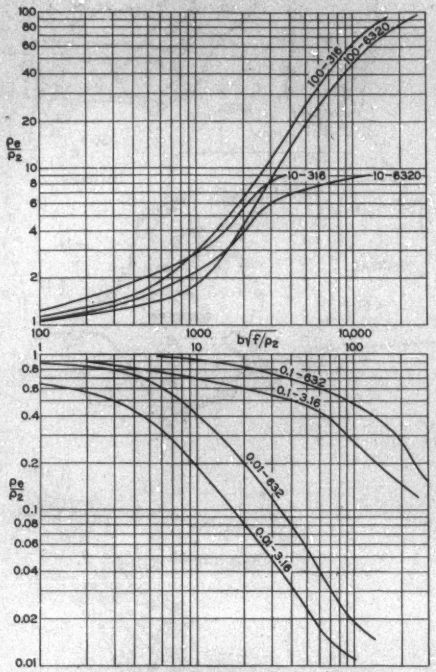


Fig. 8. Two-layer earth—variation of effective resistivity with thickness of upper layer, resistivities of upper and lower layers, and frequency, for wires on the surface of the earth

b = thickness of upper layer
x = separation between wires
ρ_e = effective resistivity
ρ_1 = upper-layer resistivity
ρ_2 = lower-layer resistivity
f = frequency
Resistivities in meter-ohms; distances in feet; frequencies in cycles per second

Figures on each curve are values of $\frac{\rho_1}{\rho_2}$ and $x\sqrt{\frac{f}{\rho_2}}$ respectively

and the effective resistivities decrease to values of 10 to 25 meter-ohms.

At the test sites in the Gulf Coastal Plain areas of figure 7 the Mesozoic and Cenozoic strata are very thick, in most instances more than 2,000 feet. The effective resistivities are uniformly low, most of the mean values lying between 4 and 18 meter-ohms.

Concluding Remarks

Study of the electrical characteristics of the earth's crust is in its infancy. Much remains to be done in the way of determinations in the field of the characteristics of the component parts of structures and of these structures as a whole. Such field studies of electrical characteristics should be paralleled by studies of the physical characteristics of these structures and of the composition of their impregnating waters. Furthermore, the data from many such investigations should be analyzed and correlated.

Further theoretical study of the behavior of various types of nonuniform structures, supplemented possibly by laboratory investigations employing reduced scale models of earth structures, would be of value.

Appendix

In connection with studies of the character of that presented in this paper some idea must be had as to what portion of the structure probably influenced the mutual impedance measurements from which the effective resistivities were derived. The complicated nature of the earth's crust together, in the usual case, with lack of knowledge of the individual resistivities of the parts of the structure precludes a direct solution of this problem. However, in any particular case it is possible to specify a certain depth and to say that it is improbable that the strata below a depth of that order influenced the results to any material extent. With no knowledge of the resistivities of the several parts it is not possible to determine just what portion of the structure above this depth is involved.

This problem may be attacked with the aid of a recently published formula[13] for the mutual impedance of grounded wires on the surface of a 2-layer earth; that is, a structure composed of 2 horizontal layers, each of uniform resistivity, the upper layer of finite thickness, the lower layer extending to an infinite depth. The curves of figure 8, which are based upon this formula, show for any frequency and for selected separations between wires and ratios of upper-layer to lower-layer resistivity, the relation between the effective resistivity, lower-layer resistivity, and thickness of upper layer.

In the usual case the deeper portions of a structure are of higher resistivity than the upper strata. Assuming this to be true for a particular case, then the resistivity of the upper strata, considering these as forming a single uniform layer, must be less than the effective resistivity if the depth to the lower strata is such that they influence the effective resistivity. If an upper layer having a resistivity somewhat less than that of the effective value and a lower layer having a resistivity which is not likely to be exceeded are assumed, then the corresponding depth as determined from the 2-layer curves will be a value below which the structure may be considered to have had relatively little influence on the measurements. For unusual cases in which there is reason to believe that the resistivity of the deeper strata may be less than that of the upper strata, the depth below which the structure probably had little influence on the measurements can be determined in a similar manner.

Table I—Representative Depths Determined for 60 Cycles

Effective Resistivity	Depth to Lower Layer	
	$\rho_1 < \rho_2$	$\rho_1 > \rho_2$
3,000 meter-ohms	5,000 feet	12,000 feet
1,000 meter-ohms	3,500 feet	7,400 feet
100 meter-ohms	1,500 feet	2,300 feet
10 meter-ohms	600 feet	600 feet

ρ_1 = resistivity of upper layer
ρ_2 = resistivity of lower layer

Representative depths determined by this method for a frequency of 60 cycles are given in table I. For the condition of a lower layer of higher resistivity than the upper layer, these depths were determined by assuming an upper layer having a resistivity equal to $^2/_3$ of the effective resistivity and a lower-layer resistivity of 10,000 meter-ohms. For the opposite condition, an upper layer having a resistivity 50 per cent greater than the effective resistivity and a lower-layer resistivity of 1 meter-ohm were assumed.

For both types of structure, at frequencies lower than 60 cycles greater depths would be of concern; for higher frequencies, smaller depths.

Other facts of interest concerning the expected behavior of a 2-layer structure can be deduced from the curves of figure 8. For instance, it will be noted that effective resistivities for small and large separations between wires may differ in some instances by factors as great as 2.5 to 1. This difference is greatest where the upper layer is of the lower resistivity.

The possible effects of relatively thin upper layers, such as soils, sands, glacial drift, and alluvial deposits, may also be determined from figure 8. It will be seen that, for low frequencies, where the upper layer is of the higher resistivity, this layer will have little influence on the effective resistivity unless it is very thick. For example, for a frequency of 60 cycles, a lower-layer resistivity of 10 meter-ohms, and a 200 foot upper layer having a resistivity anywhere between 10 and 1,000 meter-ohms, the effective resistivity will not exceed 20 meter-ohms. Where the upper layer is of the lower resistivity the effective resistivity may vary widely with variations in the resistivity of this layer even though it may be very thin. Given a 1,000 meter-ohm lower layer and a 200 foot upper layer, the 60 cycle effective resistivities for wide separations will be around 60 and 600 meter-ohms for upper layer resistivities of 10 and 100 meter-ohms, respectively.

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A Cable Code Translator System

By means of specially devised translators, described in this paper, 3-element cable-code signals may be translated into 2-element signals suitable for transmission over ordinary landline telegraph plants; by means of retranslating circuits, also described, the signals may be restored to their original 3-element form. Signals in the 2-element form may be monitored without the aid of retranslators. Synchronism is not required between the translators and retranslators.

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EVER SINCE its first cables were laid, The Commercial Cable Company, which owns and operates several submarine telegraph cables between North America and Europe, has used a 3-element code for signaling. In this code a dot is represented by a positive potential applied to the cable for one unit of time, a dash by a negative potential applied for one unit of time, and a space between letters by a ground potential applied for a similar length of time. The combinations assigned to the letters of the alphabet are in accordance with the continental code.

This method of signaling is used quite generally by other administrations over long submarine cables. It has, among other advantages, the marked advantage of greater accuracy than the 5-unit 2-element code which is in general use in landline systems and on some cables. In the 3-element cable code practically all mutilations of signals that might occur are detected readily by the receiving operator, and necessary corrections can be made before delivery of the message to the customer. In the 5-unit code, however, it is not possible for the receiving operator to detect most errors, except in plain language messages, and consequently the number of undetected errors is much greater. Because a large proportion of cable traffic is in unpronounceable code words, it is desirable to use a code that offers a means for readily detecting errors.

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The disadvantages that previously have been held against the 3-element cable code have been that it would not directly operate an automatic printer and that it was not suitable for transmission over landline systems equipped to repeat only 2-element signals.

An automatic printer operated directly from 3-element cable-code signals is now in general use both in the Commercial Cable and All America Cable systems.[1] It is the purpose of this paper to describe a system of automatically translating 3-element cable-code signals into a special higher-frequency 2-element code suitable for transmission through ordinary landline equipment, and nonsynchronous retranslating circuits for restoring the signals into their original form.

Translator System Comprises 4 Units

The need for a suitable translator has been felt for some time, but the announcement of the British Post Office that it soon would be unable to lease metallic underground conductors between the cable landing at Weston-super-Mare and the main cable office in London made the need more pressing. The British Post Office proposed to lease channels of its voice frequency carrier system in place of the metallic conductors. The voice frequency system, however, was capable of transmitting only a 2-element code and therefore was unsuited for cable code working. Unless a translator were made available it would be necessary to lease 2 channels, one for dots and one for dashes, to transmit the signals from each submarine cable.

In response to this demand a complete translator system has been developed and is now in successful operation in England as well as on an overland line between New York City and Canso, Nova Scotia. It is believed that the present development offers a better solution to the translation problem, especially on landlines of moderate length, than previously developed systems. The various units comprising the complete translator system are as follows:

Type 32*XM*. With this translator a tape perforated in accordance with the 3-element cable-code is used to transmit 2-element signals into a landline.

Type 23*RY*. This unit retranslates the 2-element signal received over a landline into the 3-element cable code. The output of this translator comes from relays and is suitable for direct transmission into a short cable, or may be regenerated and then sent into a long cable.

Type 23*DW*. This unit retranslates the 2-element signals received over a landline into the 3-element cable code in form suitable for recording on an ink writer. It is somewhat simpler than the type 23*RY*, but is not suitable for operating printers or transmitting into another cable.

Type 32*RG*. This translator operates in conjunction with a regular cable code regenerator and translates the 3-element cable-code signals received over a submarine cable into 2-element signals for transmission into a landline.

Two-Element and 3-Element Codes

The 2-and 3-element codes are shown in figure 1. It may be noted that the 2-element signals are not of the standard continental code. In this 2-element

1. See reference at end of paper.

code, each dot, dash, or space occupies the same amount of transmission time. A 2-element dot consists of 1 unit of spacing, 1 unit of marking, and 1 unit of spaeing, thus making a total of 3 units. A dash consists of 2 units of marking and 1 unit of spacing, or a total of 3 units. The zero signal consists of 3 units of spacing. In the 2-element code 3 units occupy the same period of time as one "center hole" or unit in the 3-element cable code. There is, therefore, no need of storing any signals at the translator station.

When recorded by an ink writer, the 2-element code may be easily read and therefore may be readily monitored. It is not intended, however, that messages shall be written up regularly from this code. Before recording or writing up the signals they will be retranslated into their original 3-element form. It should be noted that the third or last unit of each 2-element cable code signal is always spacing. It should be noted also that the ending of the marking interval on both dots and dashes occurs at regular intervals. On the letter *C*, for example, the interval of time between the end of the dash marking and the end of the dot marking is exactly 3 units. A similar interval of time separates the end of the dot marking and the end of the dash marking. These equal intervals of time are utilized in translating the signal into the 3-element form.

Transmitting 2-Element Signals From 3-Element Cable-Code Tape

In figure 2 are shown the circuits of translator 32*XM*, a tape controlled automatic transmitter that has been adapted to transmit 2-element code signals from a 3-element cable-code tape. This may be a standard form of automatic transmitter that operates at a constant speed. Dot and dash contacts are shown which are controlled by the dot and dash peckers under the control of the perforated tape. The 2 commutators are mounted on the same shaft of the automatic transmitter and revolve at the rate of one revolution per center hole or feed hole of perforated tape. During the first third of the revolution the circuit through both cams is open and the transmitting relay during this time is invariably on spacing. It is during this interval that the peckers "feel" for and assume their new positions as determined by the holes in the perforated tape. When a dot pecker has been selected, it is obvious that the circuit to the transmitting relay will be open for $^2/_3$ revolution and closed for $^1/_3$ revolution. When a dash pecker has been selected, the circuit to the transmitting relay will be open for only $^1/_3$ revolution and closed for $^2/_3$ revolution. When a zero signal is to be transmitted, neither pecker will be operated and there will be no marking of the transmitting relay for a full revolution of the commutators. The type of signals that will be transmitted, therefore, will be in accordance with the 2-element cable-code signals shown in figure 1.

Translating 2-Element Signals to 3-Element Cable-Code Form

Means for translating the 2-element signal back into its cable code form is shown in figure 3, which is a schematic diagram of translator 23*RY*. Two adjustable timing circuits are required: One of these circuits is for distinguishing between dots and dashes by the duration of the marking time of the received signal; the other is to space the dot and dash transmitting relays when no marking signal has been received for a predetermined time interval.

Each valve together with its anode relay and shunted grid capacitor merely acts as an easily adjusted reliable "slow-operate quick-release" relay. The cathode of each valve is tied to the main power battery in such manner that the cathode potential is approximately midway between the positive and negative potentials of the main power battery shown in the figure. The actual connection usually is made by means of a potential divider. When the control relay is in a marking position as shown, the shunted $^1/_2$-microfarad capacitor has a negative charge and the grid of *V*1 is highly negative with respect to the cathode. When a marking signal is received over the telegraph line the control relay releases and the negative connection is removed from the capacitor. The negative charge leaks off the capacitor through resistance *R*1 and the grid finally becomes positive with respect to the cathode. At some definite time after the marking signal has been received, anode current flows and the anode relay operates. The shunt resistance *R*1 of the capacitor

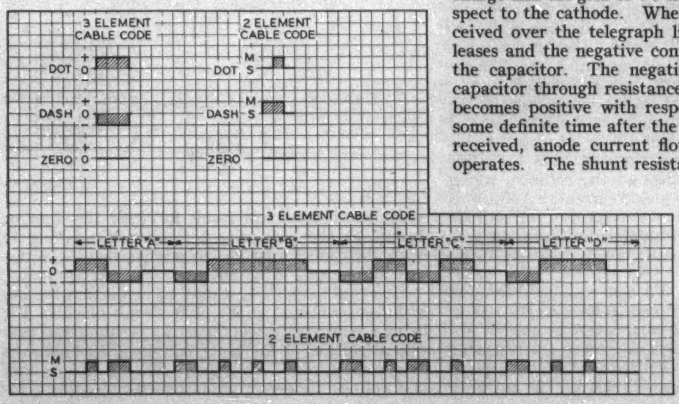


Fig. 1. Comparison of 2-element and 3-element codes

M—Marking S—Spacing

will have been adjusted so that the anode relay is not operated when a dot is received, but is operated when a dash is received. When the line relay restores to the spacing position, a circuit is completed from the line relay tongue, back contact, and thence

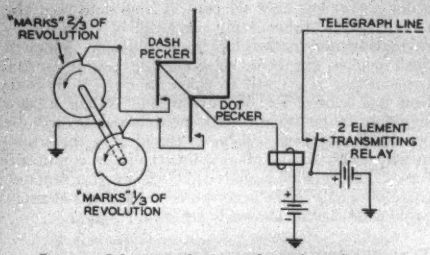


Fig. 2. Schematic diagram of translator for transmitting 2-element signals from 3-element cable-code tape

to the tongue of the anode relay. For a dot signal the anode relay is unoperated and the circuit is completed from the anode relay tongue, through the back contact, through the dot and dash transmitting relays in such direction as to "mark" the dot transmitting relay and "space" the dash relay, thereby sending out a dot cable-code signal. The dot and dash transmitting relays are polarized and remain in the positions in which they have been set. For a dash signal the anode relay will have been operated and the circuit from the plate relay tongue is completed through a holding winding on the anode relay, through the dot and dash transmitting relay, and "marks" the dash transmitting relay and "spaces" the dot transmitting relay, thereby sending out a dash cable-code signal. Each time the line relay restores to the spacing position, a cable code dot or dash is retransmitted. At the same time the control relay operates and negatively charges the capacitor connected to the grid of $V1$. If the line relay has been "marking" for only a short time a dot is retransmitted. If it has been "marking" for a longer period of time a cable code dash is retransmitted.

It should be noted that all the valves used in the different types of translators have a grid resistor of at least one megohm value. The purpose of this grid resistor is to prevent the grid from becoming highly positive with respect to the cathode, which would result in excessive anode current. As soon as the grid becomes positive with respect to the cathode the grid current produces an IR drop across the grid resistor of sufficient value to prevent excessive anode current.

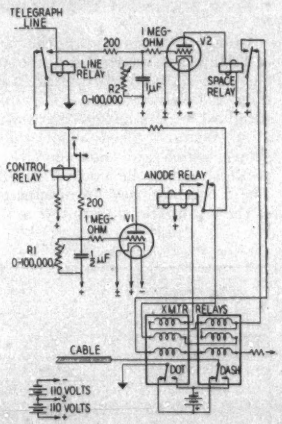
The purpose of valve $V2$ and associated circuits is to restore the dot and dash transmitters to their spacing positions so as to send a zero or ground potential signal into the cable whenever no 2-element marking signals have been received for a certain time. While the line relay is not on the marking contact the charge on the capacitor associated with $V2$ slowly is leaking off. The rate at which the charge leaks off is controlled by the adjustable shunt $R2$. When the grid of $V2$ attains a certain potential with respect to the cathode, the space relay is operated. When the tongue of the space relay leaves the back contact the dot and dash operating circuit of the dot and dash transmitting relays is opened, and when the space relay tongue reaches the marking contact a circuit is completed that restores the dot and dash transmitting relays to "spacing" in the event either one had been "marking." The restoration of the dot and dash transmitting relays to "spacing" results in zero or ground potential being applied to the cable, thus indicating a space between letters.

Translating 2-Element Signals to 3-Element Ink-Writer Records

The following is a description of the translator ($23DW$) designed for use at a station where it is desired to produce cable-code ink-writer records only from a received 2-element signal. The circuit is simpler and has some advantages over translator $23RY$, which produces cable code signals on a pair of relays. The principal advantage is that a small misadjustment of the dot-dash adjusting rheostat will not result in recording dots for dashes or *vice*

Fig. 3. Translator for converting 2-element signals to 3-element form

Resistances are shown in ohms



versa, but instead will result in either the dots or dashes, as the case may be, sometimes failing to reach their full amplitude, thus indicating the necessary adjustment to be made.

Referring to figure 4, it may be noted that the ink writer is connected in the plate circuit of valve $V1$. Being a sensitive device, the writer is shunted so that only a portion of the plate current passes through its operating coil. Resistances $R1$ and $R2$ are used as a voltage divider or potentiometer to apply a re-

duced voltage to the anode of the valve. The resistances in the plate circuit are so proportioned and arranged that when the grid is negative with respect to the cathode, there is no anode current and therefore no deflection of the ink writer pen. This condition is maintained while a dot is being recorded. When the grid is positive with respect to the cathode, there is maximum current in the anode circuit and the ink writer pen has maximum deflection. The ink writer is connected so that this deflection is in the dash or downward direction on the tape. This condition is maintained while dashes are being recorded. In order to record the spaces it is necessary, of course, for the pen to assume a position midway between the dot (zero anode current) and the dash (maximum anode current) line. The grid of $V1$ is maintained at a suitable potential with respect to the cathode so that the ink writer pen assumes a position intermediate to the dot and dash positions and thus records spaces. The zero adjustment potentiometer, shown in the schematic diagram, supplies the required grid potential for recording a space.

Assume that spacing is being received over the line. The line relay tongue remains against its spacing contact (S) thus energizing relays $PF1$ and $PF2$. When the line relay tongue has remained away from its marking contact (M) for sufficient length of time the grid of $V2$ becomes positive with respect to the cathode. The anode current energizes $VR2$ thus rendering the grid of $V1$ the same potential as the zero adjustment potentiometer slider. A zero or spacing signal therefore is indicated on the ink writer. Suppose a marking signal of dot duration now actuates the line relay. When the line relay tongue reaches its marking stop, capacitor $C4$ quickly is charged negatively thus stopping the anode current flow of valve $V2$. Relay $VR2$ leaves its marking contact and disconnects the zero adjustment potentiometer from the grid of $V1$. The small grid capacitor $C3$ maintains the intermediate voltage on the grid for as long as required. The departure of the line relay tongue from its spacing contact results in relays $PF1$ and $PF2$ being deenergized. When the tongue of relay $PF1$ reaches its spacing contact, capacitors $C1$ and $C2$ are paralleled, their charges mix and voltages equalize. Since the capacitance of $C2$ is only a small fraction of that of $C1$, the potential of $C1$ only slightly is changed. Capacitors $C1$ and $C2$ now slowly take up a positive charge through the dot-dash adjustment rheostat. At the end of the marking period of the line relay, relays $PF1$ and $PF2$ again are operated. When relay $PF1$ operates, capacitors $C1$ and $C2$ are separated and $C1$ is charged negatively. The operation of relay $PF2$ joins or parallels capacitors $C2$ and $C3$. The capacitance of $C2$ is much larger than that of $C3$; therefore the potential of $C2$ is altered only slightly when the charges mix. Capacitor $C3$ is now of the same potential as $C2$ and the grid of $V1$ is of a similar potential. For the dot signal just described $C3$ does not have sufficient charge to render the grid positive with respect to the cathode; the grid becomes negative; there is no anode current flow, and the ink writer therefore records a dot.

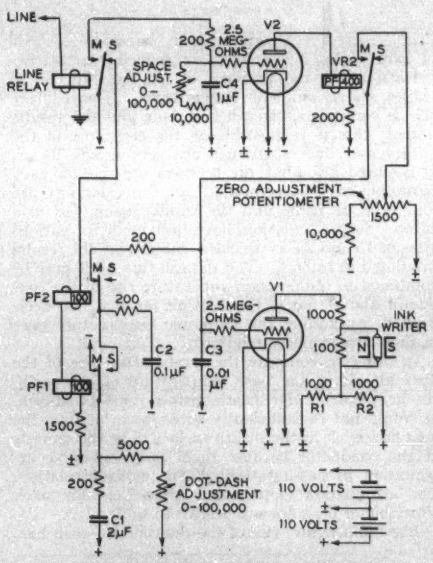


Fig. 4. Translator for converting 2-element signals to 3-element ink-writer records

Resistances are shown in ohms

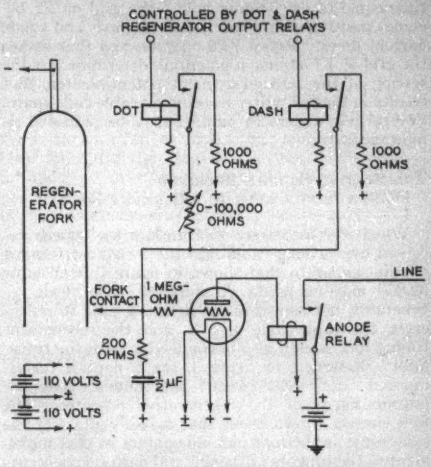


Fig. 5. Translator for converting 3-element signals received over long cables to 2-element form

Had the marking interval of the line relay been of dash length, capacitor $C1$ would have received a greater charge and $C2$ and $C3$ would have had a proportionately greater potential. The potential of $C3$ for a dash would have been sufficient to render the grid positive with respect to the cathode, and therefore maximum anode current would flow and the ink writer would record a dash.

The space adjustment rheostat is adjusted so that if the line relay does not "mark" for an interval of time equal to one "center hole," the grid of $V2$ becomes positive with respect to the cathode and anode current flows. Relay $VR2$ operates and thus makes the grid of $V1$ assume a potential, determined by the setting of the zero adjustment potentiometer, that results in the ink writer recording a cable code space. Several ink writers in parallel may be actuated simultaneously.

Translating Signals Received Over a Long Cable to 2-Element Form

When it is necessary to translate the signals received over a long cable into the 2-element form, a circuit similar to that shown in figure 5 (translator $32RG$) may be used. A standard cable code regenerator, not shown in the figure, is used to regenerate the cable code signals, and the regenerator tuning fork is used also in connection with the translator. Referring to figure 5, the 2 neutral relays, marked "dot" and "dash," are controlled by the output signal of the regenerative repeater. The fork contact shown is one that makes contact at the same time as the fork pick-up contact so that movement of the tongues of the dot and dash relays occurs only while the fork is making contact. The marking contact of the fork is adjusted to make for $^1/_3$ of the time.

While the fork is "marking," the grid of the valve is negative with respect to the cathode and there is no anode current. The anode relay, of course, will be unoperated, and a spacing signal is sent to the line. The capacitor is charged negatively. The cathode of the valve, it should be noted, is connected to the midpoint of the battery. When the fork leaves the contact the negative charge remains on the grid capacitor, provided neither dot nor dash input relay is "marking," and the output relay continues to send "spacing" to the line. If the dash input relay is in an operated position when the regenerator fork leaves its contact, then the grid capacitor quickly is discharged. The resulting anode current operates the output relay thus sending "marking" to the line. If, however, when the regenerator fork leaves its contact the dot input relay is in an operated position, it will take another $^1/_3$ "center hole" time interval, when the high resistance adjustable rheostat is set correctly, before the condenser is discharged sufficiently to operate the output relay and send a marking signal to the line.

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Economical Loading of Underground Cables

Load ratings for underground electric power transmission cables for 2 typical metropolitan load cycles are computed in this paper by the method of harmonic analysis of load cycles. Test data are given which agree reasonably well with theoretical calculations. A logical basis for emergency rating of cables also is demonstrated. A comparison of costs of transmission for various duct conditions indicates that large conduit systems are not economical because of the lower ratings necessitated by the greater heat dissipated.

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In a former paper,[1] harmonic analysis of load cycles is employed in reducing to mathematical basis, the problem of temperature rise of cables above ambient temperature. Temperature rise is computed for each harmonic and the results added; this is permissible as the constants of the cables and duct structures are very nearly linear. It is stated also that the temperature rise for each harmonic may be computed only once for any size and type of cable and the results assembled in a table. Such calculations have been made for various sizes of 15 and 25 kv shielded cables and the results tabulated in table I. The data in this table may be combined to obtain the temperature rise of the conductor above that of the duct air for any load cycle desired, by adding the harmonic temperature rises in their proper phase relations.

In order to compute the temperature rise of the duct air above the base temperature of the earth, the heat flow at the sheath surface must be known. It would not be sufficiently accurate to assume the heat flow cycle at the sheath surface to be the same as at the conductor because there is considerable attenuation in passing through the cable insulation. The attenuation factors and time lags for each harmonic of heat flow are shown in table II.

The temperature rise of the duct air for each har-

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1. For all numbered references see list at end of paper.

monic and various sizes of duct structures is given by table III. These were computed by assuming an equivalent cylindrical conduit structure as described in reference 1. The steady state duct constants are taken from reference 12. These were obtained as a result of averaging data from various operating companies throughout the country. It should be noted that the constants of the conduit structure are such that the harmonic temperature rises are practically independent of the outside radius of the equivalent cylindrical conduit structure. This would be expected since the effect of the variable components of heat flow would die out rapidly at a distance of a few feet. The dimensions of an actual 12 duct conduit and the inside radii of the assumed cylindrical structure are shown in figure 4.

By harmonic analysis, the copper losses corresponding to 2 load cycles most common in metropolitan transmission systems are expressed by the following equations:

Winter load cycle:

$$\text{Copper loss} = 0.440 + 0.330 \sin(\omega t - 5.90\text{ hr}) + 0.175 \sin(2\omega t + 1.70\text{ hr}) + 0.073 \sin(3\omega t - 2.40\text{ hr}) \quad (1)$$

Summer load cycle:

$$\text{Copper loss} = 0.560 + 0.252 (\sin \omega t - 3.36\text{ hr}) + 0.229 (\sin 2\omega t - 1.00\text{ hr}) + 0.045 (\sin 3\omega t + 3.37\text{ hr}) + 0.180 (\sin 4\omega t - 1.81\text{ hr}) \quad (2)$$

Curves of equations 1 and 2 adjusted for 8 per cent dielectric loss are shown in figure 1, together with the corresponding temperature rise curves for 4 400,000-circular mil, 25-kv cables installed in a 4 duct conduit.

All components of equations 1 and 2 are given as ratios to maximum copper loss, this maximum being taken as 1.00. The average copper loss (loss factor) is given by the first term of each equation. Each harmonic component is multiplied by the corresponding factors in tables I, II, and III, obtaining the temperature rises for each harmonic. These are added together in their proper phase relations and maximum temperature rises obtained as shown in table IV, *A* and *B*. These factors, when combined in proportion to the steady state thermal resistances from the earth to duct air and duct air to conductor, give the total maximum temperature rise, ϕ, from earth to conductor caused by the copper loss. Strictly speaking, each harmonic temperature rise for earth to duct and duct to conductor should be combined in its proper magnitude and phase relation and the results totaled to obtain the value of ϕ. It has been found for the usual load cycles, as illustrated in figure 1, that the temperature curves are flat enough at the peaks so that the difference in times of the maxima does not affect the results appreciably. A table of values of ϕ for 2 shielded cables and various numbers of ducts is given in part *C* of table IV.

Table II—Conductor-to-Duct Heat Flow Attenuation Factors, With Time Lags, for Harmonics 1 to 4

Constants of Cables Given in Table I

Rated Kv	Size of Conductor, B & S Gauge or Cir Mils	Attenuation Factors 1	2	3	4	Harmonic Time Lag in Hours 1	2	3	4
14	4/0	0.990	0.910	0.835	0.760	0.825	0.790	0.750	0.705
	350,000	0.980	0.890	0.795	0.710	0.960	0.910	0.800	0.790
	500,000	0.965	0.860	0.765	0.670	1.075	1.005	0.925	0.845
25	4/0	0.980	0.890	0.800	0.720	0.975	0.940	0.890	0.840
	300,000	0.970	0.865	0.770	0.680	1.080	1.025	0.965	0.895
	500,000	0.950	0.825	0.720	0.625	1.245	1.145	1.055	0.965

Steady and Cyclic Loading Ratings

The rating that may be given a cable for cyclic loading may be expressed as follows:

$$\text{Rating under cyclic loading} = \text{Steady state rating} \times \lambda$$

$$\text{where } \lambda = \sqrt{\frac{1.0 + \gamma}{\phi + \gamma}}$$

(For complete list of symbols see Appendix I.)

Steady state ratings may be computed by familiar methods [3-7]. In table IV *a* steady state and cyclic loading ratings based upon the 2 load cycles of equations 1 and 2 are shown. The earth base temperature was assumed to be 5 degrees centigrade in winter, and 20 degrees in summer. The maximum allowable temperature rise was $90-E$ where E is the voltage (kv) to neutral, which corresponds to the A.I.E.E. rule for temperature limit of 3-conductor shielded and single-conductor paper-insulated cables.

Belted cables require a lower rating than shielded cables for 2 reasons: the greater thermal resistivity

Table I—Ratio of Harmonic Conductor-to-Duct Temperature Rise to Steady Load Rise, With Time Lags, for Shielded Cables

S_i = 700 deg C per watt per cu cm, 14 kv cables
S_j = 650 deg C per watt per cu cm, 25 kv cables
K_s = 1,100* deg C per watt per sq cm

C_c = 0.107 watt per gram
C_i = 0.493 watt per gram
C_s = 0.035 watt per gram

ρ_c = 6.9 grams per cu cm
ρ_i = 1.16 grams per cu cm
ρ_s = 11.4 grams per cu cm

Rated Kv	Thickness of Insulation, Cm	Size of Conductor, B & S Gauge or Cir Mils	Sheath Dimensions, Cm: Diameter	Sheath Dimensions, Cm: Thickness	Ratio of Harmonic (1 to 4) Rise to Steady State Rise 1	2	3	4	Harmonic (1 to 4) Time Lag in Hours 1	2	3	4
14	0.556	4/0	5.23	0.318	0.980	0.905	0.835	0.765	0.745	0.700	0.650	0.605
		350,000	6.30	0.357	0.970	0.885	0.795	0.715	0.865	0.810	0.750	0.685
		500,000	7.04	0.357	0.965	0.865	0.765	0.680	0.975	0.900	0.825	0.745
25	0.874	4/0	6.75	0.318	0.965	0.880	0.800	0.720	0.805	0.760	0.705	0.650
		300,000	7.43	0.357	0.950	0.860	0.765	0.680	0.905	0.845	0.780	0.705
		500,000	8.27	0.357	0.925	0.830	0.730	0.630	1.060	0.975	0.880	0.785

*It has been customary to use 1,200 degrees centigrade per watt per square centimeter for the surface heat resistivity of the sheath. It is believed that 1,100 more nearly represents the condition at average loading, as the surface resistivity decreases with increase of heat flow.[3]

Table III—Ratio of Harmonic Earth-Base-to-Duct Temperature Rise to Steady Load Rise, With Time Lags

S_r = 3.5 deg C per watt per cu ft $\qquad$ $C_d \times \rho_s$ = 20 watts per cu ft

Number of Ducts	Steady State Duct Constant	Inside Radius, Ft	Ratio of Harmonic (1 to 4) Rise to Steady State Rise				Harmonic (1 to 4) Time Lag in Hours			
			1	2	3	4	1	2	3	4
4	0.93	0.33	0.340	0.250	0.220	0.190	2.36	1.26	0.86	0.66
6	0.82	0.46	0.330	0.240	0.210	0.185	2.42	1.29	0.89	0.68
9	0.75	0.59	0.310	0.220	0.190	0.170	2.52	1.32	0.91	0.69
12	0.72	0.65	0.295	0.205	0.175	0.155	2.56	1.34	0.92	0.70

of the cable, and the A.I.E.E. rule for which E in the expression $90-E$ refers to line voltage rather than the voltage to neutral. Consequently a correction factor may be applied to the steady state rating of a shielded cable to make it apply to the belted cable of the same size and voltage rating. This correction factor may be computed from the following formula:

$$\xi = \sqrt{\left(\frac{R_0}{R'_0}\right)\left(\frac{90 - E' - \theta' - A}{90 - E - \theta - A}\right)} \tag{3}$$

where primes refer to belted cable constants. The value of this expression does not vary much with different sizes of cable of the same voltage rating, so an average value may be used. This factor may be applied with reasonable accuracy to the cyclic ratings, neglecting the effect of the greater thermal capacity of the belted cable compared with that of the shielded cable of the same size, and the greater dielectric loss of the shielded cable. These errors are both small and are partly compensating. Average values of this factor accompany the ratings for shielded cables given in table V.

It has been the experience on some power systems that if the temperature of the earth surrounding a duct structure be higher than a certain critical value, the earth will dry out, increasing thereby its resistivity to heat flow, and still further increasing its temperature until finally dangerous temperatures are reached in the cable insulation. Experience in the system of the Edison Electric Illuminating Company of Boston indicates that the average duct temperature should not exceed 50 degrees centigrade in order that this unstable condition may not be encountered. For other localities this limit will be higher or lower depending upon the composition of the soil and average annual rainfall.

It is a comparatively simple matter to compute ratings for cables such that the limiting duct temperature may be 50 degrees centigrade. These ratings are tabulated in table VI. The proper rating to assign a cable under a given duct concentration should be chosen from either table V or VI, whichever gives the lower value. The larger cables are limited more often by maximum duct temperatures than by maximum copper temperatures, especially in summer when the base temperature is high, or where the load factor is high as indicated by the ratings for steady load which generally are limited by duct temperatures.

Ratings for ambient temperatures other than those given in tables V and VI may be obtained by multiplying the summer rating (ambient 20 degrees centigrade) by the factor η, obtained by substituting in the following formula:

$$\eta = \sqrt{\frac{(90 - E)(1 - \gamma) - A}{(90 - E)(1 - \gamma) - 20}} \tag{4}$$

This correction factor obviously will apply to both the steady and cyclic ratings.

Partially Loaded Conduits

Ratings given in tables V and VI were calculated for fully loaded conduits. Very little error will be involved if these ratings are assumed to apply to the number of cables in a conduit disregarding the number of empty ducts. For instance, the 9 duct

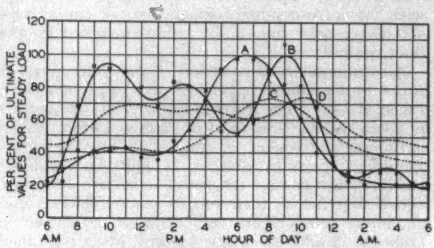


Fig. 1. Load cycles in terms of watts loss, and resultant temperature cycles of 4 400,000-circular mil 25-kv shielded cables in a 4 duct conduit

A—Winter load cycle, equation 1 in text plus dielectric loss

B—Summer load cycle, equation 2 in text plus dielectric loss

C—Temperature cycle of conductors with load cycle of curve *A*

D—Temperature cycle of conductors with load cycle of curve *B*

Plotted points (o, x) indicate actual losses

rating will apply to a 12 duct conduit with 9 fully loaded cables. This neglects the effect of ventilation in the empty ducts and the effect of the larger cross section of conduit for heat flow and storage, all of which will increase slightly the rating of the cable.

It is believed that little ventilation is obtained from empty ducts at the usual manhole spacings of 100 feet or more, the ducts usually being horizontal and not forming convection currents to any appreci-

able extent. If it be desired to take the increased heat flow and storage capacity of the partially loaded conduits into account, the following method may be used, illustrated by 9 cables in a 12 duct conduit. The steady state duct constant of a 12 duct conduit is used. Equation 20 of reference 6 then may be modified as follows to obtain the steady state rating:

$$R_0 = \frac{0.00522SG}{n} + \frac{0.00411K}{D} + NH \qquad (5)$$

where H is the duct constant for the 12 duct conduit. The rating for cyclic loading may be calculated by multiplying by a modified value of ϕ, obtained by adding the cyclic temperature rise from duct to conductor, to $^9/_{12}$ of the cyclic temperature rise from earth to duct for 12 ducts. This method is predicated on the assumption that the loaded cables are on the outside of the conduit. If they be on the inside the ratings for the 9 fully loaded ducts should be used.

Soil Conditions

Ratings for almost any combination of partially loaded conduits, cables, or different soil conditions may be obtained by substituting the proper constants in the fundamental equations given in Appendix II.

Average soil conditions were assumed in the calculations in this paper. For dry sandy soils the thermal resistivity given in table III should be increased by as much as 50 per cent, and for wet clay soils decreased 25 per cent. The thermal capacity will not change much with different soil conditions.

Table IV—Ratio of Maximum Temperature Rise for Copper Loss to Rise for Steady Full Load Copper Loss; Shielded Cables

A—Temperature rise, duct to copper

Size of Conductor, Cir Mils	Rated Kv	Winter Load Cycle		Summer Load Cycle	
		Maximum	Time	Maximum	Time
500,000	14	0.952	7:31 p.m.	0.913	9:51 p.m.
500,000	25	0.932	7:35 p.m.	0.892	9:55 p.m.

B—Temperature rise, earth to duct; all ducts loaded with 400,000 circular mil 25-kv cables

Number of Ducts	Winter Load Cycle		Summer Load Cycle	
	Maximum	Time	Maximum	Time
4	0.597	9:12 p.m.	0.678	10:47 p.m.
6	0.590	9:13 p.m.	0.675	10:48 p.m.
9	0.585	9:14 p.m.	0.672	10:49 p.m.
12	0.575	9:15 p.m.	0.670	10:50 p.m.

C—Total per unit temperature rise, earth to conductor

Load Cycle	Size of Conductor, Cir Mils	Rated Kv	Values of ϕ for 4–12 Ducts				Average Value of γ
			4	6	9	12	
Winter	500,000	14	0.718	0.693	0.669	0.648	0.025
	500,000	25	0.708	0.686	0.659	0.642	0.041
Summer	500,000	14	0.756	0.743	0.727	0.715	0.039
	500,000	25	0.750	0.737	0.722	0.712	0.067

Table V—Steady State and Cyclic Loading Ratings for 500,000 Circular Mil Shielded Cables

Based upon maximum copper temperature of 90—E degrees centigrade

No. of Fully Loaded Ducts	Rated Kv	Summer Rating, Amp			Winter Rating, Amp		
		Steady	Cyclic	ξ*	Steady	Cyclic	ξ*
4	14	331	377	0.908	370	435	0.920
	25	314	360	0.850	357	420	0.873
6	14	303	349	0.913	339	405	0.925
	25	287	331	0.857	327	390	0.880
9	14	270	315	0.920	303	365	0.931
	25	255	297	0.863	291	355	0.886
12	14	245	288	0.924	275	337	0.936
	25	230	270	0.869	262	321	0.892

* Multiply shielded cable rating by ξ to obtain ratings for belted cables.

Table VI—Steady State and Cyclic Load Ratings for 500,000 Circular Mil Shielded and Belted Cables

Based upon average duct temperature of 50 degrees centigrade (ξ = 1.0)

No. of Fully Loaded Ducts	Rated Kv	Summer Rating, Amp		Winter Rating, Amp	
		Steady	Cyclic	Steady	Cyclic
4	14	280	368	355	526
	25	276	360	345	507
6	14	245	322	305	452
	25	240	312	301	442
9	14	210	276	260	386
	25	205	267	257	378
12	14	185	243	230	341
	25	180	234	226	332

Emergency Ratings

If an extremely liberal view be taken of the subject of emergency ratings, cables may be loaded to their normal ratings continuously; and if a transmission line in a group feeding a station be lost, the load may be carried by the remaining line or lines for a short time raising the temperature above the maximum allowable value on the theory that this would not occur often enough to injure the cable. However, if only 2 lines normally feed a station and one of them goes out of service at the time of peak load, this means that the remaining line will be loaded to 4 times its normal copper loss which, even though it occurred for only a short time, would injure the cable. If this liberal view be taken the greatest amount of load that a given cable may be required to carry in an emergency for the required length of time should be subjected to careful study in order that excessive temperatures may not be reached at any time. The excess temperature that a cable may withstand successfully is as yet uncertain, which introduces an added uncertainty to the point at which a cable may be loaded without injury.

The other and extreme conservative view is that a cable never should be allowed to exceed the maximum allowable temperature limit as specified by the A.I.E.E. Standards for cable temperatures, even for a short time. On this basis, if a cable has been loaded to its normal rating for an appreciable length of time

previous to application of any overload, the temperature of the cable necessarily will exceed its maximum allowable value shortly after the overload is applied and an emergency rating has therefore no meaning, being no higher in value than the normal rating.

To apply an emergency rating for any given length of time to a cable on this basis it must have been loaded to a value less than its normal rating for some specified time previous to the application of the overload. In figure 2 the solid and dash-dot lines give the per cent increase in rating for different sizes of cables that may be allowed for 2 hours when the cables previously have been loaded to various percentages of their normal ratings. These curves were obtained by substituting in the following expression, using the intersections of the curves in figure 3 with the ordinate 2.00 hours:

$$\mu = \sqrt{\left(\frac{1}{\beta} - 1\right)\left(\frac{1 - \alpha^2}{1 + \gamma}\right)} \times 100\% \qquad (6)$$

The curves in figure 3 were computed by making use of equation 11 in Appendix II.

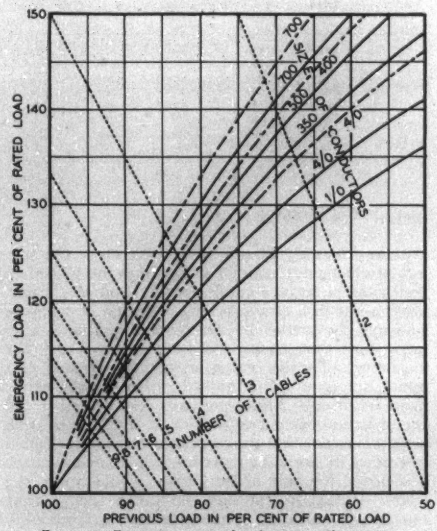


Fig. 2. Emergency overload ratings for various sizes of shielded 3-conductor cables installed in 9 duct conduit

Solid curves for 15 kv cables and dot-dash curves for 25 kv cables give allowable 2-hour emergency loads when cables previously have been loaded to various percentages of their normal ratings. Dotted curves give loads applied when one cable of a group goes out of service. Intersections of dotted curves with solid curves and dot-dash curves give maximum emergency ratings, reading on vertical scale, and maximum normal loads reading on horizontal scale that may be carried in order that emergency ratings will not be exceeded when one cable of a group goes out of service. Sizes of conductors are indicated in B. & S. gauge or thousands of circular mils

Since uncertainties are involved in the calculation of allowable overloads if cyclic loading be assumed, such as time of application of overload during the load cycle, it is believed that the suddenly applied steady load basis is the best way of attacking the

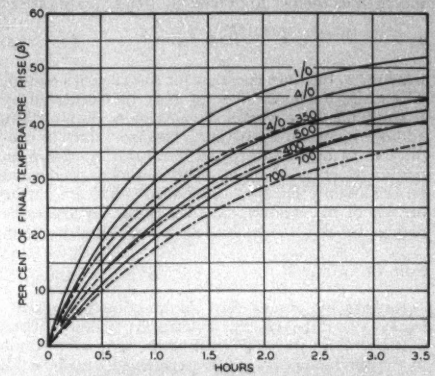


Fig. 3. Temperature rise curves with steady load suddenly applied to shielded 3-conductor cables of various sizes installed in a fully loaded 9 duct conduit

———15 kv cables —·—·— 25 kv cables
Sizes of conductors are indicated in B. & S. gauge or thousands of circular mils

problem. The results at least will approximate the condition where the overload is applied at or shortly after the peak of the load cycle, which will be the condition giving the highest copper temperature.

The load a cable has been carrying previous to the application of an overload determines the amount and duration of this overload. Most transmission systems are provided with spare capacity to take care of outages. Normally, therefore, the cables are operating at a load somewhat less than their ratings, the maximum percentage of full load to which they normally are loaded depending primarily upon the number of cables in the group. Usually a cable may be repaired within 24 hours of the time of breakdown so the load need be carried by the remaining cables through only one daily peak. When an outage occurs on one of the group the remaining cables, therefore, may be loaded to a certain percentage higher than their normal rating for a short time, say 2 or 3 hours.

The dotted lines of figure 2 give the percentages of normal rating that are applied to remaining cables of a group when one is out of service, for different initial loads and original numbers of cables in the group. The intersections of the dotted lines with the other curves in figure 2 give the maximum safe emergency rating that may be applied to the remaining cables in the group, reading on the vertical scale. The maximum percentage of rated load that may be allowed to be carried by the group under normal operating conditions also is given by these intersections,

reading on the horizontal scale. If these percentages of rated load be not exceeded during normal conditions, assuredly the maximum allowable temperature of the cables never will be exceeded with one cable of a group out of service.

There is, of course, some difference of opinion as to whether the liberal or the conservative view should be taken in loading cables in emergencies. Many

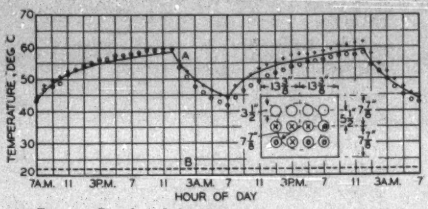


Fig. 4. Results of duct temperature tests on station tie lines

A—Calculated temperature rise
B—Temperature at a distance from duct structure beyond which load cycle had no appreciable effect on temperature cycle
Test points designated + and o taken in different manholes. Insert shows configuration of a 12 duct conduit with inside radius of equivalent cylindrical structure; x = ducts occupied by cables in test; o = ducts occupied by other cables.
(See text for description of test)

believe that the A.I.E.E. temperature limit is conservative enough that it may be exceeded quite materially for a short time without injury to the cable. The author and other engineers of the company with which he is affiliated have taken the conservative view in assigning ratings to cables for foreseen emergencies. In unforeseen emergencies there would be no hesitation to exceed these ratings if it were necessary in order to maintain service.

Temperature Tests

Figure 4 shows the results of a test made in February 1932 on 4 generating station tie lines over which it was possible to maintain a constant load for any length of time desired. The theoretical curve, computed by the same method as was used to compute the curves in figure 3, may be seen to check reasonably well with the test points. Variations of these test points from a smooth curve are caused by other cables in the same duct bank carrying appreciable load only during the evening hours.

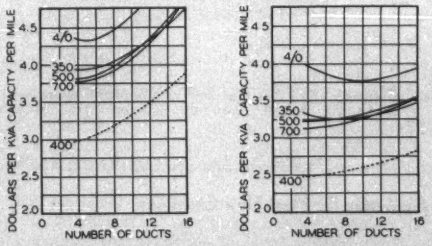
The high average temperature shown by this test was caused by the drying out of soil mentioned in a previous section of this paper, the cables having been loaded continuously at a load equal to the maximum of the test for several months previous. It has been found necessary to reduce the continuous ratings of the cables in these tie lines to a value considerably less than that calculated by the A.I.E.E. copper temperature limit, to prevent overheating during the summer months.

Economical Sizes for Duct Banks

It may be noticed that the ratings of cables decrease quite rapidly as the number of fully loaded ducts increases. This leads to the conclusion that there is an economic limit beyond which the number of fully loaded ducts in a conduit should not be increased. This limit will be determined by 3 factors: the ratings of various sizes of cables in different numbers of fully loaded ducts; cost of conduit and cable; capitalized losses at the various ratings. The charts in figure 5 show cost of transmission per kilovolt-ampere per mile corrected for losses for different numbers of fully loaded ducts and various sizes of cables. These curves are based upon average conduit and cable costs on the Boston system and will vary in different localities. However, large variations in individual costs will not effect the relative values shown by the curves, and hence they will be representative for all systems. These curves do not include the cost of terminal apparatus, which will decrease the slopes of the curves but will not affect appreciably their minimum points. For the average lengths of transmission cable the cost of the terminal apparatus is a small part of the total cost, so the curves of figure 5 will not be greatly affected by it.

It can be seen from figure 5*B* that for transmission cables of the large sizes, the number concentrated in one conduit should be limited to not more than 6 and in some instances 4, using the winter cyclic rating as a basis. The winter load generally is so much higher than the summer load that it may be used as the limiting factor in determining ratings.

For distribution cables at lower voltages with lower costs per circuit foot, a similar calculation will show the lowest cost in 8 to 12 duct conduits. Sometimes congestion may dictate a 16 duct conduit, especially close to substations where end ventilation will compensate for the greater congestion. On long distances, however, it seems that efforts should be made toward keeping the concentration of ducts in any one conduit down to 12 or less, if possible, to obtain the maximum return from the investment.



A—Cost based upon summer cyclic rating

B—Cost based upon winter cyclic rating

Fig. 5. Cost of transmission for various load concentrations, 3-conductor shielded cables, ducts fully loaded

———15 kv cables ----25 kv cables
Sizes of conductors are indicated in B. & S. gauge or thousands of circular mils

Appendix I—List of Symbols

A = ambient temperature
C = specific heat
c = subscript referring to conductor
D = outside diameter of sheath
d = thickness of sheath
E = voltage to neutral
E' = line voltage
e = subscript referring to conduit and earth
G = geometric factor[6]
H = thermal resistance of conduit and earth (duct constant)
i = subscript referring to insulation
j = operator indicating 90 degree phase shift
K = sheath surface resistivity
N = number of loaded cables in conduit
n = number of conductors in cable
Q_0 = copper loss per unit length of conductor
Q_s = vector sheath loss per unit length of cable
Q_2 = vector heat flow at outside surface of sheath per unit length of cable
Q_2' = heat flow at outside surface of sheath at time t after application of a constant load
q = $\sqrt{\omega C\rho S}$
R_0 = total thermal resistivity, conductor to earth base
R_1 = inside radius of equivalent cylindrical duct structure
R_2 = outside radius of equivalent cylindrical duct structure
r_1 = radius of conductor
r_2 = outside radius of insulation
S = heat resistivity
s = subscript referring to sheath
T_0 = temperature of conductor at time t after application of a constant load
T_1 = vector temperature of conductors (same as inside surface of insulation)
T_2 = vector temperature of duct air
t = time in hours
α = ratio of initial load to rated load
β = fraction of final temperature rise at any time t after a constant load is applied to a cable carrying zero load
γ = dielectric loss expressed as a ratio of maximum load copper loss
δ = vector thermal impedance to heat flow[1]
η = factor for ambient temperature
θ = temperature rise of conductor at no load but with voltage applied (temperature of dielectric loss)
λ = ratio of rating for cyclic loading to constant load rating
μ = short time load expressed as a fraction of rated load
ξ = correction factor for belted cables
ρ = specific gravity
σ, τ, ψ = heat flow constants[1]
ϕ = maximum temperature rise expressed as a ratio of constant load rise
ω = angular velocity of heat flow vectors (0.262 for 24 hour period)

Appendix II—Heat Flow Equations

$$\delta = \frac{1}{2\pi} \times \left\{ \frac{1}{\frac{1}{S_i}\left[\frac{\tau}{\sigma} q_i r_1 - \frac{2\pi K}{S_i\sigma^2\{\pi D(1 + j\omega d C_s\rho_s K) - KQ_s\} + 2\pi K\psi q_i r_2}\right] + j\omega C_c\rho_c r_1^2} \right\} \quad \text{(single conductor)} \tag{7A}$$

$$\delta = \frac{1}{2\pi} \times \left\{ \frac{1}{\frac{1}{S_i}\left[\frac{\tau}{\sigma} q_i r_1 - \frac{6\pi K}{S_i\sigma^2\{\pi D(1 + j\omega d C_s\rho_s K) - KQ_s\} + 6\pi K\psi q_i r_2}\right] + j\omega C_c\rho_c r_1^2} \right\} \quad \text{(3 conductor)} \tag{7B}$$

$$T_1 = \delta Q_0 \tag{8}$$

$$Q_2 = \frac{S_i\sigma}{2K}\left\{\left[\frac{2\tau}{S_i\sigma} q_i r_1 + j\omega C_c\rho_c r_1^2\right]\pi\delta - Q_0\right\} \quad \text{(single conductor)} \tag{9A}$$

$$Q_2 = \frac{S_i\sigma}{6K}\left\{\left[\frac{2\tau}{S_i\sigma} q_i r_1 + j\omega C_c\rho_c r_1^2\right]\pi\delta - Q_0\right\} \quad \text{(3 conductor)} \tag{9B}$$

$$\frac{T_2}{Q_2} = \frac{S_e\sigma_e}{2\pi q_e R_1 \tau_e} \tag{10}$$

$$T_0 = \frac{2Q_0}{\pi}\int_0^\infty \delta_r \frac{1}{\omega} \sin \omega t \, d\omega, \text{ where } \delta_r = \text{real part of } \delta \tag{11}$$

$$\frac{Q_2'}{Q_0} = \frac{2}{\pi}\int_0^\infty Q_{2r} \frac{1}{\omega} \sin \omega t \, d\omega, \text{ where } Q_{2r} = \text{real part of } Q_2 \tag{12}$$

$$H = \frac{S_e}{2\pi} \ln \frac{R_2}{R_1} \tag{13}$$

Equation 7 is an explicit function for the thermal impedance of the cable from conductor to air at sheath surface.

Equation 8 gives the temperature of the conductor in terms of the heat flow at the conductor.

Equation 9 is explicit function for the heat flow at the outside surface of the sheath in terms of the copper and sheath losses.

Equation 10 is an expression for the thermal impedance of an equivalent cylindrical duct structure representing the actual duct structure.

Equation 11 gives the temperature rise above ambient at any given time after a constant load is applied to a cable.

Equation 12 gives the heat flow at the surface of the cable sheath at any given time after a constant load is applied to the cable.

Equation 13 is the expression for thermal resistance of an equivalent cylindrical duct structure.

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Power Company Service to Arc Furnaces

Before an electric arc furnace, which is a rapidly fluctuating load during part of its operating cycle, is connected to an electric power distribution system, the electrical characteristics of the furnace must be known in order that the service may be provided in such a way that the resulting voltage fluctuations on the system will not exceed allowable limits. These and related factors are discussed in this paper which outlines a general procedure that may be followed in planning electric service for such loads.

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WHEN a power company considers serving an electric arc furnace, it is confronted with the problem of balancing 2 conflicting but essential interests. The good revenue producing possibilities make the load highly desirable, but to offset this there is always the chance that other customers may be disturbed by voltage fluctuations set up by the furnace. The expected power consumption and high load factor, however, usually warrant any special study and planning that may be necessary to provide service satisfactory to the prospective furnace user and at the same time protect other customers from any disturbing effects of the load on the distribution system. This paper outlines a general procedure that may be followed in planning service for such loads.

There are 4 important considerations which will be discussed in the following order:

1. A full and accurate knowledge of the electrical characteristics of the load is of prime importance.
2. Allowable limits of voltage fluctuation or "flicker" on the distribution system must be established.
3. Methods of furnace operation that either reduce the magnitude of current fluctuations or affect the time of occurrence may be considered.
4. Selection of the most economical method of serving a known fluctuating load without exceeding established flicker limits is the final objective.

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Electrical Characteristics of Arc Furnaces

It is highly essential that the operating characteristics of a prospective furnace be defined accurately. In the past, lack of definite knowledge of just how disturbing a prospective load might prove to other customers sometimes has caused power companies to be somewhat hesitant about providing service without either imposing prohibitive regulations or spending more than a reasonable amount to "play safe."

By systematic testing and study of existing installations, it has been possible to accumulate operating data on furnaces of various types and sizes which can be referred to whenever new jobs are proposed. Different installations of the same sized furnace may have slightly dissimilar electrical characteristics because of variations in the secondary bus layout or perhaps different voltage or reactance taps; but, in general, estimates for new jobs based upon similar existing installations prove to be reasonably accurate. The electrical characteristics, which must be known before intelligent service planning can be attempted, include the average load and power factor, the current fluctuations during different parts of the heating cycle, and the so-called starting currents.

There are 2 general types of arc furnaces: the single-phase indirect-arc type in which the arc plays between 2 electrodes and does not come into direct contact with the metal of the charge; and the 3-phase direct-arc type in which the arc plays from the 3 phase electrodes to the metal charge.

Single phase furnaces range in size from small laboratory models to a maximum size requiring transformer capacity of about 900 kva. Any of these single phase furnaces on regular production schedules operates at an average power factor ranging from 0.7 to 0.8, depending to some extent upon the arrangement and length of secondary bus between the transformer and the furnace. Oscillograph records show that the power factor at any given instant may be as low as 0.3 or as high as 0.9, but that the average power factor as determined by watt-hour and reactive kilovolt-ampere-hour meters generally will fall in the range between 0.7 and 0.8.

The 3 phase furnaces encountered on the system of The Detroit Edison Company range in size from about 200 kva to a maximum of 10,000 kva. The larger 3 phase furnaces operate at power factors ranging between 0.8 and 0.9, which are slightly higher than those of the smaller furnaces. One 10,000 kva furnace has had an average power factor of 0.86, a 2,100 kva furnace 0.84, and a 750 kva furnace 0.82.

The electrical load of a furnace can be regulated by the settings of the electrodes, but the stability of the arc and corresponding stability of load are dependent to a large extent upon the reactance in the circuit, the character of the furnace charge, and the temperature within the shell. During the preheating period of a cold furnace the arc is unsteady with resultant current fluctuations, but once the furnace becomes heated the arc is relatively stable and the current fluctuations are of a minor nature. Even when a furnace is operated only 8 hours per day,

the period of unstable arc operation is relatively small compared with the period of stable operation when the load is under direct control of the operator or under automatic electrode control. The upper limit of average load for any appreciable period is imposed by transformer heating and therefore under normal operating conditions does not exceed the rating of the transformer.

The largest current swing usually occurs when the arc is started, especially in the smaller furnaces. At times the arc may be started without causing a current surge of any appreciable magnitude, but usually there is an accompanying maximum current swing just as the arc is struck.

In general, the single phase and 3 phase furnaces have somewhat the same characteristics; however, the current fluctuations of the larger 3 phase furnaces do not represent as large a proportion of the normal full load current as is true for the smaller furnaces. For instance, both types of furnaces up to a size of about 2,000 kva may have a starting current of 2 to 3 times the rating of the furnace transformer; from 2,000 up to 10,000 kva the proportion decreases, and for the 10,000 kva furnace the starting current fluctuation in any single step does not exceed approximately full load at about 0.6 power factor. It is true that current drawn by a 10,000 kva furnace sometimes exceeds its normal full load value and occasionally may approach 3 times normal, but it does not reach such a value in a single swing or fluctuation. Overcurrent line relays set to pick up and start timing out at 3 times full load current give satisfactory protection and usually do not operate except in the event of actual trouble.

Table I—Current Fluctuations in Single Phase Furnaces

Furnace Rating			
Nominal Rating, Kw	Approximate Rating of Transformer, Kva	Metal Capacity With Average Scrap Iron	Maximum Swing, Kva
125	190	350 pounds	400 at 0.4 power factor
400	525	1/2 ton	1,000 at 0.4 power factor
600	875	1 1/2 tons	1,600 at 0.4 power factor

Experience does not indicate any particular advantage from the standpoint of voltage fluctuations of the small 3 phase furnace over the single phase furnaces in the sizes so far encountered on the Detroit Edison system. While a *continuous* single phase load of a given value will cause twice the voltage regulation of a *continuous balanced* 3 phase load of the

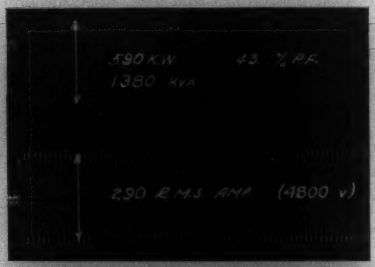

Fig. 1 (left). Star of operating cycle

Fig. 2 (right). Preheating period

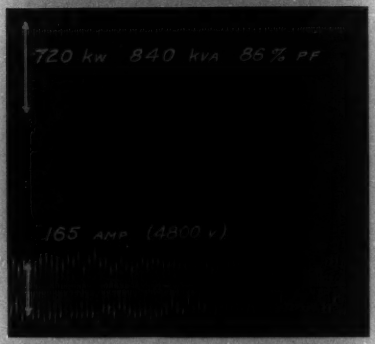

Fig. 3 (left). Melting down of cold charge

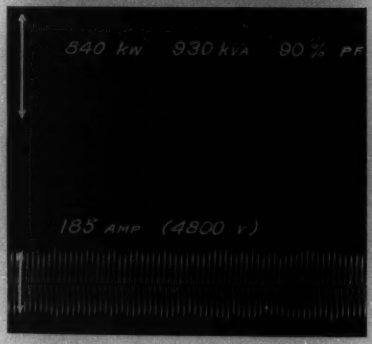

Fig. 4 (right). Normal operation with molten charge

Figs. 1 to 4. Line current and power input to a 600-kw 1 1/2-ton single-phase arc furnace for producing high grade cast iron

Upper traces show power input and power factor of load. Lower traces show line current in the 4,800 volt circuit supplying furnace transformer

Fig. 5. Start of operating cycle

Fig. 6. Early part of melt with electrodes boring down through charge

Figs. 5 to 7. Line current and voltage and power input to a 10,000-kva 45-ton 3-phase arc furnace for producing high grade steel

A—Single phase power, current in phase *Y* and voltage across phase *YZ*
B—Voltage across phase *YZ*
C, D, and *E*—Line currents in phases *Z, Y,* and *X,* respectively

Fig. 7. Normal operation after pool of molten metal has been established at bottom of furnace

same value, this simple relationship does not apply to electric furnaces as built and used. In the 3 phase furnace, each phase arcs independently to the charge and, especially during the preheating periods, the phases act as 3 separate highly variable unbalanced single phase loads. It must be assumed that the so-called starting current may exist as a single phase current at any instant the same as in a single phase furnace.

Tables I and II show the maximum current swings that can be expected on several typical single phase and 3 phase furnaces. These values are the starting currents and are of a rapidly recurring nature only during the first 15 or 20 minutes of the preheating period.

Figures 1 to 4 show oscillograms of line current and power input to a 600-kw $1^1/_2$-ton single-phase furnace used for producing high grade cast iron in a jobbing foundry, for various periods during its operating cycle. It is interesting to note the progressive improvement in current stability from the highly erratic arc performance during preheating, through a much more stable period while melting down a cold charge of scrap, and finally to a period of comparatively smooth performance after the charge becomes molten.

Table II—Current Fluctuations in 3 Phase Furnaces

Furnace Rating		Maximum Swing, Kva	
Rating of Transformer, Kva	Metal Capacity With Average Scrap Steel, Tons	3 Phase	Single Phase
750	1	2,000	1,200 at 0.4 power factor
2,500	3	4,500	2,500 at 0.45 power factor
5,000	8	7,500	4,500 at 0.5 power factor
10,000	45	11,500	6,500 at 0.6 power factor

Figures 5 to 7 show oscillograms of line current and voltage and power input to a 10,000-kva 45-ton 3-phase furnace used for producing high grade electric steel, for various periods during its operating cycle. Figure 5 shows how the load at times is entirely a single phase one, especially at the start of a heat. The smooth performance indicated in figure 7 is typical of the major part of the cycle of operation.

Effect on Distribution System

Fluctuations in current drawn by an arc furnace through the impedance of that part of the power company's system which is ahead of the point of service, cause voltage variations or "flickers" which may

prove objectionable and disturbing on lighting circuits. After establishing the maximum value of current fluctuations that may be set up by the furnace under consideration, it is a relatively simple matter to calculate the voltage flickers that will result at different points on the distribution system.

The amount of fluctuation that can be allowed depends to a large extent on its frequency of occurrence. Tests show that flickers, or voltage changes caused by instantaneous changes in current, begin to be noticeable, under ordinary reading conditions with 40 and 60 watt lamps, at about 2 volts on 115 volt circuits. Therefore, this must be the maximum allowable on lighting circuits for rapidly recurring flickers; but for less and less frequent flickers the limit can be raised on the basis that, although the more pronounced flicker possibly may be noticed, it is not objectionable because of its infrequent occurrence.

Based upon this reasoning, tentative flicker limits, covering both magnitude and frequency of occurrence, have been adopted for use on the distribution system of The Detroit Edison Company. From a study of these limits, shown in table III, it may be noted that the magnitude of flicker allowable depends not only upon how often the flicker occurs, but also upon the class of customers affected. "Power line" customers buy essentially power, and consequently a greater flicker is tolerated than on distribution circuits where the predominating load is lighting.

Table III—Voltage Flicker Limits for Distribution System of The Detroit Edison Company

Location	Volts on 115 Volt Base		
	Infrequent*	Frequent†	Extremely Frequent††
A. On a substation bus feeding only power lines	6	4	3
B. On a power line primary circuit the entire output of which is not taken by one customer and read at the customer's premises	8	6	4
C. On a power line the entire output of which is taken by one customer and read at the customer's premises	No limit		
D. On a substation bus feeding distribution circuits (lighting) and on distribution circuit primary circuits	6	3	2

* Infrequent flicker shall include fluctuations occurring 6 times or less in 24 hours, but not more than once between 6:00 p.m. and midnight. This provision is intended to cover apparatus, such as motor generators, fans, pumps, etc., which normally runs continuously throughout the working day.

† Frequent flicker shall include fluctuations occurring not oftener than 3 times per hour, except that between 6:00 p.m. and midnight they shall not occur more than once per hour. This provision is intended to cover apparatus such as machine tools, electric furnaces, etc., which is started and stopped periodically throughout the working day.

†† Extremely frequent flicker shall include all fluctuations occurring more frequently than the above. This provision is intended to cover such apparatus as flashing signs, welders, gravel pit hoists, and certain electric furnaces, which are stopped and started frequently and repeatedly or rapidly loaded and unloaded during normal use.

Applying these flicker limits to the specific problem of furnace operation, it is reasonable to allow a 2 volt limit for lighting customers affected during the preheating period of the furnace when the flickers are of a rapidly recurring nature. For less frequent fluctuations, as caused by starting the furnace during normal operation, a more liberal limit in the order of 3 to 6 volts is generally permissible. Local conditions and experiences of the local power company are a big factor in the determination of allowable flicker.

Solving the Problem of Voltage Flicker

The logical procedure to follow in determining just how a given furnace shall be served with electric power is to select the simplest method of service and calculate the amount of disturbance to other customers. If the flicker be excessive, the furnace supply must be tapped onto the distribution system nearer the source, that is, where the impedance is lower and the flicker correspondingly less. Using this method a point finally is reached where the flicker is within allowable limits. The cost of providing service then can be estimated, and by balancing this cost against the expected revenue a decision can be made as to whether or not it is commercially and economically feasible to provide the service.

To be balanced against system changes, there are possible changes in the furnace installation itself that may be made to limit the current fluctuations. For single phase furnaces, this has been accomplished by utilizing reactor starting; although The Detroit Edison Company has had no experience with similar reactor starting for small 3 phase furnaces, it is logical to expect that like results can be accomplished. Large 3 phase furnaces generally have

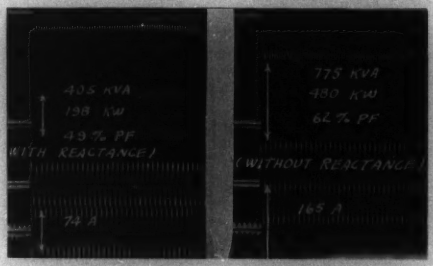

Fig. 8. Start of 300-kw single-phase arc furnace with and without starting reactance in primary circuit

Lower traces show line current in 4,800 volt circuit supplying furnace transformer. Second trace from top shows the power input and power factor of load

such inherently high impedance in the secondary bus and electrodes that any further temporary addition of reactance for starting is of doubtful value. However, similar results are accomplished by operating at reduced voltages during the start of a melting down period as the electrodes bore down through the charge. When a molten pool has been established at the bottom of the furnace and the electrodes are no longer in direct contact with the steel, the operating voltage is raised about 25 per cent higher for faster melting.

The usual single phase furnace transformer is equipped with a combination of taps to provide reactance ranging from 10 to 40 per cent. By adding another block of 40 or 50 per cent reactance and an additional primary bushing, a starting reactor is provided which, with the necessary short-circuiting breaker and relays, adds from 10 to 15 per cent to the installation cost. By having this reactance in the circuit whenever the arc is struck, the current surge is reduced to the following values:

Nominal Rating of Furnace, Kw	Maximum Swings, Kva	
	Without Reactor Starting	With Reactor Starting
400	1,000	550
600	1,500	900

By using reactor starting it is sometimes possible economically to serve a furnace for which otherwise the cost of service would be prohibitive, thereby

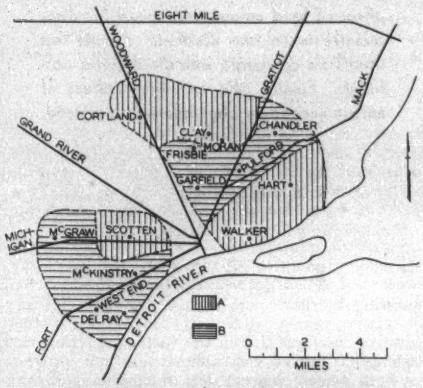

Fig. 9. Map of industrial area of Detroit, showing substations capable of serving highly fluctuating loads

A—Areas in which fluctuating loads are served from special busses

B—Areas in which special busses can be established

obviating the necessity for using a smaller furnace. By leaving the reactor in the circuit during the preheating period of the furnace cycle, the worst of the fluctuations can be reduced to permissible values. Tests show that the heating time remains about the same with or without the reactor in the circuit. Figure 8 shows oscillograms of starts of a 300 kw furnace equipped with a starting reactor which reduces the current surge to about 50 per cent of the value obtained on a start with the reactor short-circuited.

As the current fluctuations during the preheating period usually cause the most serious disturbance, an alternative operating procedure is the simple expedient of governing the furnace operating schedule in such a way that the furnace always is preheated during a period of the day when there are few lighting customers to be affected, such as between midnight and 6 o'clock in the morning. During the daylight hours, flicker will be confined to the occasional starting of the arc; and since the lighting load is small during the daylight hours, this might not prove objectionable. On such a basis the last heat would have to be started before the late afternoon lighting load comes on.

If a schedule such as the foregoing one is not practicable and service must be available at any time, then the supply must be taken from the power

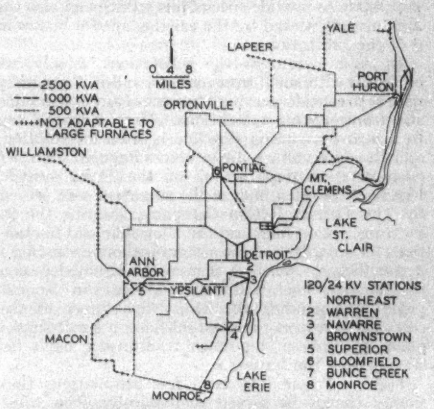

Fig. 10. Map of 24 kv transmission lines in suburban territory of The Detroit Edison Company showing maximum single phase load swings allowable without exceeding a 2 volt flicker limit on the distribution circuit

system at a point far enough back toward the substation or generating source so that the resulting flicker at that point is not objectionable. For instance, a given circuit feeding both power and lighting customers might be of such length and impedance as to be unsatisfactory for serving a prospective furnace load at the end of the line. In this event, it would be necessary to build a separate line for the furnace back to a point on the existing line where the impedance is small enough not to cause an objectionable flicker. Sometimes it will be necessary to carry the furnace service all the way back to a substation, that is, to provide a separate line for the furnace. If the voltage disturbance on the substation bus be in excess of accepted standards, a separate transformer and bus section must be set aside to serve the furnace.

In an industrial center of any magnitude there is often sufficient furnace and welder load to make it economical to set aside one or more bus sections per

substation for these so-called "bad" loads. By grouping such loads and keeping all lighting and "good" power loads off this bus, the need for keeping the voltage fluctuations within standard limits often can be avoided, and there still will be a reasonable load for the bus section set aside.

There has been sufficient fluctuating load, including both furnaces and welders, in the central industrial area of Detroit to warrant setting aside special busses in 6 out of 14 substations serving this area. The total peak load on these special busses amounts to more than 30,000 kva, including about 2,000 kva of railway motor generator sets. The railway equipment not only helps to load the bus sections, but also aids in smoothing out the voltage flickers. Figure 9 shows the industrial load area in which it is possible to provide special bus service and also the area already served by the existing special busses in 6 of the substations.

In suburban areas the substations usually are equipped with small transformers, and it is generally useless to consider serving a furnace of any appreciable size from existing substations. Here, a simple tap to a near-by transmission line is often the solution, and the only voltage disturbances imposed on other customers are those set up on the 24 kv system. Figure 10 shows a map of the suburban area served by The Detroit Edison Company, showing the 24 kv transmission lines and the allowable load fluctuations for any point on the system without exceeding a 2 volt flicker. Where a customer is situated near a transmission line, reasonable service can be provided by extending the 24 kv line direct to the customer's property and establishing a small single-phase or 3-phase step-down transformer bank for serving only the furnace.

There are bound to be a few installations that simply cannot be served economically even when using reactor starting or when operating on a restricted schedule; for these few exceptional cases, the only remaining solution is service through a motor-generator provided by the customer. The motor-generator need not be an expensive flywheel set, such as is used in steel mill service, but can be an ordinary induction or synchronous set. A synchronous set has additional value to the customer in improving the power factor of the plant, and sometimes the investment can be justified partially on that basis. It is true that a flywheel set or even an induction set without a flywheel is more effective than the synchronous set in shielding the distribution system from current surges, but usually the benefit from the synchronous set is found to be sufficient. The current surges at the furnace are at low power factor and do not represent enough variation in energy to justify a flywheel.

In conclusion, there are 2 points that should be stressed: First, electric furnaces are large power users and therefore the power company can well afford to spend some money to take them on; and second, once the electrical characteristics and operating schedules are accurately defined and well understood, excessive margins of safety can be eliminated, thereby keeping the cost of providing adequate service at a minimum.

Flashing of Railway Motors Caused by Brush Jumping

Theories and concepts developed in connection with circuit rupturing by switches and circuit breakers are used to analyze the factors involved in the flashing of railway motors. The investigation is limited to cases where flashing is caused by brush jumping, which occurs principally with railway motors. Voltage conditions as applying at the commutator circumference and as affecting the sustenance of an arc are studied for varying designs of main poles with different ratios of armature ampere turns to field ampere turns. The effect of load current and speed is subsequently taken into account. Actual test results are compared with the theories outlined. Finally, the modifying effect of certain secondary phenomena is discussed.

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FLASHING at the brushes of commutating machines has been a common difficulty for many years, particularly in railway motors. However, an analysis of the factors entering into flashing has proved very difficult and little progress has been made. A great deal of experimental work has been carried on, but usually nothing but a very rough qualitative interpretation of the results obtained was possible on account of the great many variables entering into the problem. In the absence of analytical methods, designers have used certain empirical rules relating to such matters, as, for instance, the ratio of armature ampere turns to field ampere turns, but naturally the results obtained with such rules have been irregular and unreliable in practice. With the extensive studies made during recent years in connection with arc rupturing of switches and circuit breakers and certain concepts that have been established through these studies, the possibility of analyzing flashing characteristics of commutating machinery successfully has been improved; an attempt will be made in this paper

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The author acknowledges the assistance of R. L. Hellmund in the preparation of this paper.

to indicate a method of attacking this problem. In order to make progress in clarifying this rather involved problem, certain simplified assumptions will first be made and subsequently other factors will be taken into account. Furthermore, the present study will be limited to certain kinds of flashing and certain types of motors.

Referring particularly to railway motors, it is known that there are 2 major causes of flashing. One of these is the interruption of the power supply caused by trolley bouncing, third-rail gaps, etc., and subsequent sudden re-establishment of the power supply. A second cause is the jumping of brushes. While it is difficult to state which of the 2 major causes mentioned is encountered most in practice, it is believed that the jumping of brushes has frequently been the reason for flashing troubles; at any rate, there is much evidence that it has been a rather common cause of flashing in railway work. This statement is supported by the fact that in a great many cases where flashing occurred, increasing the brush pressure has yielded marked improvement, either by preventing the brush from leaving the commutator or by reducing the time interval during which the brush is not in contact with the commutator. Flashing caused by brush jumping therefore will be made the subject of the present analysis.

Causes of Brush Jumping and Flashover

There seems to be some doubt as to the cause of brush jumping, but it is quite possible that the mechanical vibrations of the motor are responsible in some instances. In other cases roughness of the commutator may be the principal cause of brush jumping. While variations in mechanical conditions may affect the nature and the duration of the brush jumping and consequently the results obtained, the electrical theories subsequently given will apply regardless of what the cause of the brush jumping may be.

Reference may be made to figure 1. Figure 1*A* shows the brush at the instant it has left the commutator, and the arc *S* which has formed between the brush and the commutator segment *a*. Experimental investigations have indicated that there is little tendency for this arc to cause flashing if the brush is negative. On the other hand, the very worst flashing conditions are obtained when a positive brush is lifted and the direction of rotation is such that segment *a* approaches directly the other brushholder of a 4 pole motor having only 2 brushholders. This is to be expected, because with a positive brush a hot-cathode spot forms on the segment *a* and therefore the arc terminal tends to remain at the hot-cathode spot of segment *a* while it moves along as indicated in figure 1*B*. Figure 1*C* shows the condition just after the brush has returned to the commutator. The arc *S*, however, may still continue to exist if the voltage between the brush b_1 and segment *a* is of sufficient magnitude to sustain it with the condition of ionization prevailing at the time. It therefore seems expedient to consider more in detail both the ionization condition and the voltage conditions as they may exist at the time when the brush recontacts the commutator and during the time following.

Ionization Affected by Armature Current

The arc and the amount of ionization present in it, when the brush leaves the commutator, are primarily governed by the armature current flowing at the time. This current, previous to the formation of the arc, depends upon the load, the speed, and the control position. Equilibrium in the motor circuit for such given condition exists if the impressed electromotive force minus the counter-electromotive force equals the ohmic drop. When the brush lifts, the circuit resistance is increased by that of the arc, and since the arc resistance may be an appreciable percentage of the previously existing ohmic resistance, there is a tendency for the current to decrease. With decreasing current, the flux of a series motor tends to decrease. This tendency of the flux to decrease with the current is counteracted by the damping effects in the motor frame, which prevent any sudden and appreciable field changes. Nevertheless, certain portions of the main flux do not go through the solid frame and therefore a certain decrease in flux will take place with decreasing current. As soon as the flux decreases, however, the counter-electromotive force decreases as well, which, in turn, increases the voltage available for the ohmic drop. Therefore, a new condition of equilibrium will be established with a current but slightly decreased. Even this somewhat smaller current may not be reached in the short time intervals under consideration, because any decrease in current will be temporarily opposed by the self-inductance of the armature and field coils, as well as by any other inductance in the system, as may be present with third rail installations and the like. Especially with heavy currents flowing, it is therefore not to be expected that during the very short interval which the brush is away from the commutator any appreciable decrease in current will take place, which also means that no appreciable decrease in ionization will occur before the brush returns to the commutator. With smaller currents, causing less ionization in the first place, a decrease of the current and the consequent deionization of the arc during the time the brush is raised, may be of practical importance. If this deionization is sufficient to cause an interruption of the current before the brush returns to the commuta-

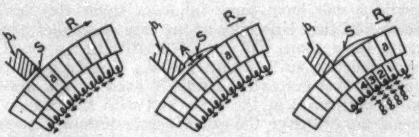


Fig. 1. Formation of arc on d-c machines during and after jumping of brushes

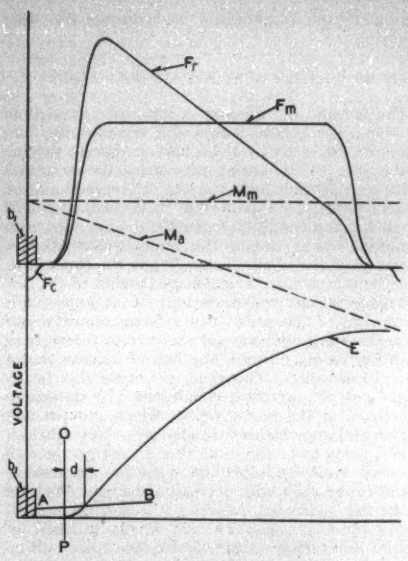


Fig. 2 (left). D-c machine with narrow poles and low armature ampere turns

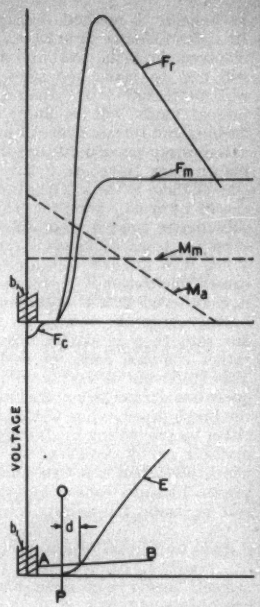


Fig. 3 (right). D-c machine with narrow poles and high armature ampere turns

Upper curves—Field form

Lower curves—Voltage between brush and various points on commutator

tor, there is no longer any problem in connection with flashing, and therefore no need to consider such cases further.

Although the phenomena described as applying during the time that the brush is away from the commutator will have some influence upon the flash characteristics, especially in the case of smaller currents, the designer has very little latitude in appreciably affecting such conditions. As already pointed out, the load current is definitely fixed by the work to be performed at the time, and with the conventional motor design the other factors discussed, such as self-inductance, resistance of the circuit, and the damping effect of the frame, cannot be altered economically over wide ranges for a given rating. However, these factors vary appreciably with the rating of the motor. The inductance and resistance, for instance, decrease as a rule with the rating of the motor, so that a motor with a large rating may have less tendency to sustain certain small currents while the brush is away from the commutator than a motor of a lower rating would have with the same current (in amperes).

Effect of Induced Voltage

If conditions are such that the arc going from the brush to the hot-cathode spot of segment a is still in existence when the brush returns to the commutator, with a definite ionization present the subsequent behavior of this arc will be governed largely by the voltage induced at that time and during subsequent periods between the brush and segment a. In order to study these voltage conditions, a field form F_m, without armature reaction, a commutating field form F_c and a resultant field form F_r have been shown in figure 2A with the field and armature magnetomotive forces indicated by the lines M_m and M_a, respectively. The voltage between any point on the circumference of the commutator and the edge of the brush b_1 can be determined by graphical integration of the resultant field F_r up to such a point. Thus the voltage curve E in figure 2B has been obtained. It may be assumed that, at the time the hot-cathode spot has reached the line OP, the brush has returned to the commutator. It is known that the voltage necessary to sustain an arc is from 25 to 80 volts, depending upon the current in the arc and its length. The line AB has been drawn to indicate the voltage necessary to sustain the arc for different positions of the segment with the hot-cathode spot. This line shows a slight increase with the length of the arc. It will be seen that over the distance d the induced voltage available to sustain the arc is lower than the line AB, which means that a certain amount of deionization of the arc takes place while the cathode spot travels over this distance d. If for the present a definite speed is assumed, the distance d also represents the time elapsed. If the distance and time indicated by d is sufficient for bringing about complete deionization, there will of course be no flashing. However, even though deionization occurs very rapidly, it nevertheless requires a finite time, and moreover there are other factors such as the self-induction of the armature coils, 1, 2, 3, and 4, which

tend to maintain the arc, as will be discussed more in detail later on. If as a consequence of this the deionization is only partly accomplished the arc may be fully re-established after the time d when the voltage again increases appreciably. The chances that this will occur and bring about motor flashing depend essentially upon the ionization remaining at the end of the time d and the subsequent rate of increase in the voltage, as indicated by the steepness of the voltage curve E.

Effect of Ratio of Ampere Turns

In order to study the influence of the ratio of armature ampere turns to field ampere turns upon these conditions, figure 3 has been worked out by using the same main field F_m but doubling the armature ampere turns M_a. Figure 3B shows the resultant voltage curve E. It will be seen that the distance and time d are decreased to about 80 per cent of the value shown in figure 2B and that the rate of rise of the voltage is also greater. Nevertheless, it is quite conceivable that with the assumptions made, the time d is still sufficient for complete deionization and if such is the case the greater rate of rise of voltage is of no practical importance; in other words, it is quite conceivable that under the conditions assumed, a very appreciable increase in the ratio of ampere turns will have no effect of practical importance upon the flashing characteristics.

An entirely different effect may be obtained, however, in a case as shown in figures 4 and 5. In this case a wider pole arc has been assumed, which results in an appreciably reduced distance and time d as shown in figure 4B, with the smaller ratio of armature ampere turns to field ampere turns. Nevertheless, it is conceivable that the deionization obtained during the time d and the subsequent small rate of rise of voltage may be insufficient to sustain the arc. However, if in a case like this the ratio of armature ampere turns to field ampere turns is materially increased, as shown in figure 5, conditions change materially. It will be noted in figure 5B that the time d available for deionization is zero because, at the time the brush returns to the commutator, the voltage available for the arc is equal to that necessary to sustain it and, furthermore, from then on there is a high rate of rise in the voltage. Flashing is almost certain to occur, with the assumptions made.

Figures 6 and 7 assume conditions somewhat similar to those in figures 2 and 3 except that the rise in the field curve starts nearer to the brush and is more gradual, as might be obtained with changed pole tips or by skewing the slots with poles similar to those in figures 2 and 3. Inspection of these figures indicates that conditions are less favorable than with figures 2 and 3. The deionizing time has been reduced to 80 per cent with the small ratio of ampere turns (compare figures 2 and 6), and to 66 per cent with the large ratio of ampere turns (compare figures 3 and 7).

Figures 8 and 9 show conditions that may be obtained with a pole having a tapered air gap. Here the conditions are more favorable than in figures 2 and 3. The deionizing time has been increased to 155 per cent with the small ratio of ampere turns

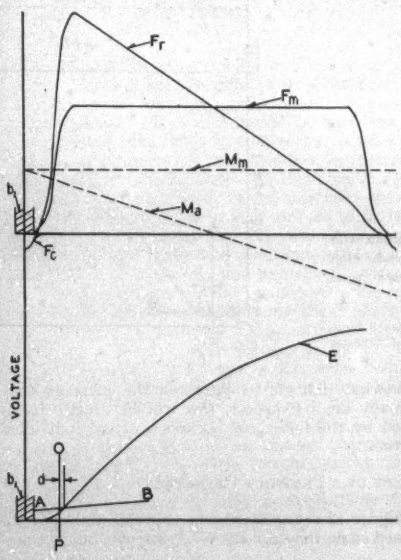


Fig. 4 (left). D-c machine with wide poles and low armature ampere turns

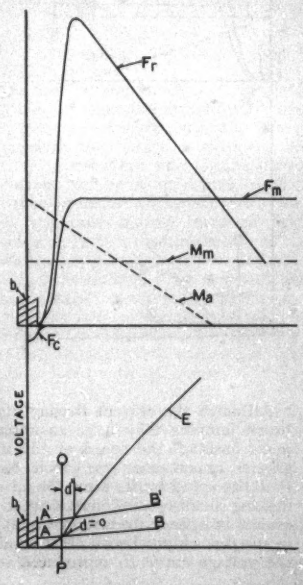


Fig. 5 (right). D-c machine with wide poles and high armature ampere turns

Upper curves—Field form

Lower curves—Voltage between brush and various points on commutator

(compare figures 2 and 8), and to 125 per cent with the large ratio of ampere turns (compare figures 3 and 9). As a matter of fact, the deionizing time with the large ratio of ampere turns of figure 9 is the same as that with the smaller ratio used for figure 2. The rate of rise in voltage also has been reduced with figures 8 and 9 as compared with figures 2 and 3, respectively.

Effect of Current and Speed

Comparisons so far have been made under the assumption of a definite current and a corresponding voltage line AB; it has also been assumed that the speed is the same in all cases. If the same study were made for a smaller current but still with the same speed, it would be necessary to simply enter a line $A'B'$, as indicated in figure 5B. This line is higher in accordance with the well-known arc characteristics indicated in figure 10. It will be noted that with the smaller current and everything else being assumed the same, there is a deionizing time d' so that flashing might be avoided, while with the larger current and a corresponding line AB it would most likely occur, because the deionizing time d is zero.

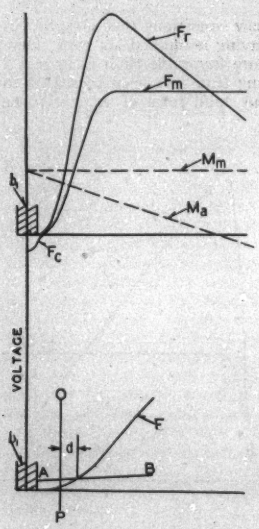
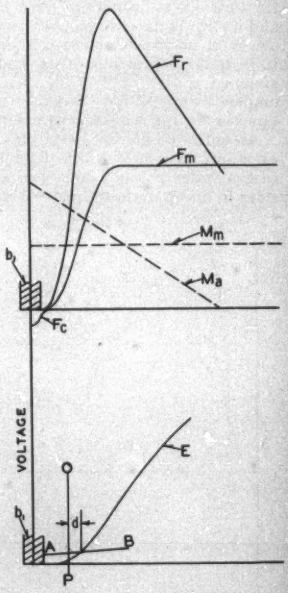


Fig. 6 (left). D-c machine with narrow skewed poles and low armature ampere turns

Fig. 7 (right). D-c machine with narrow skewed poles and high armature ampere turns

Upper curves—Field form

Lower curves—Voltage between brush and various points on commutator



Although the current flowing at the time of the brush jumping may have an appreciable influence upon flashing, the speed of the motor is of even greater importance. So far it has been assumed that the speed is the same for all cases considered, making the distance d equivalent to the time. However, if in figure 7 for instance, a 50 per cent increase in speed is assumed with other conditions unaltered, the voltage curve E, reproduced in figure 11 on a larger scale from figure 7, changes to curve E' for the higher speed if time is used as a basis. In this case it is further assumed that the time during which the brush is off the commutator has not been changed. This, in turn, means that the hot-cathode spot has traveled 50 per cent farther, when the brush returns to the commutator and has reached a position for which the voltage between the spot and the brush is e. It will be seen that while there is a chance of avoiding flashing with the voltage curve E and the deionization time d, such chance is practically zero with the 50 per cent increase in speed, as indicated by the fact that the voltage curve E' is equal to the values needed for sustaining the arc at the time the brush returns to the commutator, and the fact that the subsequent rate of rise in voltage is increased.

In actual practice, especially over the operating range of a series motor, all of the conditions previously discussed, such as load current, speed, and the effect of the armature ampere turns upon the resultant field form undergo certain changes which, as indicated in the beginning of the paper, make it somewhat difficult to interpret the facts as they actually are. However, this will be greatly facilitated by the foregoing discussion of the individual factors.

Study of a Previous Experiment

Figure 12 reproduces some experimental data obtained some time ago by W. A. Brecht, but not pre-

viously published, on a small railway motor, by means of a mechanical arrangement permitting adjustment of the time during which the brush is off the commutator. The curves were obtained by gradually increasing the time for any load condition and recording the time at which flashover occurred.

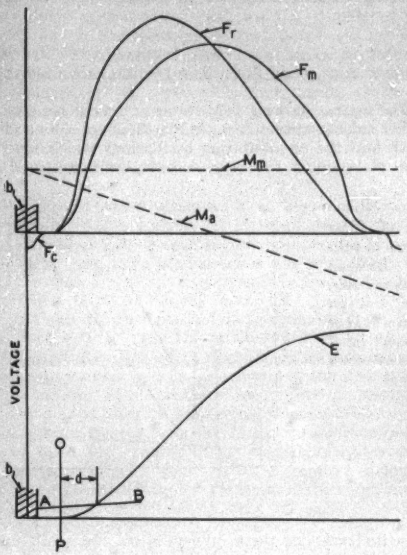


Fig. 8 (left). D-c machine with poles having tapered gap, and low armature ampere turns

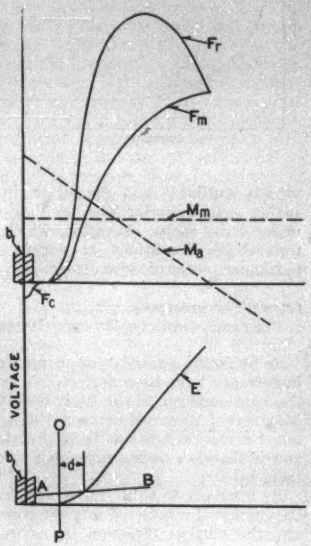


Fig. 9 (right). D-c machine with poles having tapered gap, and high armature ampere turns

Upper curves—Field form

Lower curves—Voltage between brush and various points on commutator

Curve A applies to a motor operated as a series motor; curve B, to operation with a constant field excitation of 60 amperes; and curve C to operation with constant field excitation of 30 amperes. It will be noted that curve B, with a constant field excitation of 60 amperes, is rather flat for the range over which tests were made. In this case, increased armature current results in an increased ratio of armature ampere turns to field ampere turns which in turn tends to crowd the flux into the interpolar zone and to thus make field conditions less favorable. This effect is, however, not appreciable with this particular motor on account of the saturation of the pole tips. Whatever unfavorable effect along this line existed was probably compensated for by the favorable effect of a slight decrease in speed. With such conditions, the flatness of the curve seems to indicate that, starting with a certain value, increasing the current above such value does not affect the arc conditions materially, which is quite in accordance with the tendency of normal arc characteristic curves to flatten out above certain current values, such as shown in figure 10.

Curve C, as will be seen, is appreciably below curve B, the major part of this difference undoubtedly being due to the very much higher speed obtained with the 30 ampere field excitation. In addition to this, however, conditions are unfavorably affected because the field distortion caused by the heavy armature currents crowds the field into the interpolar zone and thus makes field conditions less favorable. It will also be noted that curve C has a drooping characteristic even for the higher currents, which is probably due to the fact that the armature ampere turns can have greater influence with the lower saturation obtained in the pole tips with the 30 ampere field. The rather steep part of the curve for the lower current values is, of course, caused even more by the decreased distortion with decreased ratio of armature ampere turns to field ampere turns, since there is no saturation at all in the pole tips with the lower load currents. In addition, it is likely that the reduced ionization and the consequent higher voltage necessary for maintaining the arc is partly responsible for the steepness of the lower branch of curve C. The effect of speed is, of course, of somewhat secondary importance with the reasonably constant speed with the constant excitation of the fields.

Coming now to curve A applying to the series operated motor, it is evident that with 60 ampere loads, meaning in this case also 60 ampere excitation, this curve should closely approach curve B; similarly curve A should closely approach curve C at the 30 ampere load, which will be noted to be the case. Below 30 amperes curve A should be expected to be, and it is, somewhat less favorable than curve C on account of the greater field distortion, as well as

on account of the higher speed obtaining with series motor operation over this range. It will be seen that, considering the nature of these tests and certain limitations in their accuracy, the practical results obtained agree very closely with the theory previously outlined, and the latter, in turn, explains rather satisfactorily the peculiar curve obtained under series motor operation, which indicates most unfavorable conditions at normal rating in this particular motor of older design.

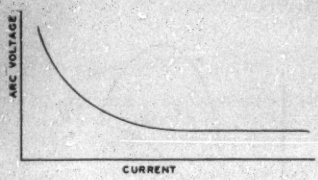


Fig. 10. Typical arc characteristic

Other Phenomena—
Voltages Induced During Current Reversal

So far, quite a number of phenomena of secondary importance have been neglected in order to simplify the consideration of the basic conditions. The importance of these phenomena varies, but they may under certain conditions be of practical consequence and it therefore seems necessary to outline some of them briefly.

By reference to figure 1*B*, it will be seen that, while the current is conducted into the commutator by the arc, the current direction is, as indicated by the arrows below the coils, with the direction of rotation as indicated by the arrow *R*. When the brush returns to the commutator (figure 1*C*) the current will tend to flow in a normal direction in coils 1, 2, 3, and 4. This means that the current in these coils has to be reversed, as indicated by the opposite arrows *g* near these coils. This reversal will induce a self-inductive voltage in these coils, which adds to the voltage induced by rotation, as covered in the previous discussion. In other words, this self-inductive voltage will assist in maintaining the arc. The amplitude of this voltage increases with the size of the current which has to be reversed. This, in turn, means that the effect is less favorable with the heavier loads. Furthermore, the greater the number of turns in the armature coils, the larger the self-inductance will be, which is merely another reason for keeping the number of conductors in the armature as small as other practical considerations permit. While the effect of this self-inductive voltage is probably not negligible in a great many cases, the variations possible within practical design ranges are somewhat limited, so that, in practice, the effect of such voltage probably does not vary over wide ranges for a given rating.

As already indicated, the armature current tends to decrease while the brush is off the commutator, and consequently the field excitation will also decrease and the main field will tend to diminish. After the brush returns to the commutator, opposite changes will take place. Any such change will also induce certain voltages in the armature coils 1, 2, 3, and 4 with which the main flux interlinks; however, as already pointed out, such changes will be small on account of the various reasons previously indicated. Therefore, the influence of these voltages may not be appreciable.

Effect of Slots and Teeth, Interpole Flux, Armature Flux, and Hot-Cathode Spots

The figures showing field forms and voltages give rather smooth curves because the effects of slots and teeth and the commutating oscillations which may take place under the brushes have been neglected.

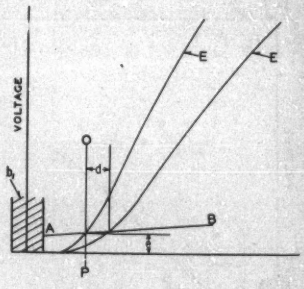


Fig. 11. Rate of rise of voltage between brush and cathode spot on commutator segment for 2 different motor speeds

In actual practice these influences usually result in rather irregular curves with many higher harmonics. The higher harmonics in the voltage curve, if they cause sudden rises at the critical moment of arc rupturing, may be instrumental in sustaining the arc; on the other hand, such harmonics, if they happen to result in sudden decreases at the critical moment, may assist in extinguishing the arc.

In the figures previously given, the interpole flux F_i has been assumed to be the same in all cases. Since this interpole flux is negative in the interpolar zone, it assists in reducing the voltage over the critical range. It is therefore evident that by increasing the interpole flux, conditions may be favorably affected. A wide interpole extending beyond the interpolar zone, for instance, may be of practical value. Unfortunately, however, commutation considerations definitely limit practical possibilities along this line.

In developing the field forms of the figures given, the armature flux has been assumed to be constant. As a matter of fact, there is some shift in the distribution of the armature ampere turns while the current flows as shown in figure 1*B*. This is equivalent to a shift in the brush, which, in turn, has the same effect as a chorded winding. The result is a decrease of the magnetomotive force in the commutating zone and this permits the commutating flux to increase and results in somewhat more favor-

able conditions, as pointed out in the previous paragraph.

In the considerations up to this point it has been assumed that there is a single arc, with the hot-cathode spot remaining on segment a. With larger currents, it is not entirely inconceivable that while this arc is lengthening, a new cathode spot will form at the segment near the brush.* If this occurs, it is of course equivalent to the brush temporarily returning to the commutator at that point. Considerations, therefore, are much the same as outlined before, the difference merely being that such a phenomenon will reduce the time during which the original arc carries the entire load current, which in turn favors the elimination of flashing.

Artificial Means of Reducing Flashing

A great many attempts have been made in the past to reduce flashing by artificial means, such as air currents or magnetic-blow effects, but on the whole, such attempts have not been very successful. The reason for this apparently is that during the critical point in the arc formation, the arc is short and the air currents readily obtainable have little effect upon it. As the arc becomes longer the air currents have the effect of changing its direction and possibly blowing it to other parts of the motor, but, in general, little has been accomplished thereby in the way of entirely preventing flashing. The use of magnetic-blow effects for the same purpose seems to have had similar effect. Practical observation seems to indicate that the air currents A shown in figure 1B caused by the rotation of the commutator and being carried along near its surface tend to carry the arc along and favor an arc formation as indicated in figure 1B.

Numerous attempts have been made to influence flashover conditions favorably by mechanical arrangements of parts, and certain minor improvements have been accomplished. Certain tests, for instance, have indicated that with other conditions unchanged a somewhat larger commutator and wider spacing has a noticeable, but not an appreciable, favorable effect. Certain improvements have also been made in mechanical arrangements for diverting the arc and the consequent damage from the most vulnerable parts of the motor. However, as a rule, the possibilities of eliminating flashing by mechanical arrangements seem to be definitely limited by the very much restricted space conditions in railway work.

Effect of High Speeds, and Number of Brushes per Arm

In the previous theoretical study of the voltage conditions, the time during which the brush is off the commutator has been assumed to be a definite value. This, of course, is not the case in actual practice, as it is very probable that this period increases with higher speeds. This, together with the other unfavorable effects of high speeds previously discussed, explains the fact that most flashing occurs with the higher speeds of the motor. The only redeeming fact is that the currents are usually somewhat smaller at the higher speeds, which partly counteracts the unfavorable effects.

In the previous considerations, it has been assumed that there is only one brush per arm. If there are 2 or more brushes side by side, there is, of course, the possibility that one brush will remain on the commutator while the other brush jumps, which in turn should materially reduce flashing. Unfortunately, however, high commutator bars, causing brush jumping, may at times extend over the entire commutator width, and any other mechanical shocks causing brush jumping may act upon both brushes alike. In some such cases no marked difference has been noted in practice between the results obtained with 1 and 2 brushes per arm, but in general it should be expected that 2 brushes per arm will reduce the chances for flashing caused by brush jumping. If 4 brush arms per motor are used and only 1 set of a given polarity leaves the commutator, the current can be transferred to the other brush of the same polarity; this transfer, however, means the overcoming of the self-induction of the one armature coil connected between the segments of the same polarity. Depending upon this self-inductive voltage, the voltage available for the arc between the raised brush and segment a may or may not be sufficient to sustain it. However, even if the arc is sustained until the brush b_1 returns to the commutator, at least some of the current will have been transferred to the other brush of the same polarity. It is therefore to be expected that the presence of the second set of brushes of equal polarity will be favorable to the elimination of flashing conditions as affected by brush jumping, even though it should not be expected to eliminate flashing entirely in all cases. A complete analysis of this more involved case is beyond the scope of this paper.

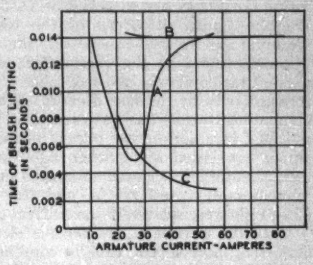


Fig. 12. Curves indicating the time of brush lifting required to cause flashing

A—Field in series with armature
B—Separately excited field, 60 amperes
C—Separately excited field, 30 amperes

Many of the phenomena have by necessity been touched upon only briefly as it is obviously impossible to cover this inexhaustible subject in full in the limited space available here, particularly because of the many different conditions encountered in practice. It is believed, however, that the fundamentals given will assist in clearing this rather intricate problem.

* An analysis of the test results shown in figure 12 seems to indicate that this actually took place with some of the larger current values, but further investigations will be necessary to confirm it.

Applications of a Photoelectric Cell

A photoelectric cell of the dry disk type, consisting of a light-sensitive disk and not requiring any vacuum or liquid was developed a few years ago, and has proved to be a very useful device. Characteristics of one type of dry disk photoelectric cell are described in this paper, and a number of typical applications of the cell are given.

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PHOTOELECTRICITY is not new to science. There are records of the Becquerel effect of 1839, the Fritts dry disk cell of 1855, and the Willoughby Smith discovery of the resistor type of selenium cell in 1873; however, the application of photoelectricity in the commercial world has progressed rather slowly and has taken a definite stride forward only in the last decade. While the actual commercialization has just recently begun, it was not lack of vision on the part of our early engineers which prevented its quicker adoption but rather lack of suitable associated apparatus such as sensitive microammeters and relays, and the fact that the older cells were relatively insensitive.

With the advent of inexpensive electronic amplifiers, the photoelectric tube in combination with an amplifying system, was found to offer a solution to many industrial control problems, but early in the last decade it became evident to research engineers that the photoelectric tube, with its associated amplifying tubes, was not the complete answer to most photometric measurement and control problems.

Accordingly, intensive research work was carried on, first with the wet type of copper oxide cell, then with the same cell in its dry disk form and finally as an outgrowth of these investigations the first commercially practical dry disk type of photoelectric cell, which is described in this paper, was offered to the industrial world late in 1931. Due to its high current output (about twice that of the photoelectric tube), the simple and sturdy construction, and the ease of adapting it to existing measuring and control devices, it has found a ready and fertile field.

The dry disk photoelectric cell consists essentially of a metal disk on the surface of which light-sensitive material is deposited. (See figure 1.) Contact fingers resting against the face and back of the disk collect the current generated, which is then carried directly to the measuring or control instrument. The light-sensitive disk is usually mounted in a bakelite or metal case, the case is not evacuated or filled with gas, as is the photoelectric tube, and no liquid is used. The action of the light striking the sensitive surface is entirely electronic, that is, the radiant energy is directly transformed into electrical energy and there is no physical or chemical change in the sensitized material; thus a practically unlimited life is to be expected.

In the photoelectric tube, or emissive type of photoelectric cell, electrons are ejected into space by the impinging light; but a polarizing potential of a relatively high order, that is, 90 volts or more, is required to collect them. In the dry disk photoelectric cell there is no space between electrodes but instead they are bonded together electrically at the barrier layer thus allowing the direct flow of current without the use of an external aiding voltage.

The total current generated in the cell is a function of the illumination and is proportional to it. This fact has been verified in experimental circuits, from low to the very highest values of illumination. This current divides between an internal conducting path in the cell and the external path, or load, in accordance with the ordinary laws of parallel circuits.

Frequency Response and Internal Resistance of Cell

A consideration of the equivalent cell circuit (see figure 2) which has been proved experimentally, will indicate the reason for some of the unusual and interesting characteristics of this cell.

It is interesting to know that this cell, in common with other types of electronic photoelectric cells, is a rectifier (R, figure 2), that is, it offers a resistance to the flow of current in one direction many times that of the opposite direction. This characteristic is often utilized. The capacitance C between the conducting surfaces of the cell is of the order of 0.5 microfarad. This causes a drop in output with an increase in

Fig. 1. View of component parts of the dry disk photoelectric cell

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frequency of the modulated light (see figure 3) and makes the cell unsuited for use at audio frequencies, such as are used in talking pictures. By the use of special filters and coupling transformers, a practically flat response curve may be obtained up to 5,000 cycles but the power level is reduced and additional amplification would be required.

There are many applications, however, where linear response is not required at all frequencies, such as, for instance, in the measurement of projectile velocity. The U.S. War Department has built a device using dry disk photoelectric cells to detect the passage of a rifle bullet at speeds up to 3,000 feet per second with an accuracy of plus or minus one foot per second.

The internal resistance of the cell is relatively high, varying from 6,000 to 7,000 ohms for a dark cell to 1,000 to 2,000 ohms under intense illumination. (See figure 4.) This allows the use of fairly high resistance meters in the external circuit and accounts for the fact that lead resistance is negligible, and, therefore, the cell may be mounted any desired distance from the meter or relay. This characteristic

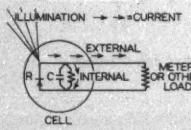


Fig. 2. Equivalent circuit of the dry disk photoelectric cell

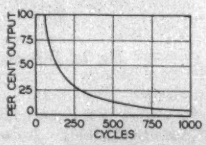


Fig. 3. Frequency response of the cell

was taken advantage of by the engineers for the Holland tunnel under the Hudson River, who mounted a cell in the middle of the tunnel and had it record smoke density at that point, on a recorder in the New York control room, over 3,000 feet distant.

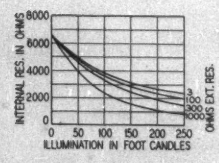


Fig. 4. Internal resistance of cell under varying conditions of illumination and external resistance

Tungsten filament source at 3,000 degrees Kelvin

There are many other installations where leads pass from 300 to 500 feet through water, earth, or air, from the cell to its associated meter or relay.

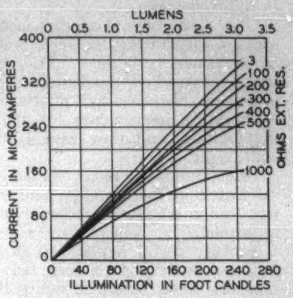
Current Output and Spectral Response

For low external resistances, the current output of the cell varies directly with the illumination. (See figure 5.) This has permitted the making of direct reading foot candle meters having a uniformly divided scale. Such meters are made with ranges from as low as 1 foot candle up to 20,000 foot candles.

For ranges of 50 foot candles and higher one cell supplies sufficient current to operate a rugged microammeter. For lower ranges of illumination 2 or more cells are connected in parallel, and the current increase is approximately in proportion to the number of cells. (See figure 6.) In the instance of meters made for checking very low values of illumination such as for street lighting measurements as many as 16 cells in parallel are sometimes used. This may

Fig. 5. Current output and effect of external resistance

Tungsten filament source at 3,000 degrees Kelvin



sound cumbersome but actually it is not, as the cells all fit nicely into the standard instrument cover. The dry disk photoelectric cell, especially when more than one is mounted in a single housing, is often referred to as a light target, or light collector. In figure 7 a light collector is shown containing 6 cells, another contains 3 cells in a weatherproof case used for mounting at the tops of poles or towers; for instance, on lighted airways the 3-cell light collector is mounted on top of the beacon tower, sometimes 150 feet above the ground, and the relays are mounted at the base of the tower.

The spectral response of the cell is fortunately such that it overlaps that of the human eye in both the violet and red ends of the spectrum. (See figure 8.) Thus by the use of a colored glass filter it is possible to cut out the overlapping response and make the cell practically identical in response with the human eye. As will be seen on the curve, the cell also responds well to invisible radiation and by simply using a quartz window instead of glass it was possible to calibrate meters for use in reading ultra-violet intensities directly. It has also been found practical, when a suitable metal or composition filter is used, to determine X ray intensities.

It may readily be seen, therefore, that where sensitivity to any part of the spectrum from the X ray through the infra-red is required, it is merely necessary to use a filter which will cut off most of the undesired radiations. As an additional example, in the steel industry temperatures in open hearth furnaces are being measured by means of a dry disk photoelectric cell and are being directly recorded. This would be impossible by any ordinary pyrometric method of temperature measurement. Billet temperatures are also being measured by a cell as the billet moves along through the rolls.

The Illumination Meter and the Exposure Meter

The usefulness of the dry disk photoelectric cell has been enhanced by the fact that only extremely simple circuits need be used to obtain the full advantages of direct measurement and control. For the measurement of illumination, color, opacity, etc., it is necessary only to connect the cell directly to the terminals of a suitably calibrated microammeter, or milliammeter.

One of the first measuring instruments to be devised incorporating this cell, was the illumination meter shown in figure 9. Prior to its introduction, only such relatively inadequate comparison methods, as used in the grease-spot photometer, were available in portable instruments for the measurement of illumination, and they were good only in normal white light.

This illumination meter consists of a microammeter, calibrated in foot candles, and connected, by a 5 foot cord, to a light target containing 2 cells connected in parallel.

Another useful application of this cell, for the measurement of light values, is in the photographic exposure meter shown in figure 10. All prior, and commonly used, exposure meters relied on the ability of the human eye to distinguish between various degrees of brightness, since it is the brightness of the object at which the camera is directed that determines the required exposure time. The human eye, however, is quite capable of reading newsprint in moonlight and in sunlight, a range of about a million to one, but is incapable of determining minor variations, over this great range, with sufficient exactitude to suit the relatively narrow requirements of light intensity of the usual photographic emulsions. Having the relation between brightness and the density of exposure resulting, it was a relatively simple matter to make a calculator, or translator, that would interpret brightness measurements in terms of exposure time.

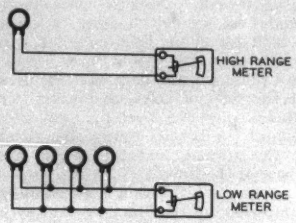


Fig. 6. Parallel connection to obtain higher output

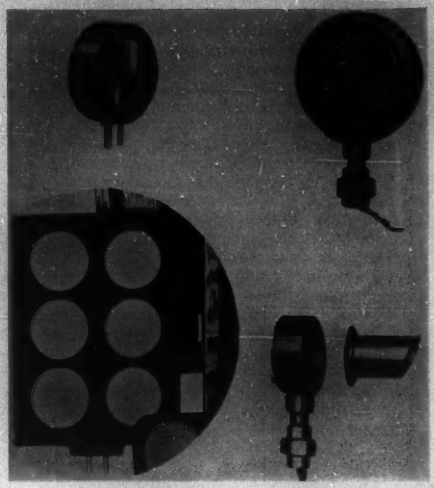


Fig. 7. Different types of cell housings

Door Opening Circuit and Automatic Weighing Circuits

The dry disk photoelectric cell readily adapts itself to most industrial control problems and as the technique of applying it as a mechanical tool is becoming well established, it is finding a very definite place in this field. Industrial control may usually be divided into 3 groups:

1. Complete cut-off of the light beam.
2. Change in light intensity.
3. Change in color.

Complete cut-off of the light beam is usually associated with the counting of opaque objects moving through a light beam. This is a simple type of control and is used successfully in nearly every industry which packs or manufactures small articles. But of greater interest to technicians are some of the unusual applications of this versatile cell.

Photoelectrically controlled doors, for instance, operate by the complete cut-off of a light beam as a person or vehicle passes through. It has been found necessary at all recent installations of photoelectric cell controlled doors, such as those in the Pennsylvania Railroad Station in New York City, to pass a diagonal beam of light through the open doorway so that if anything should remain in the doorway, the

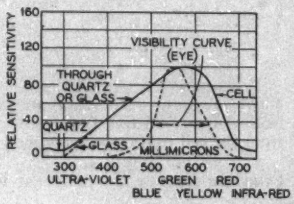


Fig. 8. Spectral response of dry disk photoelectric cell

Fig. 9. Illumination meter

doors will not close. As shown in figure 11, there are 3 cells connected in series, cells 1 and 2 being operated from either approach, and cell 3 being used to hold the door open when anyone remains in the doorway. When the door closes cell 3 is short-circuited by the switch *S*. The dark resistance of the cell is 5 to 6 times that of the cell when illuminated; therefore, when the door is closed and cells 1 and 2 are connected in series, blocking either light beam will reduce the output current practically to zero and thus operate the relay. Likewise when the door is open and all 3 cells are in series, blocking the diagonal beam or either of the other beams, will cause the relay to close and the door to remain open.

Another application of complete cut-off control

Fig. 10. Exposure meter

is in the use of dial scales for automatic weighing of coal, coke, liquids, etc. Again, one industrial control relay is connected to the cell circuit but in this application the cells are connected in parallel. (See figure 12.) On the tail of the scale pointer a target *T* is mounted, and arranged to pass over 2 or more holes in the dial face. Behind each hole is an electric light and over each hole a photoelectric cell. The cells are connected in parallel to one relay. Operation is as follows (in the case of automatic coal weighing): The truckman turns a rotary switch, marked in tons, to the number of tons desired. The switch is arranged to light only the lamp under the proper cell so that the target or the pointer will pass through the light beam when the proper weight is reached. The other cells are dark, but since their dark resistance is so high, they have practically no effect upon the circuit. The one cell which is lighted energizes the relay and causes the coal to start flowing; this continues until the correct weight is reached at which instant the tail of the pointer darkens the lighted cell and causes the relay to operate and stops the flow of coal.

These control circuits are extremely simple when one considers the difficult and complicated task per-

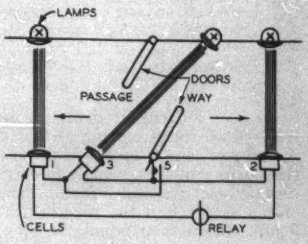


Fig. 11. Door opening circuit

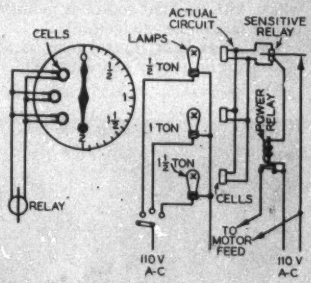


Fig. 12. Automatic weighing

formed. These controls were made possible only by understanding and taking advantage of the characteristics of this cell.

Other Control Circuits

Control by light intensity change is illustrated well by a smoke alarm. (See figure 13.) A light beam is directed across the inside of a stack, striking a cell which is connected to a relay. The device is so adjusted that when a predetermined amount of smoke is present in the stack, an alarm rings in the boiler room, thus warning the attendant. The relay

is mounted in the boiler room and the cell is mounted any distance away and at any desired height on the stack.

A simple type of control is used at a sewage disposal plant where a cell and light source are placed in the liquid in the last tank. (See figure 14.) As the sludge becomes sufficiently dense at the light

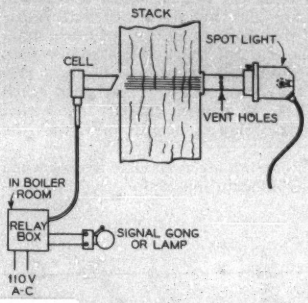


Fig. 13. Smoke alarm

beam, the cell output decreases and operates the relay which starts a pump so that the sludge is removed and placed back into the system. By using this equipment it is possible to operate the plant at considerable overload without danger of overflow of the sludge into the river which carries off the liquid. In this installation, the relay box is mounted indoors approximately 200 feet away from the cell which with its light source is mounted 5 feet below the surface of the sludge tank.

The street light control relay is another instance of control on slowly changing light intensity. (See figure 15.) The relay box may be mounted in a manhole under ground or at any other point near to the power mains, while the cell may be mounted on top of a pole or roof or wherever convenient. This same relay is used for lighting radio towers, and airway and marine beacons, and in each installation the cell is mounted wherever convenient without regard to the length of leads to the relay box. This relay may be set, by adjusting an index, to turn the lights on and off at any desired value within its range, and any range may be supplied to meet the desired conditions.

Color change may be made to operate these relays since the cell produces a different current output for any change of color. In automatic coffee roaster control, the green beans produce by reflected light an output several times higher than the finished brown beans. It is, therefore, an easy matter to adjust the relay to dump the roast or operate a signal when the proper shade of brown is reached.

While this paper covers only a few of the high spots of recent advances in the application of the dry disk

Fig. 15. Street light control

photoelectric cell, it will indicate that many new fields of photoelectric measurement and control have been opened. The simplicity of the circuits involved and the use of standard instruments and relays operating on well-known principles, largely eliminate the hesitancy of the industrial engineer toward adaptation of photoelectric methods to his control problems.

Photoelectric measurement and control is young but it will surely take its place in the commercial world along with the lamp, the battery, and the motor; and simple devices, such as are made possible by the correct technical application of the dry disk type of photoelectric cell, will hasten its acceptance.

Fig. 14. Sludge level control

"Angle Switching" of Synchronous Motors

Commercial applications of "angle switching" of synchronous motors are given especial attention in this paper. "Angle switching" refers to a method of starting synchronous motors whereby the time of application of the excitation voltage with respect to the relative angular position of the field poles and the impressed voltage is controlled. The advantages of this method of starting are pointed out, the equipment is described briefly, and a number of practical applications in which increased starting torque, reduced starting current, or other features were obtained are described.

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As the speed of a synchronous motor during the starting period approaches synchronism, d-c excitation is applied and the motor pulls into step. If the time of application of the excitation voltage to the synchronous motor is controlled with respect to the relative angular position of the field poles and the impressed voltage, the method of starting is referred to herein as "angle switching." Several papers have been presented before the Institute[1] on the subject of the effects of this type of control. As previously pointed out, one of the chief advantages of such control is to increase the torque against which the motor will consistently pull into step with a given value of starting current. The present paper points out certain commercial applications of "angle switching" and gives some experimental results obtained along these lines.

The equipment used for commercial installations consists essentially of a means of checking the position of the rotor against the space position of a particular phase winding at a predetermined point on the wave of voltage impressed across that phase. This angle switching equipment is used in conjunction with synchronous motor starting control of standard type. The control functions in an ordinary manner up to the point of applying the excitation voltage, but instead of applying the excitation at this point, the angle switching equipment is energized. This device, in turn, applies the excitation voltage to the motor the first time the rotor and the impressed voltage pass through the predetermined relative angular relation.

Let *a* in figure 1 represent a portion of the voltage wave impressed across one phase of the motor. For convenience, a check is made each time the voltage has its maximum value in an arbitrarily chosen positive direction, as at the point indicated by the arrow. Let *b* in figure 1 represent a section through a full pitch coil in the phase across which the voltage shown at *a* is impressed, and let the positive direction of the wave shown be such as to tend to make current flow in the coil in the direction shown by the arrows. For a machine operating in synchronism with the direction of rotation shown, and at true no load, a "north" pole will be directly under the coil side shown each time the voltage wave has its maximum positive value. For various steady loads the pole will be a certain distance ahead of or behind the position shown at the time of maximum voltage, depending upon whether the machine is loaded as a generator or a motor, respectively. Positions up to 180 degrees ahead of the no load position are said to be in the "generator region" and positions through 180 degrees behind are said to be in the "motor region."

The Saturating Transformer and Inductor Generator

To determine the time at which the voltage impressed upon the reference phase of the motor is maximum, a small saturating transformer is connected across this phase through a potential transformer. This saturating transformer gives a sharp peaked wave in time phase with the maximum value of the voltage wave. The rotor position is checked by means of a small generator. This generator is of the inductor type without rings, brushes, or other

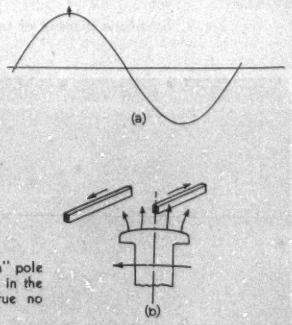

Fig. 1. Principles involved in angle switching

a—Voltage wave impressed on reference phase of the motor. Rotor position is checked at point indicated by arrow

b—Position of a "north" pole with respect to a coil in the reference phase at true no load

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1. For references, see list at end of paper.

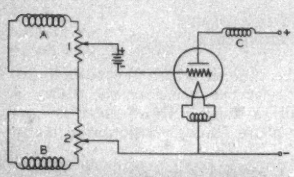
wearing parts. The rotor is mounted on the shaft or spider of the main motor and the stator is mounted on one of the bearing pedestals or the brush rigging support. The magnetic circuit is so arranged that during one revolution a sharp voltage impulse is generated for each pair of poles on the motor. Provision is made for circumferential adjustment of the stator to obtain the required angular position of the generated voltage peaks. The power required from the generator and from the saturating transformer is practically negligible.

The outputs of the saturating transformer and the inductor generator are connected in series between the grid and the cathode of an electronic tube of the gas or mercury vapor filled type as shown in figure 2. *A* and *B* are respectively the secondary of the saturating transformer and the voltage coil of the inductor generator. The bias on the grid is such that a coincidence of the voltage peaks from the 2 sources is necessary to render the tube conducting. When the motor is operating on its starting windings below synchronous speed the impulses from the generator still denote the position of the rotor of the motor in space but its position is continually changing with respect to the constant frequency voltage impressed across the reference phase. However, since the frequency of the impulses generated by the saturating transformer is different from the frequency of the voltage produced by the inductor generator, there will soon be a coincidence of the voltage peaks from these 2 sources. As soon as the tube becomes conducting the current through the operating coil *C* of a high speed relay causes the relay to close and apply the excitation to the motor.

Figure 3 shows the 2 voltage peaks and the resultant wave as impressed between the grid and cathode of the tube. This film was taken with the 2 voltage waves at the same frequency and approximately 60 degrees apart. Figure 4 is a view of the tube and its panel. The saturating transformer is mounted on the back. The dials are for the adjustment of the 2 potentiometers. It is evident that the tube need be energized during only a part of the starting period. This gives it a relatively long life.

Results Obtained With Angle Switching

Pull-in tests have been taken on motors from 200 to 900 horsepower and with different values of excitation, load inertia, and field circuit time constants. These tests show that for a given motor with a given starting current the maximum torque against which it pulls into step consistently with a fixed moment of inertia can be increased more than 50 per cent in some cases by the use of angle switching. The results of such a test on a 290 horsepower, 1,200 rpm, 60 cycle, 80 per cent power factor motor are shown in figure 5. These curves are plotted between the maximum torque against which the motor will synchronize consistently and the angle at which the excitation



A—Secondary of saturating transformer

B—Voltage coil of inductor generator

C—Operating coil of high speed relay

1 and 2—Potentiometers

Fig. 2. Schematic diagram of tube circuit

Fig. 3. Voltage peaks and resultant load

A—Voltage output of saturating transformer

B—Voltage output of inductor generator

C—Total voltage between grid and cathode, not including bias

Fig. 4. Electronic tube and its panel. The saturating transformer is mounted on the rear

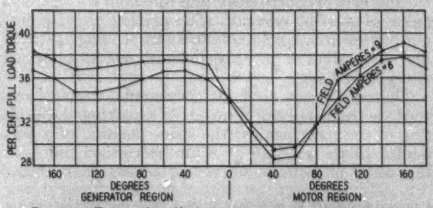


Fig. 5. Tests of pull-in torque against angle for a 290 horsepower, 1,200 rpm, 60 cycle, 80 per cent power factor motor

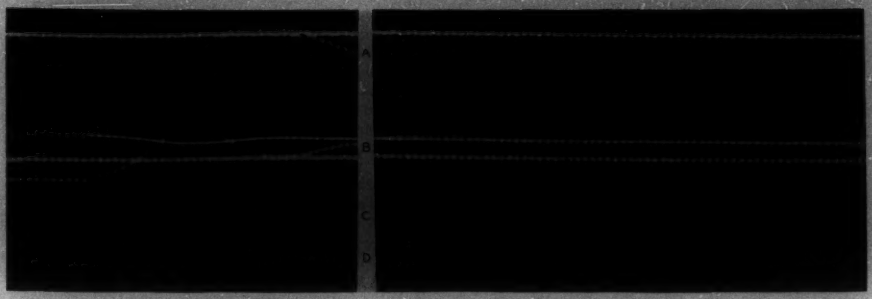


Fig. 6. Pull in with field energized at 40 degree generating position

A—Speed *B*—Field current *C*—Line voltage *D*—Line current

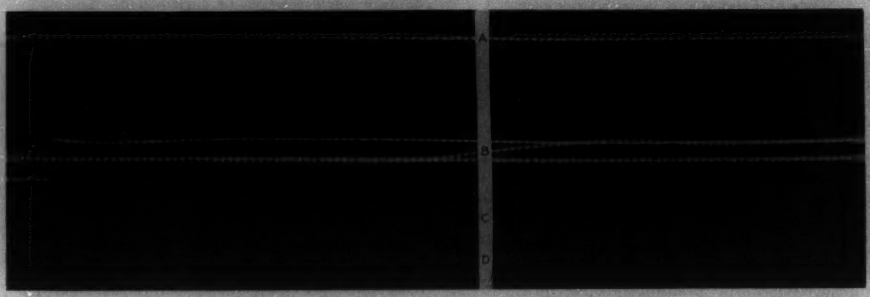


Fig. 7. Pull in with field energized at 100 degree motoring position

A—Speed *B*—Field current *C*—Line voltage *D*—Line current

voltage was applied. The 2 curves submitted are for the same value of total moment of inertia, and 2 different values of field current. These particular curves were taken at half voltage.

The greatest practical value of this means of increasing the torque against which a motor is certain to synchronize appears to be that it permits a decrease in the starting current for a given pull-in requirement. Figure 5 shows that this particular motor with the particular value of moment of inertia, and the higher value of excitation would pull in every time against only 29 per cent torque with uncontrolled field switching. At the voltage at which these tests were taken the motor had 65 per cent starting torque and 170 per cent starting kilovolt-amperes. Assume that 29 per cent pull-in torque is sufficient for the particular load. The speed-torque characteristic for this motor shows that the slip corresponding to 29 per cent torque on the starting windings is 2.5 per cent. However, figure 5 shows that the motor will synchronize consistently from 3.5 per cent slip with angle switching, as 3.5 per cent is the slip corresponding to 38 per cent torque on the starting windings. Therefore, this motor with angle switching will synchronize against 29 per cent torque with a higher impedance damper winding which will bring it to only 3.5 per cent slip with this value of torque. Because of the higher impedance damper winding the starting current will be reduced from its present value of 170 per cent to approximately 125 per cent.

An example of the effects of synchronizing against the same load at different angles is shown in figures 6 and 7. The set up for taking these films consisted of the 290 horsepower motor, referred to above, connected to a 200-kw d-c generator. This generator was loaded on a resistance bank and compounded in such a manner that the torque was substantially constant over a considerable speed range. The motor was controlled through an angle switching device similar to the one described above. The different character of the pull-in phenomena is evident from the films. Figure 6 shows the motor being synchronized with the field applied at a 40-degree generating position. Figure 7 shows synchronizing from the less favorable angle—from the torque standpoint—of 100 degrees motoring. When synchronized from 40 degrees generating, the motor at once pulled into step and oscillated over a rather wide angle before settling down to its final angular position. When

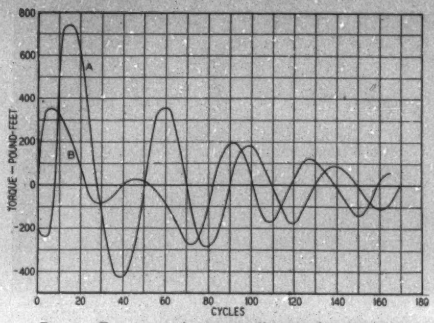


Fig. 8. Torque producing oscillation of motor rotor and load during pull in

A—Field applied at 40 degree motoring position
B—Field applied at 100 degree generating position

synchronized from 100 degrees generating position, the fluctuations in speed are of considerably less magnitude even though the motor does not synchronize at the first opportunity.

Another aspect of this synchronizing phenomena is shown in figure 8 which gives the calculated torque which produced mechanical oscillations based upon the speed variations shown on the films and the known moment of inertia of the system. It is seen from curve *A*, which is for the 40 degree generating position, that the oscillating torque is from 750 pound-feet positive to 460 pound-feet negative. For the 100 degree motoring position shown at *B*, the oscillation is from between 360 pound-feet positive to 275 pound-feet negative, or only 53 per cent as much total pulsation. The constant load torque was 280 pound-feet. Since the total torque is the sum of the inertia torque and the load torque, there was no reversal of mechanical torque in the mechanical system during the entire synchronizing process.

An example of an application of this principle in which angle switching has been applied is in the case of the cement mill of the National Portland Cement Company, where the requirements of the tube mill drives were such that the torques during the synchronizing period had to be controlled within certain limits. These mills are driven by 800 and 900 horsepower, 720 rpm motors. One of the requirements was that the torque delivered through the gears, which coupled the motor to the load, should not reverse during the synchronizing period. There was also a limit on the maximum value of positive torque. By tests under load conditions the angle switching equipment was adjusted so that the desired torques were obtained.

Another point which may be of interest in some applications is the comparison of the line current drawn by synchronizing from the 2 angles. The currents are shown in figure 9, which is drawn from the oscillograms shown in figures 6 and 7. Curve *A* shows the current for switching at 40 degrees generating, which is the more favorable angle from the torque standpoint. The maximum root mean square value is 87 amperes and the average value of the effective current over the first 2 seconds is 40 amperes. For the more unfavorable angle of 100 degrees motoring, the maximum effective value is 96 amperes and the average value of the effective current is 50 amperes for the first 2 seconds.

A Modification of Angle Switching

Another practical problem to which a modification of the angle switching equipment has been applied is that of synchronizing 2 motors so that they will operate with a predetermined angular relation between the rotors of the 2 machines. A particular case was in the air conditioning of the new Kansas City Auditorium in which it was specified that the motors driving 2 identical refrigerant compressors must be synchronized in such a manner that the cranks of the 2 compressors would always be displaced by a definite angle relative to each other. The purpose of this requirement was to distribute the current pulsations caused by the torque variations in the 2 compressors. The motors were rated at 400 horsepower, 225 rpm.

To accomplish this an inductor generator was mounted on each machine. With one motor started in a normal manner and operating in synchronism the impulse generator gives an impulse each revolution when the rotor is in a particular position. The inductor generator on the second machine is adjusted so that it produces an impulse each revolution at a position displaced by the required amount from the position at which the rotor on the first machine produces its impulse. These generators differ slightly from those previously described in that the former give an impulse for every pair of poles. Since the first motor is operating in synchronism and the second on its starting windings, it is evident that the peaks from the 2 generators will sooner or later coincide.

The tube control circuit is quite similar to that shown in figure 2. As shown in the figure, potentiometer 2 is energized from the inductor generator of the machine which is to be synchronized. But potentiometer 1, instead of being energized from the line is energized from the inductor generator which is

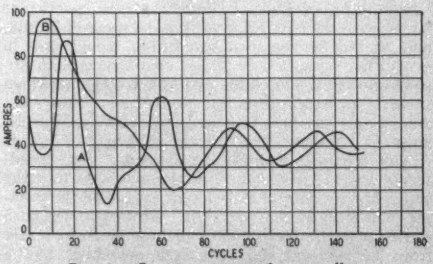


Fig. 9. Current variation during pull in

A—Field applied at 40 degree motoring position
B—Field applied at 100 degree generating position

mounted on the shaft of the machine which has already been synchronized. When the tube becomes conducting the excitation is applied to collector rings of the second machine. Obviously the same result could be approximated by some sort of electrical or mechanical contactors. But no such devices appear to have the speed, accuracy, and freedom from wearing parts found in the angle switching equipment described herein.

Since the first machine is synchronized and operating at some rather definite average angular displacement, it is entirely possible to adjust the impulse generator on the second motor so as to take advantage of the increase in pull-in torque which can be obtained through angle switching.

The angle switching equipments which have been built have been used in conjunction with the standard, definite-time type of control. There may be certain types of loads where it is desirable to incorporate a means of checking the speed at which the tube is energized. The inductor generator affords a convenient means of doing this. But unless the load conditions vary widely from one start to the next, such a feature does not appear to be necessary.

In addition to increasing the torque against which a motor is certain to synchronize, it is seen that angle switching may be used to advantage for other purposes as outlined in this paper. The installed equipment to date, using electronic tube type of equipment, consists of 10 motors totalling 5,200 horsepower. Such control of the "pulling-into-step" process is now a special feature. But with a growing understanding of its advantages, some form of angle switching equipment will probably become more or less standard for many applications of synchronous motors.

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2. The Pulling-Into-Step of a Salient Pole Synchronous Machine, H. E. Edgerton and Paul Fourmarier. A.I.E.E. Trans., v. 50, June 1931, p. 769–81. (A good set of references to previous articles is given in this paper.)

Electric Furnaces With Carbon Radiator

A type of electric furnace for application to metallurgy and to operations at very high temperatures has been developed in which the heat producing element is a carbon electrode raised to a very high temperature and conveying heat to the charge by radiation. Furnaces of this type, which have incorporated in them a number of novel features, have been devised and perfected in France in the electrothermic laboratory of the company with which the author is connected.

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THE ESSENTIAL feature of the electric furnaces described herein is a carbon radiator mounted within the furnace chamber and raised to a very high temperature by the current flowing through it. This radiator can be reduced to a simple graphite rod, which allows high current densities (200 to 500 amperes per square centimeter) to be used, and which radiates freely to the charge and to the walls; hence the furnace, which has been frequently called a "radiation furnace," can be compared to a large incandescent lamp, the filament of which is the resistor.

The general properties of the furnaces with an internal radiator can be derived from their physical characteristics:

1. From the electrical viewpoint, these properties are those of a resistance furnace: constant load for each value of the supply voltage, and absence of any inductance.

2. From the thermal viewpoint, the use of graphite resistors makes it possible to attain very high temperatures (3,000 degrees centigrade in special furnaces) or, in the case of normal operation, to build very flexible furnaces, the power rating of which may be quite considerable.

Construction

The radiator type furnaces embody, besides the conventional elements, several interesting features which are made important by the necessity of bringing large currents to a radiator of small diameter, of eliminating eddy current losses, and also of avoiding the inductance caused by any closed loops in the feeders.

Before examining these features, a small single-phase 100-kw furnace for melting steel, which has a capacity of 100 kilograms (220.5 pounds) will be described briefly. Figure 1 represents a vertical cross section of that furnace. The chamber consists of a sheet metal cylinder which is terminated at each end by truncated cones. The lining com-

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Translated from the French by L. A. Huguenont, of the General Electric Co.

prises a heat insulating layer and a refractory lining baked on the job. Two circular tracks are secured to the central furnace cylinder and these rest on rollers. Thus equipped, it can rotate or oscillate for churning and for pouring the molten metal. Both the spout and the charging door are on the cylindrical part of the furnace wall.

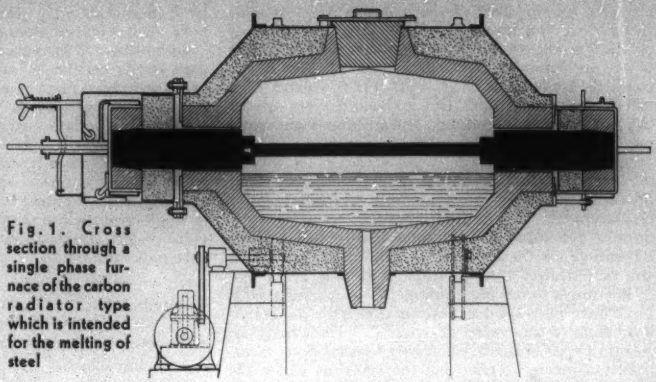

Fig. 1. Cross section through a single phase furnace of the carbon radiator type which is intended for the melting of steel

The radiator is a graphite rod coaxial with the furnace; one of its ends is screwed to a cylindrical graphite element while the other end, which is conical, rests in a conical recess in another cylindrical graphite element into which it is forced by a spring outside the furnace. Each one of the end parts is screwed into an extension consisting of amorphous carbon which in turn is fitted into a metal collar through which water circulates. It is through these collars that the current is conducted to the heating element. The furnace is of the closed type; on one side it is closed by one of the carbon extensions that rests against an insulating disk which in turn is supported by the furnace plating. On the other side it is closed by a sheet metal box which contains the second carbon extension, the electric connection of which slides in a tubular guide built on the bottom of the box. The carbon extension can move freely within the box, and it is forced toward the interior of the furnace by a spring which also presses the resistor element against its electric contact, thus preventing loose contacts such as may be brought about by the motion of the furnace and by expansion and contraction.

In order to withdraw the electrode from the furnace, the movable carbon extension is disconnected and removed from the furnace by means of the carriage provided for that purpose. In this manner the resistance element can be changed or placed aside to protect it from being broken while the furnace is being charged. In order to prevent the oxidation of the graphite parts that have been removed while still hot, it is necessary only to cover them with a hood or to lower them into a suitably arranged well.

In general, the furnace is subjected to voltages

Fig. 2. A 200 kilogram (441 pound) furnace which is installed in an iron foundry

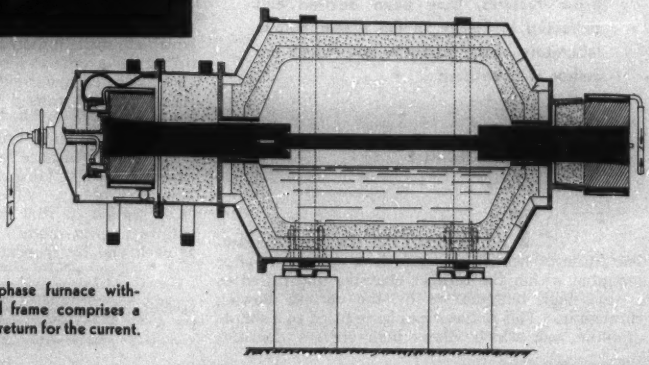

Fig. 3. High-capacity single-phase furnace without magnetic losses. The steel frame comprises a copper lining which serves as a return for the current. The feeder system has no loop

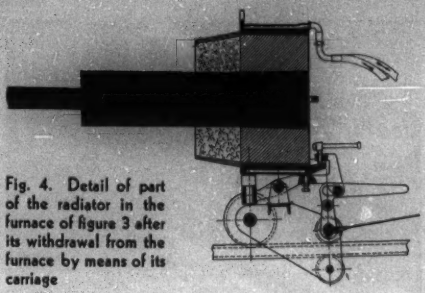

Fig. 4. Detail of part of the radiator in the furnace of figure 3 after its withdrawal from the furnace by means of its carriage

which may be varied with respect to a nominal value. The range of the regulation depends upon the wear which is allowed for a given resistor.

The small 100-kw furnace of figure 1 has given the following results:

For steel which is cast at 1,650 degrees centigrade, the power consumption amounts to 0.8 kilowatt-hour per kilogram.

For cast iron and bronze, the corresponding figures are 0.5 and 0.25 kilowatt-hour per kilogram, respectively.

The furnace is provided with a graphite rod of 35 millimeters diameter which weighs 1.320 kilograms (2.91 pounds); after 7 operations, the diameter of that rod or resistor is reduced to 20 millimeters throughout its entire length. Should it have to be replaced then, this would imply a consumption, including the drop, of 1.650 kilograms (3.64 pounds) of graphite per thousand kilowatt-hours; this is much lower than can be attained with an arc furnace. These low consumptions, which have never been attained in such a small furnace before, become still lower in large furnaces.

Figure 2 represents one of the first furnaces with an internal radiator that were installed in France.

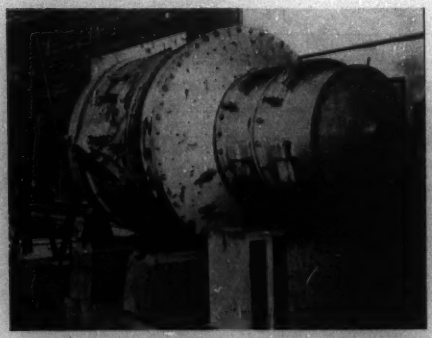

Fig. 5. A 2-ton single-phase furnace for the melting of steel. The control buttons for rotating the furnace, for churning the charge, and for the pouring are visible

Its design is nearly in conformity with the layout of figure 1. It is used for the casting of cast iron piston segments.

Elimination of the Magnetic Losses and of the Inductance of the Loop

The construction which has been described herein is satisfactory only in the case of low-capacity single-phase furnaces which bring into play only currents below 5,000 amperes. Beyond that, the eddy current losses in the magnetic parts of the frame become considerable, and at the same time the power factor drops as a result of the inductance of the loop formed by the supply conductors.

Fig. 6. Detail of the furnace of figure 5, showing external and internal connections

One can evidently avoid the losses by avoiding any magnetic metal in the construction of the frame. However, the difficulty can be overcome better by annulling the field in the magnetic parts and by bringing about the return of the current which has traversed the resistor, by means of a copper lining on the metallic housing of the furnace so that the 2 incoming conductors terminate at the same end of the furnace. In this manner the magnetic losses and the loop formed by the supply conductors are eliminated.

Figure 3 represents a cross section of a detail of that type of construction, which has also the advantage of facilitating the handling of the radiator, which is made an integral part of the carbon extension at which no conductor whatever terminates.

Figure 4 represents, on its carriage, the radiator and its connecting members withdrawn from the furnace. Attention is called to the bronze piece which, at its cylindrical part, is clamped by a ring to the carbon extension, and the conical part of which fits into the conical recess at the end of the furnace which is electrically connected to the copper lining of the frame. By means of this construction it was possible to lower the power consumption, for the

Fig. 7. The radiator of the furnace of figure 5 is represented withdrawn from the furnace for the charging, and tilted into its pit

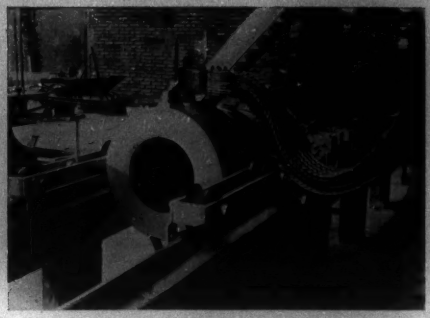

Fig. 9. A 300 kw centrifugal furnace for calcination and fusion at very high temperature

casting of steel in furnaces of 500 kilograms capacity, to 0.68 kilowatt-hours per kilogram.

Figures 5, 6, and 7 represent various views of a single phase furnace of 2-tons capacity which is installed in a steel mill. The current rating for this furnace is 15,000 amperes; the power factor is 98 per cent. It is obvious that the furnaces may comprise several radiators and may be connected directly to a 3 phase system.

Centrifugal Furnaces With Internal Radiator for Operation at a Very High Temperature

An interesting application of carbon radiator furnaces on an industrial scale is found in fusion and calcination processes at high temperature. At the temperatures which come into consideration here, no refractory linings are available, and it is necessary to have recourse to special artifices.

When it is a question of melting or calcining pulverized or granular products, centrifugal furnaces may be built. In these furnaces the enclosure is a steel cylinder which rotates at a fairly high speed so that the pulverous material which it contains assumes the shape of a tube. The internal radiator is pushed into that tube by means of its carriage, but it does not participate in the rotation of the enclosure. Figure 8 represents schematically furnaces of that type. The part of the charge which is to be molten or fritted has been represented by surfaces shaded by short lines. It will be noted that there is no contact between the radiator and the charge, and that a slight air circulation makes it possible to avoid any reduction or carburization of the product which is being treated.

In the 300 kw furnace which is shown in figure 9, thorium oxide, which is used as refractory material, has been successfully calcined without carburization, at 2,700 degrees centigrade.

It is evident that with furnaces of this type one can adopt the very high power ratings which the principle of the internal radiator furnaces permits. With a special industrial furnace, which has been used since 1932 in the manufacture of fused silica tubes, one can obtain ingots of 20 kilograms within not more than 6.5 minutes, starting from a cold charge on which a power of 270 kw is applied.

Advantages of the Carbon Radiator Furnace

These furnaces are the simplest and least expensive among the industrial electric furnaces. Be-

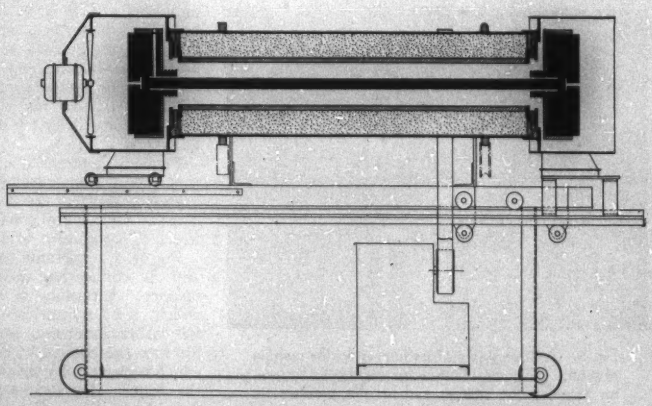

Fig. 8. Schematic cross section of a centrifugal furnace with graphite radiator

cause of limited space here, it is possible to dwell but briefly on their metallurgical advantages, which are likewise remarkable and which can be summarized as follows:

Flexibility, uniformity of temperature, a definite atmosphere, the possibility of operating in a vacuum, easy regulation of the carburization, facility of reduction processes, and last, but not least, the constancy of the analysis of the metal prior and after fusion.

This furnace has met with the instant approval of French metallurgists, as soon as it was placed on the market in 1934.

Power companies are greatly interested in its promotion since they hope that its low cost will make for its ready adoption by metallurgists who so far have refrained from installing furnaces of another system.

Resolution of Surges

Into Multivelocity Components

Based upon a theory of traveling waves previously expounded by the author, this paper presents a method of resolving oscillograms of traveling waves on electric power lines into their multivelocity components. The effects of a ground wire on multivelocity waves also are pointed out.

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THE multivelocity theory of traveling waves has proved essential for explaining several peculiar attenuation and distortion effects observed in the behavior of both natural and artificial surges on transmission lines.[1] The theory also has found a practical application in analyzing the counterpoise.[2,3] While these previous applications were confined either to qualitative predictions, or to calculations based upon known ground planes and line constants, no method has been given for obtaining the multivelocity components directly from cathode ray oscillograms without knowing the line constants. It is the object of the present paper to show under what conditions this can be done and, incidentally, to point out the effect of a ground wire on multivelocity waves.

In general, there will be as many multivelocity components on a multiconductor system as there are separate line conductors;[1] but for certain conditions of symmetry one or more of these velocities may become redundant. Thus for a 3 phase line with horizontal configuration there will be only 2 independent velocities. For a double 3 phase circuit completely transposed there will be 2, not 6, velocities. Most lines are transposed, or may be so regarded for the purpose of this paper without introducing much error. It is shown in appendix I that on a completely transposed n-conductor system with corona on one of the conductors (the one carrying the main surge), there are only 3 velocities, and all waves induced on adjacent conductors are alike. The multivelocity equations are

$$e_1 = f_1(x - v_1t) + f_2(x - v_2t) + f_3(x - v_3t)$$
$$e_2 = a_1f_1(x - v_1t) + a_2f_2(x - v_2t) + a_3f_3(x - v_3t)$$

in which f_1, f_2, and f_3 are the 3 wave functions, v_1, v_2, and v_3 their respective velocities, and a_1, a_2, and a_3 coefficients depending upon the circuit constants. The inductances and capacitances in turn depend upon the diameter of the corona and the average depth of the ground plane, neither of which in general can be determined. At the point of inception of the surge, all the wave components have identically the same shape, as proved in appendix I; but very soon thereafter the waves become dissimilar because of the different distortions experienced by the components as a result of different corona and ground currents. Thus the problem presented is to find 3 different wave shapes traveling at different velocities, and 3 amplification factors, when all that is given are the 2 oscillograms of the main and induced surges, e_1 and e_2, respectively. Analytically this cannot be done; but as a matter of fact it is possible by cut-and-try sketching to draw fairly good approximations of the wave components, because the points on the oscillograms where the slower components arrive usually are well defined.[1] Of course, even this possibility is defeated if the surge has not traveled far enough for the component waves to separate out so that their presence can be distinguished on the oscillograms.

In the event that the voltage of the surge is below the corona limit and the conductors are completely transposed, a most fortunate simplification takes place. As shown in appendix I, only 2 velocities are present and the a coefficients are evaluated to fixed values independent of the circuit constants; so there results for an n-conductor system:

$$e_1 = f_1(x - v_1t) + f_2(x - v_2t)$$

$$e_2 = \frac{-1}{(n-1)} f_1(x - v_1t) + f_2(x - v_2t)$$

or resolved

$$f_1 = \frac{n-1}{n}(e_1 - e_2) = \text{fast wave}$$

$$f_2 = \frac{e_1 + (n-1)e_2}{n} = \text{slow wave}$$

A paper recommended for publication by the A.I.E.E. committees on power transmission and distribution, and electrophysics, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 28–31, 1936. Manuscript submitted May 6, 1935; released for publication Sept. 13, 1935.

1. For all numbered references see list at end of paper.

For a 3 phase line these relationships become:

$$f_1 = \frac{2}{3}(e_1 - e_2) = \text{fast wave}$$

$$f_2 = \frac{1}{3}(e_1 + 2e_2) = e_1 - f_1 = \text{slow wave}$$

Thus by plotting the oscillograms of e_1 and e_2 together and to the same scale, their difference can be found quickly by a pair of dividers and $^2/_3$ of this difference is the fast wave. The difference between e_1 and this fast wave is the slow wave. Figure 1 shows oscillograms of main and induced surges taken 9.3 and 22 miles from the origin. At the bottom of the figure, these oscillograms have been replotted and resolved into their multivelocity components by the foregoing "$^2/_3$" rule.

The fast wave so found may be seen to fit the front of the main surge quite well, as it should because the slow wave has not yet arrived. The front of the slow component is longer than that of the fast component, and in the 12.7 miles of travel represented by the 2 pairs of oscillograms, the slow component suffers more attenuation. This is because the slow component has an image current in the earth, and therefore experiences the flattening of the front and elongation of the tail characteristic of waves with earth return.[1]

From figure 1 it is also possible to find the velocities of the waves. It is known from both theory and test with traveling waves on transmission lines that the velocity of the fast wave is the velocity of light (or at least very nearly it). Let

Δt = separation of waves at point x on the line
$\Delta t'$ = separation of waves at point x' on the line
t = time of passage of the fast wave

Then

$$(x' - x) = v_1 t = v_2 (t + \Delta t' - \Delta t)$$

$$v_2 = \frac{x' - x}{t + \Delta t' - \Delta t} = \frac{x' - x}{(x' - x)/v_1 + \Delta t' - \Delta t}$$

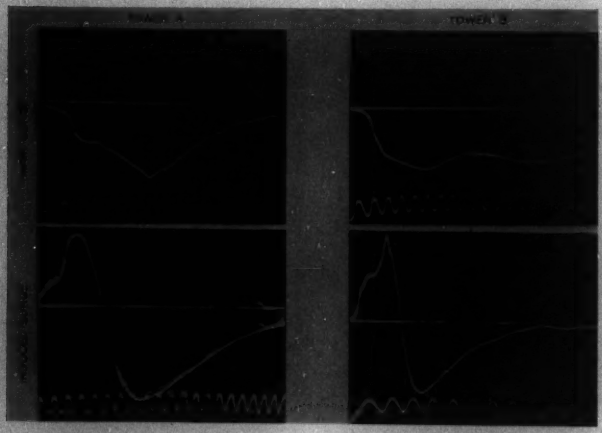
$$= \frac{(x' - x)\, v_1}{(x' - x) + v_1 (\Delta t' - \Delta t)}$$

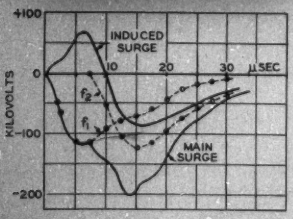
In figure 1 the 2 sets of oscillograms were taken 12.7 miles apart, and the separation of the wave components are $\Delta t' = 15$ at tower B and $\Delta t = 7$ at tower A. Therefore

$$v_2 = \frac{12.7 \times 5280 \times 985}{12.7 \times 5280 + 985\,(15 - 7)} = 880 \text{ feet per microsecond}$$

Thus the slow wave travels at approximately 89 per cent the velocity of light.

It should be remarked that if the main and induced surge oscillograms are not properly matched with respect to their starting points, spurious oscillations and residues will appear in the derived multivelocity components and the front of the fast wave component will not coincide with the front of the main surge. This point is illustrated in figure 2. The top sketch shows a perfect match of the main surge e_1 and the induced surge e_2. The component waves derived from the "$^2/_3$" rule are smooth and definite. The middle sketch shows the same e_1 and e_2, but mismatched by $-\epsilon$. The derived f_1 component no longer coincides on its front with the main surge, while the f_2 component now shows a long undulating toe; several major errors have crept into the analysis: The f_1 component is too high and has too long a front, the f_2 component is too low and has a spurious toe, and the indicated wave separation Δt is too much. The bottom sketch shows the same e_1 and e_2, but mismatched by $+\epsilon$. The derived f_1 component now contains a ripple and has a reduced crest, and its front does not coincide with that of the main surge; f_2 is led by a reversed polarity loop. Since the exact start of a surge is usually indefinite on the oscillograms by a microsecond or more, matching by trial so that the spurious residues vanish and the front of the derived fast wave com-





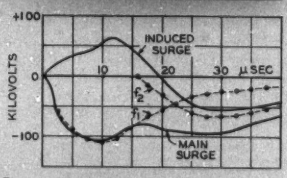


Fig. 1. Resolution of oscillograms into multivelocity components

ponent coincides with the front of the main surge up to the point where the slow wave component appears, seems to be the best criterion for proper matching of the oscillograms.

Effect of Ground Wires

In appendix II it is shown that a ground wire does not add to the number of multivelocity components, but it does change the relative velocities of those components. The proximity of a ground wire lowers the potential at which corona can appear on an adjacent conductor, and the corona envelope is of larger diameter for a given potential; but the greater the diameter of the corona envelope the slower the slow wave,[1] and consequently the more the separation of the components for a given distance of travel. For a surge the voltage of which is below the corona level, however, the slow wave moves faster if a ground wire is present, because the effective inductances are decreased; thus the separation of the waves is not as much in a given distance of travel. From these considerations it would be concluded that the attenuation of a given surge is initially more, but finally less, with a ground wire than without, and this is exactly the situation from field tests.[4] The point is illustrated in figure 3 for both positive and negative surges. It may be noticed that for the negative surge the transition from more to less attenuation occurs at a higher potential than for the positive surge. This is in line with the fact that corona appears at a lower positive than negative voltage. However, the differences of attenuation with and without ground wires are not great.

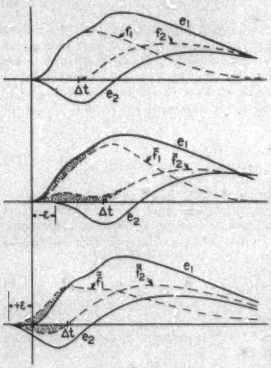


Fig. 2. Spurious oscillations and residues in the multivelocity components resulting from displacement between main and induced surges

Simplified Theory Adequate for Practical Purposes

Multivelocity waves owe their origin to corona and to ground currents in a resistive earth. The effect of a resistive earth on the propagation of steady state currents over a system of parallel wires has been treated rigorously by J. R. Carson in several excellent articles,[5,6] and for such steady state solutions the "modes of propagation" are the counterpart of what are called here the "multivelocity components" of a surge. When the propagation of a single surge over a system of parallel wires is considered,

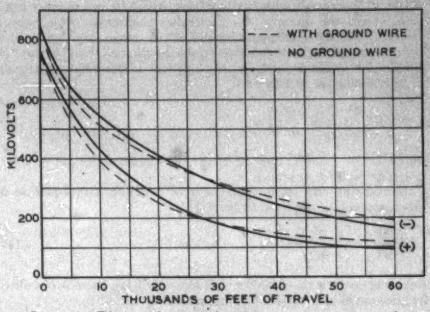


Fig. 3. Effect of ground wire on attenuation of traveling waves

as contrasted to periodic currents, a rigorous mathematical solution based upon Maxwell's equations not only becomes too formidable, but even if it could be achieved the chances are that it would be too complicated for ordinary use. In this paper and its forerunners[1,2,3] only simple multiconductor traveling wave theory is used, and the different velocities appear as a consequence of the corresponding inductance and capacitance coefficients being based upon different ground levels and conductor diameters. That this simplified theory is quite adequate and sufficiently exact for purposes of this paper is now supported by 3 groups of evidence:

1. A great variety of peculiar and otherwise unexplainable distortion and attenuation effects observed on cathode ray oscillograms of surges were shown in the first of these papers[1] to be described qualitatively by the theory.

2. From experimentally determined circuit constants it was shown in the third of these papers[3] that multivelocity waves calculated with these constants checked the cathode ray oscillograms for all the reflections calculated.

3. In the present paper it is shown that the multivelocity theory offers a simple rule for resolving the oscillograms into multivelocity components and that the components so derived obviously fit the oscillograms.

Appendix I—Resolution of Oscillograms of Surges Into Multivelocity Components

The object of this appendix is to derive the relationships existing between multivelocity wave components on a multiconductor transmission system, and to formulate the rules for resolving oscillograms of the main and induced surges at a given point into their multivelocity components. The methods of tensor analysis[7] are found most convenient for this purpose.

In general[1] there will be as many multivelocity components as there are separate line conductors, although for certain conditions of symmetry, one or more velocities may become redundant. As shown in appendix II, ground wires do not add to the *number* of

velocities present, but their presence does change the relative magnitudes of these velocities. Therefore, a system comprising n line conductors is specified with respect to its multivelocity components by n simultaneous equations,[1] which can be written in tensor notation as

$$e_r = a_r^s \left[f_s (x - v_s t) + F_s (x + v_s t) \right] \tag{1}$$

$$i^r = Y^{rs} \left[f_s (x - v_s t) - F_s (x + v_s t) \right] \tag{2}$$

where, in accordance with that notation, r may be any number from 1 to n, and the dummy index s implies summation with respect thereto. The a_r^s coefficients involve all the surge impedances and admittances of the system and are to be determined from the general differential equations. Now the general differential equations of an n conductor system are[1]

$$0 = \left(I_r^s \frac{\partial^2}{\partial t^2} - \delta_r^s \frac{\partial^2}{\partial x^2} \right) e_s \tag{3}$$

where $I_r^s = L_{rw} K^{sw}$, and δ_r^s is the Kronecker delta ($\delta_r^s = 1$ for $s = r$, $\delta_r^s = 0$ for $s \neq r$).

Substituting any wave component of equation 1 in equation 3 there results (for the forward waves):

$$\left(I_r^s \frac{\partial^2}{\partial t^2} - \delta_r^s \frac{\partial^2}{\partial x^2} \right) a_s^Q f_Q (x - v_Q t) = 0 \tag{4}$$

Equating coefficients of waves with like velocities, there is obtained for the system of equations defining a_r^s and v_Q

$$(I_r^s - v_Q^{-2} \delta_r^s) a_s^Q = c_r^s a_s^Q = 0 \tag{5}$$

where in equations 4 and 5 the summation convention with respect to q is dropped by writing it as a capital index Q. The velocities are given by

$$|c_r^s| = 0 \tag{6}$$

This makes it possible to find all the a_r^s coefficients in terms of any number n of them taken arbitrarily, and it may be assumed that

$$a_1^r = 1 \tag{7}$$

Equations 4 and 5, however, imply that the inductance and capacitance coefficients L_{rs} and K^{rs} are known so as to calculate the $I_r^s = (L_{rw} K^{sw})$. Suppose, however, that only the values of e_r are known as cathode ray oscillograms at different points along the line. Then since equation 1 contains $(n^2 - n)$ unknown coefficients a_r^s, n unknown functions f_s, and n unknown velocities v_s, it is clear that the measurement of all values of e_r at a given point on the circuit is not sufficient to evaluate all these unknowns; nor would measurements of the currents obviate the difficulty. Perhaps by taking oscillograms at enough points along the line, the unknowns could be evaluated; but practically this would involve attentuation and distortion effects not included in these equations, and of course would necessitate using many oscillographs. There is, however, a condition that can be taken advantage of to secure a reasonable solution: In order for appreciable distortion to develop as a result of the separation of multivelocity components, the waves must travel so far that the line can be regarded as completely transposed. For a completely transposed line

$$\left. \begin{aligned} L_{rr} &= L \\ L_{rs} &= L' \qquad r \neq s \end{aligned} \right\} \tag{8}$$

The corresponding relationships between the capacitance coefficients may be unsymmetrical because of corona. Suppose that the surge is impressed on conductor 1 (a direct stroke to that conductor). Then the corona will be confined principally to that conductor, and, consequently, for a completely transposed line:

$$\left. \begin{aligned} K^{rr} &= K^{11} \text{ if } r = 1 \\ K^{rr} &= K \text{ if } r \neq 1 \\ K^{rs} &= K' \text{ if } r \neq S \end{aligned} \right\} \tag{9}$$

Therefore

$$\begin{aligned} I_r^s = L_{rw} K^{sw} &= L_{rr} K^{sr} + (L_{rw} K^{sw})_{w \neq r} \\ &= (L - L') K^{sr} + L' \sum_{w=1}^{n} K^{sw} \\ &= K^{rs} L' + (n - 1) K' L' + (L - L') K^{sr} \end{aligned} \tag{10}$$

Hereby

$$\left. \begin{aligned} I_1^1 &= L K^{11} + (n - 1) L' K' \\ I_r^r &= L K + (n - 1) L' K' \qquad = I, \ r \neq 1 \\ I_r^1 &= L' K^{11} + L K' + (n - 2) L' K' = I'', \ r \neq 1 \\ I_r^s &= L' K + L K' + (n - 2) L' K' = I', \ r \neq s, \ s \neq 1 \end{aligned} \right\} \tag{11}$$

Solving equation 5 subject to equation 7,

$$a_s^Q = \frac{-A_s^r}{|b_r^s|} I_r^1 \qquad s \neq 1, \ r \neq 1 \tag{12}$$

where $|b_r^s|$ is the determinant $|c_r^s|$ with the first row and first column corresponding to $r = 1$ and $s = 1$, respectively, deleted, and A_s^r is the cofactor of b_r^s. However, by equation 11 all values of I_r^1 are equal, and the determinant $|c_r^s|$ has all elements along the diagonal equal to $b_r^r = b$ while all its other elements are equal to $b_r^s = b'$. Consequently,

$$a_s^Q = \frac{-I^r}{I + (n - 2) I' - v_Q^{-2}} = a_Q = \text{constant for } s \neq 1 \tag{13}$$

Now by equation 11 the elements of equation 6 are of 4 types:

$$\left. \begin{aligned} c_1^1 & \\ c_r^r &= c'' \qquad r \neq 1 \\ c_r^s &= c' \qquad s \neq 1, \ r \neq s \\ c_r^r &= c \qquad r \neq 1 \end{aligned} \right\} \tag{14}$$

and therefore equation 6 becomes the bordered determinant

$$|c_r^s| = \begin{vmatrix} c_1^1 c' \ldots\ldots\ldots c' \\ c'' c \ldots\ldots\ldots c' \\ \ldots\ldots\ldots\ldots \\ c'' c' \ldots\ldots\ldots c \end{vmatrix}$$

$$= (c - c')^{n-2} \left\{ c_1^1 [c + (n - 2) c'] - (n - 1) c' c'' \right\} = 0 \tag{15}$$

Substituting $c_r^s = (I_r^s - \delta_r^s v^{-2})$ there results

$$\begin{aligned} (I - I' - v^{-2})^{n-2} \{ &(v^{-2})^2 - [I_1^1 + I + (n - 2) I'] v^{-2} + [I_1^1 I + \\ &(n - 2) I_1^1 I' - (n - 1) I' I''] \} = 0 \end{aligned} \tag{16}$$

This equation has 3 nonredundant roots for v^{-2}, that is, only 3 velocities are present. By virtue of equations 13 and 16 the conclusion is reached that on the completely transposed transmission line of any number of conductors and with corona on one conductor only: (1) all waves induced on adjacent conductors are alike, and (2) only 3 velocities are present. Consequently equation 1 may be written

$$\left. \begin{aligned} e_1 &= f_1 (x - v_1 t) + f_2 (x - v_2 t) + f_3 (x - v_3 t) \\ e_r &= a_1 f_1 (x - v_1 t) + a_2 f_2 (x - v_2 t) + a_3 f_3 (x - v_3 t), \ r \neq 1 \end{aligned} \right\} \tag{17}$$

where f_1, f_2, f_3 may differ in magnitude, shape, and sign.

At the point of inception of the surge all the wave components have the same shape. To prove this, let $E(t)$ be impressed on conductor 1 at the point where $x = x_0$. The current in all other conductors at that point must be zero. Then by equations 1 and 2,

$$E(t) = a_1^s f_s (x_0 - v_s t) \tag{18}$$

$$0 = Y^{rs} f_s (x_0 - v_s t) \qquad r \neq 1 \tag{19}$$

Equation 19 may be solved for f_s in terms of f_1, and these results inserted in equation 18 yield

$$E(t) = a f_1 (x_0 - v_1 t) \tag{20}$$

where a involves a_1^s and Y^{rs}; and thus all components, for both forward and backward waves, have identically the same shape, and therefore at the point of inception

$$e_r = a_r^s f (x - v_s t) \tag{21}$$

The waves of different velocity experience very different attenuations and distortions from corona and ground current losses. Consequently, although alike at the point of origin, they soon become dissimilar. For this reason equations 17 must be retained as the general description.

Equations 17 cannot be simplified further, as there are no fixed relationships independent of the line constants among the a *coefficients*. These equations contain 9 unknowns: 3 *velocities* (v_1, v_2, v_3),

3 wave *shapes* (f_1, f_2, f_3), and 3 *coefficients* (a_1, a_2, a_3). There are, however, only 2 given data, the oscillograms of e_1 and e_2. Nevertheless, from an inspection of these oscillograms it is often possible to identify the components by the cut-and-try method.

Now in the special case that the surges are at a voltage below the corona level, $K^{11} = K$ and by equation 11, $I_1^1 = I$ and $I^r = I'$. Hence by equation 16 the velocities are

$$\left.\begin{aligned} v_1^{-1} &= (I - I') \\ v_2^{-1} &= I + (n-1)\,I' \end{aligned}\right\} \quad (22)$$

and equation 13 then gives

$$\left.\begin{aligned} a_1 &= \frac{-I'}{I + (n-2)\,I' - (I - I')} = \frac{-1}{(n-1)} \\ a_2 &= \frac{-I'}{I + (n-2)\,I' - I - (n-1)\,I'} = 1 \end{aligned}\right\} \quad (23)$$

Thus equations 17 for a completely transposed transmission line with surge voltage below the corona level become

$$\left.\begin{aligned} e_1 &= f_1 + f_2 \\ e_r &= -\frac{1}{(n-1)} f_1 + f_2 \qquad r \neq 1 \end{aligned}\right\} \quad (24)$$

Solving these equations,

$$\left.\begin{aligned} f_1 &= \frac{n-1}{n}(e_1 - e_2) = \text{fast wave} \\ f_2 &= \frac{e_1 + (n-1)\,e_2}{n} = \text{slow wave} \end{aligned}\right\} \quad (25)$$

These equations give the multivelocity components directly from the oscillograms of the main surge e_1 and the induced surge e_2 of a completely transposed line when the surge voltages are below the corona level.

Appendix II—Effect of Ground Wire on Multivelocity Waves

To determine the effect of a ground wire on multivelocity waves it is sufficient to consider the ground wire as perfectly grounded throughout its length, because differences in velocity are not very great and the wave separation that can take place in a few spans is quite insignificant.

It may be recalled[8] that the conventional differential equations of a multiconductor line are set up on the assumption that there is a conductance between wires and from wires to ground; but for perfectly grounded wires the conductances to ground are infinite. When these limiting values are inserted in the general differential equations, it is found that the order of the equations is reduced by twice the number of ground wires. If the only conductances present are those infinite conductances to ground of the ground wires, then the differential equation still is satisfied by pure waves, but the number of possible independent velocities is equal to the number of ungrounded wires. Therefore, while ground wires do not add to the *number* of velocities, they do change the numerical *values* of these velocities, because the inductance and capacitance coefficients of the ground wires become involved in the equation.

The difficulties attendant on inserting infinities in the differential equation can be circumvented by considering the number of conductors in the system equal to the number of line wires, and introducing equivalent inductances to take care of the ground wires. In general, if there are m line conductors numbered from 1 to m inclusive and $n - m$ ground wires, numbered from $m + 1$ to n inclusive, the flux linking each conductor, per unit length, is

$$\phi_r = \sum_{s=1}^{n} L_{rs}\, i^s = \sum_{s=1}^{m} L_{rs}\, i^s + \sum_{m+1}^{n} L_{rs}\, i^s, \quad (r = 1 \text{ to } r = n) \quad (26)$$

However, for the ground wires $\phi_r = 0$, and therefore

$$\sum_{m+1}^{n} L_{rs} i^s = -\sum_{1}^{m} L_{rs}\, i^s, \qquad (r = m + 1 \text{ to } r = n) \quad (27)$$

From this latter set of $n - m$ simultaneous equations the currents i_{m+1} to i_n inclusive are determined in terms of the currents i_1 to i_m, and then equation 1 reduce to

$$\phi_r = \sum_{s=1}^{m} L'_{rs}\, i^s \qquad (r = 1 \text{ to } r = m) \quad (28)$$

where L'_{rs} is the equivalent inductance for use in the traveling wave equations.

For example, if there are 3 line conductors and 2 ground wires, by equation 27,

$$\begin{aligned} L_{44}\, i^4 + L_{45}\, i^5 &= -(L_{41}\, i^1 + L_{42}\, i^2 + L_{43}\, i^3) \\ L_{54}\, i^4 + L_{55}\, i^5 &= -(L_{51}\, i^1 + L_{52}\, i^2 + L_{53}\, i^3) \end{aligned}$$

from which

$$i^4 = \frac{(L_{45}L_{51} - L_{55}L_{41})i^1 + (L_{45}L_{52} - L_{55}L_{42})i^2 + (L_{45}L_{53} - L_{55}L_{43})i^3}{L_{44}L_{55} - L_{45}^2}$$

$$i^5 = \frac{(L_{54}L_{41} - L_{44}L_{51})i^1 + (L_{54}L_{42} - L_{44}L_{52})i^2 + (L_{54}L_{43} - L_{44}L_{53})i^3}{L_{44}L_{55} - L_{45}^2}$$

Equation 26 then gives

$$\begin{aligned} \phi_r &= L_{r1}i^1 + L_{r2}i^2 + L_{r3}i^3 + L_{r4}i^4 + L_{r5}i^5 \\ &= \left[L_{r1} + \frac{L_{r4}(L_{45}L_{51} - L_{55}L_{41}) + L_{r5}(L_{54}L_{41} - L_{44}L_{51})}{L_{44}L_{55} - L_{45}^2}\right] i^1 \\ &\quad + \left[L_{r2} + \frac{L_{r4}(L_{45}L_{52} - L_{55}L_{42}) + L_{r5}(L_{54}L_{42} - L_{44}L_{52})}{L_{44}L_{55} - L_{45}^2}\right] i^2 \\ &\quad + \left[L_{r3} + \frac{L_{r4}(L_{45}L_{53} - L_{55}L_{43}) + L_{r5}(L_{54}L_{43} - L_{44}L_{53})}{L_{44}L_{55} - L_{45}^2}\right] i^3 \\ &= L'_{r1}i^1 + L'_{r2}i^2 + L'_{r3}i^3 \end{aligned}$$

which is the same form as equation 28.

The capacitance coefficients K are calculated in the usual way, taking all conductors into account, ground wires as well as line wires.

The traveling wave equations then are set up as though the ground wires were absent, but using the equivalent inductances as given by equation 28 and the capacitance coefficients associated with each line wire.

The effect of a ground wire for surge voltages below the corona level is to *increase* the velocity of the slow component. For this reason attenuation is less with a ground wire (the 2 waves do not separate as rapidly), once the surge voltage gets below the corona level. While the surge voltage is high, however, corona forms on the conductor, and the proximity of the ground wire intensifies this corona, thereby increasing the effective diameter of the conductor and with it the capacitance; and so the velocity of the slow component is less than it would be if the ground wire were not present.

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Power and Energy, Positive and Negative

An attempt to clarify the definitions of power, power factor, and related quantities has led to an intensive study which has included a large number of actual test measurements of the quantities involved. Measurements of positive and negative power, and the use of a "power ratio" based upon these 2 quantities are proposed, particularly for circuits in which the voltages and currents are nonsinusoidal or unbalanced. Positive and negative energy and power can be measured approximately with apparatus commercially available.

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THE development of electrical engineering has called for a continuous readjustment of the concepts that have previously been in use. Up to the time of the introduction of alternating current, the law of Ohm (I equals E/R) was looked upon as unalterable, and as dependable as the laws of the Medes and Persians. This law, upon the introduction of alternating current, had to be modified, i. e. (I equals E/Z). Early a-c theory, for the sake of simplicity, was delimited by the assumption of sinusoidal waves. Various conclusions that were true on the basis of sinusoids were no longer valid when harmonics were present. Upon the introduction of polyphase alternating current, the assumption of a balanced load was the most attractive method of gaining simplicity. Eventually Fortescue's method of symmetrical components came into use for handling unbalanced polyphase circuits.

One of the concepts which in its definition has not kept pace with the development of the art, is power factor. In the good old days of direct current, power was the product of current and voltage. This constituted a law as fundamental as the law of Ohm. To deny this was an act of heresy. In fact, a past-president of the British Institution of Electrical Engineers, prior to 1884 (see page 423 of April 1922, I.E.E. *Transactions*) wrathfully said to an engineer who had experimental proof that in alternating current practice the power was not always equal to the product of the voltmeter and ammeter readings, "You're a liar." Investigation soon proved that the past-president was wrong and the concept of power factor was born. In all these 50 years the definition of power factor has been a difficult problem. The concept, which is exceedingly simple and useful in sinusoidal cases, has become more and more involved as engineers have tried to modify it to cover nonsinusoidal cases and unbalanced polyphase systems. Even to this day engineers have not got over the easily demonstrable fallacy of multiplying voltmeter readings by ammeter readings in nonsinusoidal cases. This product is absolutely meaningless. Definitions of power factor based upon this product are equally meaningless. A desperate effort to clarify and rationalize the situation so far as the definitions of power and related quantities are concerned appeared in a recent paper by H. L. Curtis and F. B. Silsbee.[1] This paper was liberally discussed with no eventual solution in sight for clarifying the definition of power factor for universal application.

The authors of the present paper have been struggling with the same difficulties for a number of years. Finally, in view of the fact that the situation as to definition and measurement of power factor and re-

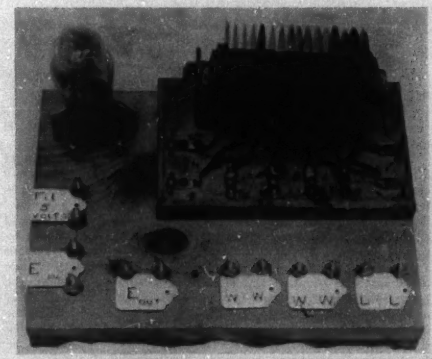


Fig. 1. Apparatus used for measuring positive and negative power and energy

W_1 W_1—Binding posts for connecting the current terminals of the positive wattmeter or watt-hour meter

W_2 W_2—Binding posts for connecting the current terminals of the negative wattmeter or watt-hour meter

LL—Binding posts for connecting the alternating current before rectification

E_{in}—Binding posts for the alternating voltage before rectification

E_{out}—Rectified potential supply for instruments

A paper recommended for publication by the A.I.E.E. committee on instruments and measurements, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 28–31, 1936. Manuscript submitted Apr. 21, 1935; released for publication Oct. 8, 1935.

1. For all numbered references, see list at end of paper.

active factor seems to have reached an impasse, some new method of approach was sought for. This line of attack which has been under way since May 1934 involved an intensive study of positive and negative power, and of positive and negative energy. After this paper was partly written, it was found that certain others had been working along a similar line, investigating the properties of positive and negative power. Notable among these were Messrs. Knowlton, Pratt, and Karapetoff. Since some of this material has already been presented,[2,3,4] it will be used as a starting point, principally that part appearing in the latter half of reference 2. Positive and negative power are entities which are measurable by apparatus to be described later. Whenever the voltage and the current are positive, the power will be positive. If either of them is negative and the other positive, the power will be negative. If both are negative, the power is positive. Integration of the positive power alternations in respect to time gives positive energy. The statement of this definition and the method of measurement of these quantities are perfectly general and not limited to sinusoidal conditions.

For the purpose of charging the customer of electricity, an obvious method would be to itemize his positive energy and negative energy, bill him at so much per kilowatt-hour of positive energy and rebate him at so much per kilowatt-hour of negative energy. This would represent a simple method which avoids entirely the use of the power factor term. In contrast with this proposal the present practice is to meter the net energy (positive − negative) and apply a penalty rate based upon the readings of a power factor meter. In either case 2 meters are required.

The object of this paper is to make a thorough study of positive and negative power and of positive and negative energy. The first part of the paper will be used to describe the apparatus in its final form without detailing the various preliminary developmental steps. The next portion will present the various groups of experimental results, which will be divided into 2 parts: (I) energy data; and (II) power data. Finally, some interpretations of the results and conclusions will be presented.

Apparatus

Figure 1 represents a photograph of the apparatus. Figure 2 represents a wiring diagram, including the apparatus of figure 1 and the accompanying instruments. The objectives in assembling this apparatus were: (1) supply of positive potential and current to one instrument, which will be designated as the positive instrument; and (2) supply of positive potential and negative current to the second instrument which will be designated as the negative instrument. It is necessary ordinarily to base measurements upon only one positive alternation of potential since the second negative alternation of potential repeats the first. In those rare and exceptional cases where the preceding statement is not true, a reversing switch should be included in the potential circuit, so that 2 positive and 2 negative readings may be obtained. The instruments used were electrodynamometer type wattmeters for power measurements and d-c type watt-hour meters for energy measurements. For rectifying the potential a type 80 vacuum tube was used. For rectifying the current a 4-part copper-oxide rectifier unit, arranged in the familiar bridge circuit, is used. A wide range of current values may be measured by interposing a current

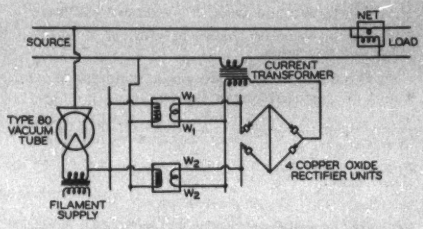


Fig. 2. Wiring diagram of apparatus for measuring positive and negative power and energy, with the necessary meters

transformer between the line and the copper oxide rectifier unit. The diagram of figure 2 is applicable to single phase tests. By use of a 2 element wattmeter or watt-hour meter and 2 such pieces of apparatus as shown in figure 1, measurements may be made on 3 phase circuits. In the present experiments a special metering panel was used to make 1 wattmeter serve in the familiar 2 wattmeter method.

Experimental Results on Positive and Negative Energy in Single Phase Cases

In these tests since only one d-c watt-hour meter was available, the watt-hour meter is placed across W_1W_1 (figures 1 and 2) for positive energy measurements and across W_2W_2 for negative energy measurements. A dynamometer type wattmeter was connected to W_2W_2 during the positive energy measurements and to W_1W_1 during the negative energy measurements. The watt-hour meter, a 10 ampere 110/220 volt d-c meter, was first calibrated on an ordinary d-c supply. Next the watt-hour meter potential circuit was corrected for the drop in the type 80 tube by shunting a decade resistance box across the resistance unit in the armature circuit, the resistance being set at 1,400 ohms. After this adjustment, a test was made to determine the positive and negative energy supplied to a load of 2 carbon lamps in parallel.

Results of the first test were as follows:

Positive energy by the watt-hour meter; 6 revolutions in 108 seconds; $6 \times 1/3 \times 2$ equals 6 watt-hours. (In this product, "1/3" is the meter constant and "2" is used because the meter is in action only every other alternation.)

Negative energy by the watt-hour meter; 0 revolutions in 108 seconds; zero watt-hours.

Net energy by watt-hour meter; 6 watt-hours.

Net energy by a wattmeter connected to the load in the ordinary way; reading 200 watts; $200 \times 1/3{,}600 \times 108$ equals 6 watt-hours.

A second test was made on a condensive load of about 15 per cent power factor. The load consisted of 40 2 microfarad paper condensers in parallel with a resistance load.

Positive energy by watt-hour meter; 8 revolutions in 150 seconds; $8 \times {}^1/_3 \times 2$ equals 8 watt-hours.

Negative energy by watt-hour meter; 5 revolutions in 150 seconds; $5 \times {}^1/_3 \times 2$ equals 5 watt-hours.

Net energy by watt-hour meter; $8 - 5$ equals 3 watt-hours.

Net energy by wattmeter; reading 67 watts; $67 \times 1/3{,}600 \times 150$ equals 2.79 watt-hours.

A third test was made on a condensive load of about 26 per cent power factor.

Positive energy; 13 revolutions in 412 seconds; $13 \times {}^1/_3 \times 2$ equals 13 watt-hours.

Negative energy; 5 revolutions in 412 seconds; $5 \times {}^1/_3 \times 2$ equals 5 watt-hours.

Net energy; $13 - 5$ equals 8 watt-hours.

Net energy by wattmeter; reading 66.6 watts; $66.6 \times 1/3{,}600 \times 412$ equals 7.62 watt-hours.

A fourth test made on an inductive load of about 39 per cent power factor.

Positive energy; 18.5 revolutions in 493 seconds; 18.5 watt-hours.

Negative energy; 5 revolutions in 493 seconds; 5 watt-hours.

Net energy; 13.5 watt-hours.

Net energy by wattmeter; reading 88.1 watts; $88.1 \times 1/3{,}600 \times 493$ equals 12.1 watt-hours.

It should be noted that in the last 3 tests the net energy as measured by the watt-hour meter was 7, 5, and 10 per cent too large, respectively, but correct for the noninductive load. For discussion of the error characteristics of commutator type watt-hour meters operating on alternating currents, see reference 5.

Experimental Results on Positive and Negative Power in Single Phase Cases

In these tests 2 ordinary dynamometer type wattmeters were used across W_1W_1 and W_2W_2 of figures 1 and 2, to measure positive and negative power. A third dynamometer wattmeter was connected to measure the net power taken by the load. In figure 3, positive, negative, and net power are plotted for a particular case. No attempt was made to correct the voltage applied to the W_1W_1 and W_2W_2 wattmeter potential coils for the drop in the type 80 tube. Consequently the positive and negative power values shown in figures 3 to 6 are low by 15 to 20 per cent. The tests of figures 3 to 6 represent the variation of positive and negative power as a variable sinusoidal potential is applied to various load circuits.

Power Ratio

Although the values of power shown in figures 3 to 6 are only approximate, the ratio of W_1W_1/W_2W_2 will have but little error, and may be measured accurately without correcting for the tube drop, or for such small errors as go with the use of copper oxide rectifier units.[6] This ratio for the purpose of

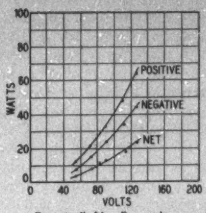


Fig. 3 (left)—For a long solenoid with iron core

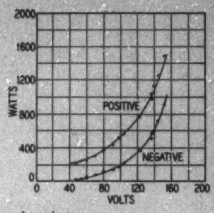


Fig. 4 (right)—For a 3-phase 7.5-horsepower 110-volt induction motor operating single phase

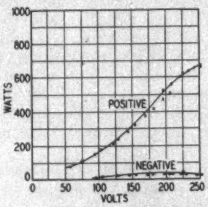


Fig. 5 (left)—For a 2-horsepower single-phase 220-volt capacitor induction motor

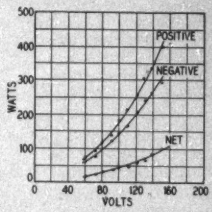


Fig. 6 (right)—For a single phase transformer, 3 kva 110/2,200 volts supplying a capacitance load

Figs. 3–6. Positive and negative power curves with variable sinusoidal electromotive force applied. Net power by an indicating wattmeter

the present paper is defined as the "power ratio" and is equal to (positive power)/(negative power). It is a very convenient index number to use in the diagnosis of the characteristics of a load circuit. For single phase sinusoidal cases this ratio has a fixed relation to power factor, thus

$$\frac{\text{positive power}}{\text{negative power}} = \frac{(\pi - \phi)\cos\phi + \sin\phi}{\phi\cos\phi - \sin\phi}$$

where ϕ is the phase angle between the current and the voltage. This relation is plotted versus power factor ($\cos\phi$) in the curve of figure 7.

It was arranged to check the accuracy of the apparatus of figures 1 and 2 against this curve for a wide range of power factors, by providing a variable phase angle through the medium of a phase shifter. A voltage of approximately 110 volts was maintained across the E_{in} terminals of figure 1 and across the potential coil of a standard wattmeter. A current of approximately 1.33 amperes was maintained in all the wattmeter current coils. For each setting of the phase shifter, readings were made of the standard voltmeter, ammeter, wattmeter, W_1W_1, and W_2W_2 values. The observations, obtained in this test, provide values of power factor and power ratio, which are plotted as crosses in figure 7 and which show a very close check with the theoretical curve. Equipped with this rapid and fairly accurate method

of diagnosis, a wide range of apparatus was studied under a variety of experimental conditions. As a sample of such testing note the circles on figure 7. In this test readings of voltmeter, ammeter, and wattmeter fix the power factor. The readings W_1W_1 and W_2W_2 fix the power ratio. Figures 5 and 7 (circles) were derived from the same test. Other tests were carried out to fix the relation of power ratio to power factor for: (*a*) an ordinary 3 phase induction motor operating single phase; (*b*) an ordinary 3 phase induction motor operating 3 phase, with test data taken between one line and neutral; and (*c*) a long solenoid with a variable length iron core. Since in these tests there was little departure from sinusoidal shape in either the current or voltage wave, the observations substantially checked the single phase curve of figure 7.

To illustrate what happens when the waves are not sinusoidal, an electromotive force with a 100 per cent fifth harmonic was used to supply a variable power factor circuit consisting of a resistance in parallel with a condenser. The results of this test are shown in figure 8 (crosses), where the observations are consistently off the theoretical curve. It is safe to conclude that barring errors in reading, a departure from the curve of figure 7 is a sure indication of the presence of nonsinusoidal current or voltage waves. Furthermore, the failure of an observation to lie on the curve is an indication that the simple definition of power factor as the wattmeter reading divided by the product of the voltmeter and ammeter readings is not applicable to that case. Figure 8 (circles) is a further illustration of a nonsinusoidal case. A 500 cycle homopolar alternator with a pronounced fifth harmonic is used to supply power to a variable power factor circuit consisting of a resistance in parallel with a condenser. Here again the observations are at wide variance with the theoretical curve. Figure 8 (triangles) is a final example of nonsinusoidal cases, in which an incandescent lamp load is paralleled by a transformer supplying 2,200 volt capacitors, and in which the source of supply is sinusoidal.

After several hundred measurements of power ratio for a wide variety of cases, the authors have become convinced of the utility of this ratio for describing the characteristics of a circuit. It is superior to the term power factor on the score of: (*a*) simplicity of conception, involving the simple idea of the ratio of 2 numbers in contrast with the concept of a trigonometrical function; (*b*) easy and accurate measurement in all cases, sinusoidal or nonsinusoidal; and (*c*) definition not influenced by the presence of harmonics.

The ratio of positive power to negative power has for different power factors, values as follows:

Power factor	0	10	20	30	40	50
Power ratio	1	1.37	1.89	2.64	3.78	5.6
Power factor		60	70	80	90	100
Power ratio		8.73	15	30.4	71.4	∞

For different angles between voltage E and current I, this ratio has values as follows:

Angle, degrees	90	80	70	60	50
Power ratio	1	1.735	3.06	5.6	10.9
Angle, degrees	40	30	20	10	0
Power ratio	23.3	59	214.5	1,930	∞

Possibly some might take exception to a ratio which has a value of infinity at unity power factor. If such a feeling exists, the reciprocal ratio, or negative power divided by positive power might be suggested, in which case the variation of the power ratio would lie between unity and zero.

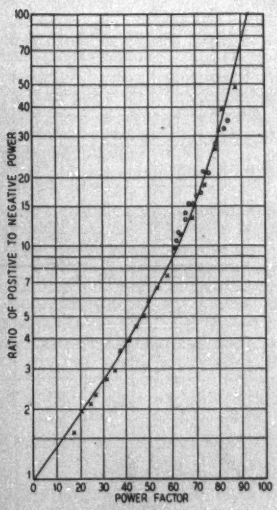


Fig. 7 (left). Relationship between power ratio and power factor, for single phase cases. Sinusoidal cases

Crosses—Measurements of the relation between power ratio and power factor obtained with the test apparatus. These points show a close check with the theoretical curves

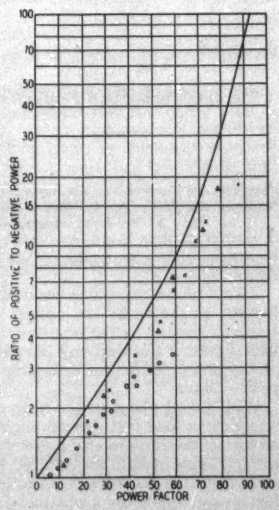
Circles—Measurements with a single-phase 2-horsepower capacitor motor, running light, with varying sinusoidal impressed electromotive force

Fig. 8 (right). Results of 3 different tests on the relationship between power ratio and power factor, for single phase cases. Nonsinusoidal cases.

Crosses—Measurements with a 100 per cent fifth harmonic electromotive force impressed

Circles—Measurements with a homopolar 500 cycle alternator, supplying a resistance-capacitance load

Triangles—Measurements with a constant sinusoidal electromotive force impressed on a single phase transformer supplying 2,200 volts capacitors, the transformer paralleled by a variable resistance load



Experimental Results on Positive and Negative Power in 3 Phase Circuits

The power ratio, having proved in the opinion of the authors such a valuable index in single phase cases, was next extended in its application to 3 phase measurements. In 3 phase measurements the 2 wattmeter method is commonly employed. The 2 wattmeters in this method have applied to them, currents and voltages which on noninductive load are 30 degrees out of phase. This peculiarity of the 2 wattmeter method leads to a different curve, relating power factor and power ratio in 3 phase measurements. Thus with a unity power factor balanced 3 phase load, the wattmeters have impressed upon them currents and voltages which have a phase angle between them of 30 degrees. Consequently, the ratio of positive to negative power at unity power factor and with 3 phase loads corresponds to an 86.6 per cent power factor with single phase loads. This correspondence between the single phase and 3 phase curves may be seen in figure 9, where a horizontal line joins the unity power factor point on the 3 phase curve with the 86.6 per cent power factor point on the single phase curve at a power ratio value of 59.

For some other value of power factor, say 70 per cent, ϕ equals 45 degrees and 34 minutes, the 2 wattmeters experience phase angles of 75 degrees, 34 minutes and 15 degrees, 34 minutes, respectively. If the line voltage is assumed to be 100 and the line current to be 10, the wattmeters will read $10 \times 100 \times \cos$ 75 degrees 34 minutes, which equals 249 watts, and $10 \times 100 \times \cos$ 15 degrees 34 minutes which equals 963 watts. The single phase power ratio for the first case is 2.23. Thus

2.49 = (positive power) − (negative power)
2.23 = (positive power)/(negative power)

Therefore

Positive power = 451
Negative power = 202

The single phase power ratio for the second case is 1,072. Thus

Positive power = 963.9
Negative power = 0.9
Total positive power of both wattmeters = 451 + 963.9 = 1414.9
Total negative power of both wattmeters = 202 + 0.9 = 202.9
Ratio of (total positive power)/(total negative power) = 6.98

A similar process is applied to other values of power factor in order to complete the 3 phase curve of figure 9.

This 3 phase curve was checked for various power factors, as shown by the crosses on figure 9. This test was similar to the one described in connection with figure 7 (crosses) and likewise involved the use of the phase shifter for obtaining various values of power factor.

With this 3 phase power ratio curve as a basis of reference, a load test was run on a 3 phase induction motor to obtain values of power factor versus power ratio. These results are plotted in figure 9 (circles) and check the theoretical curve quite satisfactorily. For a case where the 2 wattmeter power ratio is 10, then the power factor is 80 per cent. Since the single phase power ratio is 30 for this power factor, the physical nature of the induction motor for this load is such that it returns to the source one watt out of every 30 watts received.

The next 3 phase test was run on a Fynn-Weichsel synchronous induction motor. One of the field circuits was excited by a separate d-c source which provided a varying field current and thus conveniently varied the power factor of the motor. In this case the impressed voltage was sinusoidal, but the currents were nonsinusoidal. Consequently the observations lie off the theoretical curve (see figure 10). The apparatus was then used to measure the power ratio for 16 cases of unbalanced 3-phase star-connected and delta-connected loads with various leading and lagging currents in each branch. These ratios were 8.35, 2.29, 31.3, 33.2, 8.85, 8.18, 1.9, 1.682, etc. These values, although easily obtainable from the positive and negative components of the 2 wattmeter method, are in no way indicative of the character of the load. They do, however, give an indication of what is taking place at the boundary where the wattmeter measurements are made. In the case of the 31.3 and 33.2 power ratios the load was predominantly noninductive, consisting of 2 wall lamp boards taking several kilowatts each and in the third phase a single phase induction motor running light and taking a 0.5 kw. In the case of the 1.9 and 1.682 power ratios the load was predominantly inductive, consisting of 3 loads taking about the same apparent power, 1 branch at unity power factor and the other 2 at about 6 per cent power factor lagging. In contrast with the unbalanced 3 phase case, in the single phase and balanced 3 phase case the power ratio not only gives an indication of what is happening at the boundary

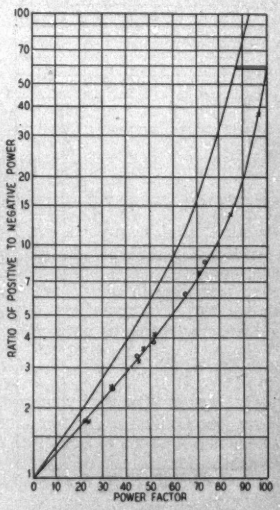


Fig. 9. Relationship between power ratio and power factor, with 3 phase balanced loads. Sinusoidal cases

Crosses—Measurements to check 3 phase curves of the relationship between power ratio and power factor, using a 3-phase phase shifter to vary the power factor. These points show a close check with the theoretical curve

Circles—Measurements with a 7.5-horsepower 3-phase induction motor, variable load with sinusoidal impressed electromotive force

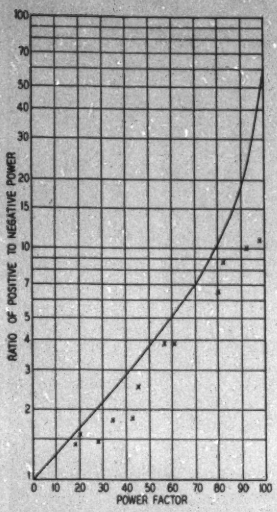


Fig. 10 (left). Relationship between power ratio and power factor with 3 phase balanced loads. Nonsinusoidal cases

Measurement with a 15-horsepower 3-phase synchronous motor, Fynn-Weichsel type, running at light load and varying field current, with sinusoidal impressed electromotive force

Fig. 11 (right). Relationship between power ratio and power factor with 3 phase balanced loads

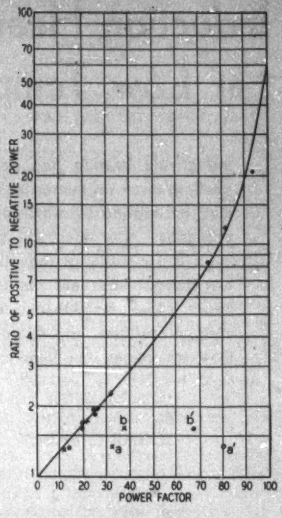
Measurement with a 3-phase 15-kva alternator, running light as a synchronous motor, field current varied

Points a, a′, b, and b′ correspond to the bottom of the V

Circles—Power factor by ratio of wattmeters

Crosses—Power factor by $\frac{\Sigma WM}{\sqrt{3}VM \times AM}$, where WM, VM, and AM represent wattmeter, voltmeter, and ammeter readings, respectively

Dots—Same motor loaded with 7.5 kw load, power factor by ratio of wattmeters



where measurements are taken but in addition fixes the characteristics of the circuit.

Finally, a series of tests was run on a 15 kva alternator, operating as an ordinary synchronous motor. Both light load and load tests were made. Power factor was calculated in 2 ways: (*a*) by ratio of wattmeter readings; and (*b*) by dividing the sum of the wattmeter readings by $\sqrt{3}$ times the product of voltmeter and ammeter readings. Sinusoidal electromotive forces were impressed on the motor. Except for points near the bottom of the "V" there was a good agreement between the observations and the theoretical curve. In the region of the bottom of the "V," where the fundamental currents to supply the load are at their minimum value, harmonics have their greatest effect. It should be noted that this particular synchronous motor was subject to considerable hunting, which would introduce some distortional currents. The results of these tests are shown in figure 11.

In using the 3 phase curve of figure 9 it should be pointed out that this curve is simply an adaptation of the single phase curve to the 2 wattmeter method of measuring 3 phase power. Therefore, in describing the characteristics of a 3 phase circuit, the procedure should be: (*a*) measure the power ratio and thus the power factor, using the 2 wattmeter method, for example, a power ratio of 7 and a power factor of 70 per cent; and (*b*) record as the true power ratio of that particular circuit a value of 15, the corresponding single phase value taken from figure 9.

Summary and Recommendations

It has been the purpose of this paper to demonstrate that positive and negative energy and positive and negative power may be measured approximately with apparatus commercially available. By adjustments of potential coil resistances for tube drop, and possibly if considered desirable by shunting current coils with suitable noninductive shunts to correct for inductances in the potential coil circuits, much greater accuracy should be obtainable.

It has been demonstrated further that the power ratio is a circuit characteristic which is measurable, definable, and a readily interpreted quantity for all conditions, single phase or balanced 3 phase, sinusoidal or nonsinusoidal. Power factor, as a circuit constant, is measurable, definable, and readily interpreted only for sinusoidal cases, single phase and balanced 3 phase.

There is no disposition on the part of the authors to recommend any departure from present procedure in measuring power, energy, and power factor in the ordinary cases. When, however, through considerable distortion of wave shapes or considerable unbalance of 3 phase loads, power factor, as at present limited in its definition, is no longer a reliable indicator, recourse may be made to a set of positive and negative wattmeters or watt-hour meters for the more equitable determination of the cost of power.

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Induction Heating at Low Temperatures

Inductively heating iron parts for drying coatings discloses interesting features which may be applied to other low temperature processes. The electrical design of the oven and circuits for induction heating at low temperatures are considered in this paper. Low maintenance and operating costs, cleanliness, and reduced processing time are among the features available.

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Fig. 1. A typical section of an induction heating oven for low temperature processes

INDUCTION heating as related to melting and very high temperature work has been repeatedly reported in the publications of the Institute, and the knowledge of the design and operation of both core and coreless melting furnaces is familiar and well understood by the electrical engineer. Induction heating as related to relatively low temperature work and for the unique purpose of baking paint or rapidly drying wet metal parts, apparently has not been previously reported in ELECTRICAL ENGINEERING. Drying paint from the "inside out," expelling the volatile products from the layer of paint next to the metal before the surface seals over, produces an exceptionally firm smooth film. Induction heating seems to be practically the only way of accomplishing this kind of drying on metal parts painted all over.

The efficiency of this type of heating is high, as the part to be processed has the heat generated directly in itself. The use of a relatively moderate frequency and voltage results in a satisfactory power input and rate of temperature rise in thin sheet metal parts, and also permits the use of practical commercial equipment.

The continuous conveyor type of oven lends itself particularly to this form of heating; polyphase windings and movement of the processed parts result in even heat being obtained. The oven is largely self-regulating in its action, as the power decreases when the parts pass out of the coil.

The fire risk in the oven is low, as the hottest point is in the part being baked. The inductor coils run relatively cool. Also, economy is effected due to the fact that the necessary air discharged to carry away the volatile products of the baking is 30 to 50 degrees lower in temperature than the baking temperature. Reduced time in baking, extremely low maintenance, together with exceptionally clean uniform work, have been obtained in the production units. A total capacity of over 600 kw of these units has already been installed.

DESCRIPTION OF OVEN

An induction oven suitable for paint baking makes use of no new fundamental principles, but rather applies the well-known laws of electromagnetic induction to a particular industrial thermal process. The oven consists essentially of a group of coils or solenoids so arranged that the metal parts to be heated are passed through them by some type of continuous conveyor. The coils are excited from a polyphase circuit to produce continuously varying magnetic fields both as to time and direction, the field strength and frequency being such as to produce the rate of temperature rise required by the process. Figure 1 shows a typical section. An enclosure of thermal insulation is provided for conveyor and coils in order to reduce radiation from the heated parts and conserve the I^2R loss of the inductor, as well as provide means of controlling the movement and disposition of the volatile products driven off the painted parts being baked. Figure 2 shows the relation of these items in the completed induction

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oven designed for baking enamel on automobile wheels.

A coil through which an automobile fender may be carried on a single chain conveyor must be about 7 feet high by 4 feet wide, while the coil for an entire automobile body is 6 feet square. Such large coils can be made of such a wire size that the IR drop is small but the IX drop is enormous with the resulting power factor (without work in the coils) of 15 to 17 per cent. Static condensers are used to bring the power factor up to nearly unity at no load, the worst condition on the circuit.

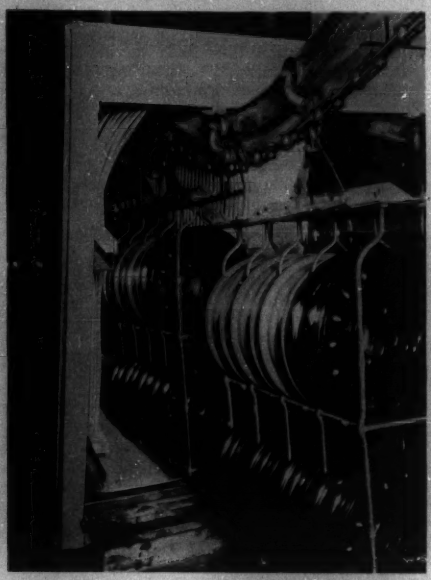


Fig. 2. Completed induction oven for baking enamel on automobile wheels

Polyphase is used for the groups of coils, which may be mounted either horizontally or vertically or both, in order to produce a more widely varied direction of flux in the irregularly shaped parts and thus produce more even heating effects. Single phase fields on fixed position parts gave very uneven heating and proved entirely unsatisfactory for paint baking where fairly uniform temperatures are important.

The selection of the proper frequency for the low temperature induction process involves satisfying 2 electrical requirements. In order to produce the watts loss required in the "work" at a rate that will raise the temperature in the time allowed, the frequency must be high enough to give a sufficiently rapid change of flux in the work, and still it must be low enough to permit the use of high currents in the primary conductors so as to give a sufficient quantity of flux in the work. The use of a relatively moderate frequency and voltage, 360 cycles and 440 volts, 3 phase, permits a satisfactory power input and rate of temperature rise even in thin sheet metal parts, and also permits the use of practical commercial generators and static condensers and low voltage insulation in the oven coils and circuits. Higher frequencies would produce the same hysteresis and eddy current losses in the metal parts at a lower flux density but the field produced by the inductor or primary coils at the lower ampere turns would have to be at a voltage too high for easy insulation.

The rate of temperature rise in sheet metal parts for various field strengths and frequencies was determined by tests, as the large air gaps and constantly changing radiation from the heated part made calculation difficult. Figure 3 shows the heating of a 6 by 12 inch panel of number 18 ordinary sheet steel similar to that used in automobiles, held in 180-cycle-per-second fields of different strengths. Figure 4 shows the effect of change of frequency at a fixed field strength. These are test values obtained on a sheet held in a vertical position in free air and show about what may be expected on work going into an oven hung on a conveyor.

Figure 5 shows the calculated power absorption

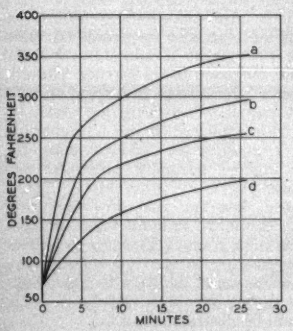
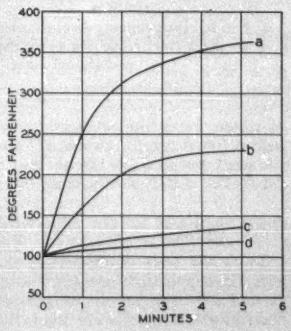


Fig. 3. Temperature-time curves showing effect of different field densities on a number 18 gauge sheet steel, at 180 cycles per second

a—300 ampere turns per inch
b—250 ampere turns per inch
c—150 ampere turns per inch
d— 66 ampere turns per inch

Fig. 4. Temperature-time curves showing effect of different frequencies on sheet metal hung vertically in flux fields

a—35 amperes at 360 cycles per second
b—35 amperes at 180 cycles per second
c—70 amperes at 60 cycles per second
d—35 amperes at 60 cycles per second



of a piece of 40 mil sheet at a flux density of 90,000 lines per square inch, it is very different from the possible absorption in an actual induction oven due of course to the low flux densities possible. The curve is given to show the small possibility of heating thin sheets of metal by 60 cycles.

Figure 6 shows the time-temperature effect on a sheet of steel made into a very shallow pan and filled

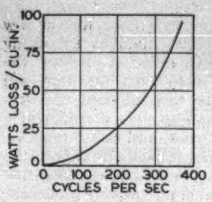


Fig. 5. Loss-frequency curve showing power absorption of a number 19 gauge body steel at a flux density of 90,000 lines per square inch, for different frequencies

with water when put into the magnetic field. Note that the temperature of the wet pan rises rapidly to the temperature where the work done to evaporate the water balances the input, and the temperature remains practically constant until all the water is evaporated. The sudden drop in temperature indicated at the moment all the water is evaporated is probably due to the wet bulb effect. All traces

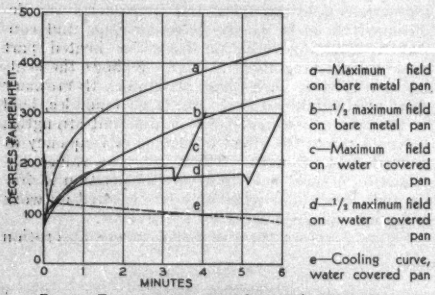


Fig. 6. Temperature curves showing heating effect on sheet steel made into a very shallow pan, with and without water

of water are entirely removed at a temperature well below 200 degrees Fahrenheit, also a large part of the work put into the circuit goes directly to evaporating the water, not heating the surrounding air.

Coil Design

From the tests accumulated, the number of ampere turns and time necessary to raise the temperature of a part of known weight to a desired heat is determined, and coils are then designed to produce this average heating over a distance of the oven length equal to the travel of the conveyor in this time. For example, if the conveyor moves one foot per minute and it takes the painted part 5 minutes to reach the baking temperature, the first group of coils will be 5 feet long. After the baking temperature is reached the flux density in the remaining length of the oven is reduced to that necessary simply to hold the heat. The power to be absorbed is known by the weight of the metal parts to be heated. The frequency and voltage of this circuit having been selected, and the power factor and ampere turns having been determined by test, there remains simply the calculations for impedance.

From the equations $X = 2\pi LF$ the inductance required is determined, and substituting the value of L in the air core inductance formula $L = a\,n^2\,Q2.54 \times 10^{-9}$, the number of turns for the coil is easily found. The fact that there are to be iron parts in the coil affects the calculations only slightly, the air gap reluctance being so great. Twenty to 30 turns carrying 250 to 300 amperes makes an average coil covering 3 or 4 feet of length along the oven.

Regulation of Heat

The regulation of the bake is determined by the flux density and the speed of the conveyor so that when the correct values are once determined, the regulation is inherently automatic. For when there is nothing going into the coils no heat is generated except the I^2R loss of coils, which is made to balance oven wall radiation.

The production ovens have a thermostat arranged to increase the ventilation from practically nothing when no "work" is going into the oven to the maximum required when the heat generated in freshly painted parts raises the air temperature in the oven. Thus the volatile products from the baking are removed as they are released, and power input is kept down to a minimum when no baking is required.

Since the work being processed furnishes the heat for the oven, naturally the "work" is the hottest spot in the oven. The air surrounding the parts in the oven generally is 30 to 50 degrees lower in temperature than the work, so that the heat loss from radiation through the oven walls and from ventilation by necessary air to scavenge the oven of volatile products is much lower than for any other type of oven. Most paints can also be processed more quickly than with other forms of baking, so that the oven is shorter and radiation losses further reduced.

Records kept on a large production oven showed 160,000 metal automobile wheels weighing 4,800,000 pounds took only 54,500 kilowatt-hours, a production efficiency of $87^1/_2$ pounds per kilowatt-hour for baking synthetic enamel normally processed one hour at 250 degrees.

Low maintenance, low fire risk, low operating cost, exceptional cleanliness, reduced time in processing with reliable high grade work seem to be features of induction heating in the low temperature field; and many processes in addition to paint baking, cleaning, and drying should be developed using this convenient form of electric heat.

Vibratorily Commutated Stationary Conversion

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A system of stationary conversion of electric energy from a-c to d-c form is described in this paper in which commutation is effected by harmonically vibrating contacts actuated electromagnetically. Combined with the vibratory commutative system is a special transformer with closely coupled primary and secondary windings which are subdivided into numerous phases corresponding to the coils of a Gramme ring; the travel of the electromagnetic field that actuates the vibrating contacts is in synchronism with the travel of flux polarity in the respective transformer members. A model converter embodying these principles is described and illustrated.

THE CONVERTER here described consists of the combination with a vibratory commutative system, of a stationary transformer having a single core system and a winding subdivided into numerous phases corresponding to the coils of a Gramme ring. In synchronism with the travel of the flux polarity in the transformer member is an invisible rotation of the zones of contact among the elements of the vibratory commutator, each unit of which serves a coil. The performance is conversion rather than rectification, in that there is a flow of polyphase current (i. e., continuous power) into the magnetic reservoir of the machine and a corresponding output flow of continuous current and power.

The vibratory commutation here described consists of the effectuation by means of harmonically swinging contacts, of qualitatively the same events that occur while the bars of an ordinary commutator slide under their brushes. These occurrences include in sequence the short-circuiting of each coil through the commutative period, the reversal of the direction of its external connection, and, finally, by the termination of the short circuit, the reinsertion of the coil in series with the others. In the new conversion, such commutation is effected dually, i. e., separately adjunct to the primary winding as well as in the secondary.

Where the input is of alternating currents, as ordinarily, the primary commutator operates in parallel with the winding and its supply; but where the input is of direct current, this commutator stands in the familiar series relationship as a "turnstile." In the usual case of a-c supply, the exciting current does not go through the "turnstile"; and the fact that it slips in otherwise (wattlessly) accordingly does not disturb the commutation. Nor does the small wattless current pass through the commutator in inversion or double conversion, being separately supplied by 3-phase leads.

In apparatus based upon these principles there must be included a correlating electromagnetic means for swinging each moving contact in unison with and in progressive phase relation to the polyphase transformation. The new commutative unit calls for a new name; accordingly the term "transmuter" is offered to designate the compact assembly, separate from the transformer, in which functionally are joined the stationary and moving contacts, the tuned reeds carrying the vibrating contacts on their ends, the reed actuating system, and the common supporting structure.

The type of transformation required with this conversion, which is mechanically nonrotatory but electromagnetically synchronous, is that wherein ordinary 2 or 3 phase power is translated into a magnetic field of poles rotating or traveling in the core. Therefrom the power is passed back into the electric state in a winding subdivided into numerous (*e. g.*, 12 to 60) primary-secondary units, in which the magnetic travel produces voltages of a corresponding number of timings or phases. The currents in the successively spaced coils are led by taps, as in the ordinary commutator, to the corresponding members of the vibratory system where transpire the commutative steps just outlined. The inductive aspects of commutation are discussed more fully later; but it should be noted here as essential that the load current inductive effects are neutralized by the combination of the mentioned dual commutation with close coupling of the primary-secondary coils.

While the new converter may be typified somewhat as a locked-rotor polyphase induction motor having a secondary winding provided with many taps brought out to the electromagnetically actuated commutative system, or as a rotary converter made stationary and having the excitation of its d-c field replaced by that of the a-c supply system, these comparisons are less simple and correct than the modified-transformer concept outlined. Extension of the rotatory analogies easily may distort the true picture of the stationary converter as a transformer, because of the large quantitative deviations in these comparisons to an apparatus having no whirl, no slip, no kinetic instability, no d-c field excitation, no high gap reluctance, and no separation of primary and secondary turns by their being mounted upon

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stator and rotor or even across an air gap in stationary apparatus. The new converter does not have differential armature currents as does a rotary converter, but it does not require separate transformers as does the latter for standard voltages.

Schematic Description

Figure 1 is a system diagram of a complete converter, comprising the transformer below and the transmuter above. For convenience of subsequent explanations and comparisons, the lower half of the transmuter diagram depicts the elements of one form of reed support and actuation, and the upper half shows another form differing only in these 2 aspects of the reeds. The contact system is the same in both. The lower form is designated as one of "xylophone reeds," and the upper as the "cantilever reed form." Attention is called to the reference numbers, which are mainly common to the 2 forms. The 2 sets of co-ordinated contacts, right and left, form the 2 separate but co-operative commutators. In each, the successive contactings of the moving members overlap in time as do those of the segments in ordinary commutation. The number and joint functioning of the parts thus distinguish the vibratory commutator from the vibratory rectifier.

The present development has been directed partly toward proportioning the contacts for current capacities sufficient for industrial scale operations, i. e., with working surfaces of the order of major fractions of a square inch, and larger. Accordingly, a 3-phase 60-cycle model has been built having a rating suitable for input from ordinary panel circuits, i. e., about 30 amperes at 208 volts. Its output rating is 10 kw in d-c series-parallel combinations of 180 amperes at 56 volts or 360 amperes at 28 volts, or the corresponding 3-wire values. Its transmuter is of the xylophone reed form, the earlier of the 2 designs.

This presentation does not detail the application of vibratory commutation to other than synchronous conversion, although mention should be made of inverted conversion and of double conversion, that is, from direct current to direct current. In inversion or double conversion the transformer may receive the small currents of its polyphase excitation from an auxiliary source, such as a little motor generator or an oscillatory circuit system tuned to the proper frequency. Dual commutation should be employed in inversion as in conversion, i. e., the operation is reversible.

The design yields mainly to rational calculation and, largely through the neutralizing of inductive effects, has left little for new empirical determination, either of an electrical or mechanical nature. For the vibrating system the starting point is the dimensioning of the reeds according to well established formulas in terms of space, density, and elasticity. As a manufacturing convenience, Young's modulus for steel is practically unvarying as between the annealed state during forming and the spring-hardened final condition. Of greater importance, the elastic property is unchanging with age and is affected too little by temperature to alter

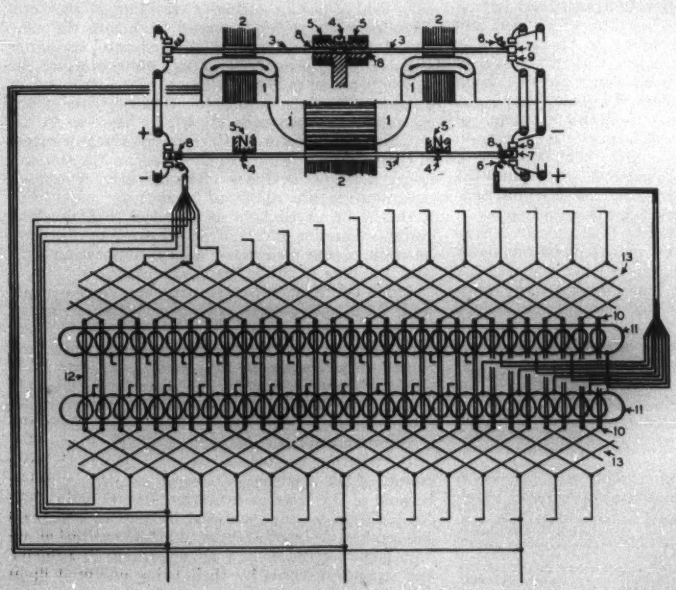

Fig. 1. Connection diagram of the new converter

1. Reed actuator
2. Flux-return ring
3. Reed
4. Reed pivot in xylophone form; reed clamp in cantilever form
5. Reed polarizer
6. Transformer contact lead-in (blade)
7. Transformer or reed contact
8. Reed insulation
9. Bus contact or V block
10. Close-coupled primary-secondary transformer coil
11. Two low voltage windings, each of one turn per coil
12. High voltage winding, 12 turns per coil
13. High voltage end connections, single wires
14. Transformer laminations
15. Thin air gaps in transformer core

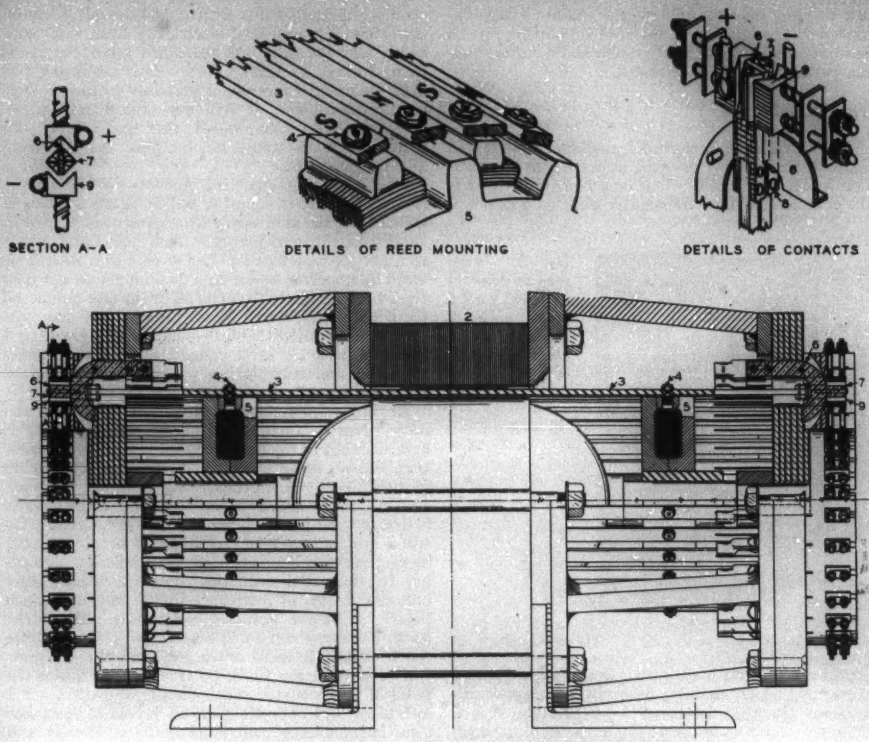

Fig. 2. Details of a 60 cycle transmuter of the "xylophone reed" form
Over-all length, 20 inches. For part numbers see caption of figure 1

its response to the electric supply frequency.

In any commutation, full flexibility of adjustment of the time-phase and duration of contact is desirable and should be available both to the designer and to the finishing and testing departments of a company manufacturing such apparatus. Vibratory commutation is adaptable to very close working adjustment for each commutated coil separately. For regulating the starting and ending of contact, adjustment is made by turning finely threaded nuts that fix the limiting positions of the resiliently mounted stationary contacts. By these means it is possible very closely to regulate the period of commutative short circuit, and, in collaboration with the unchanging steel reeds, to hold such adjustment throughout the working life of the contact members. The resilient floating of the otherwise stationary contacts is carried into the vibrating members in the forked ends described hereinafter.

Since commutative action includes the shunting of at least 2 coils at all times and in continuous succession, with proper timing for dividing the current to moderate surface density and for effecting coil-current reversal, the mechanical requirements thus readily may be defined for the new operation with its electrical and mechanical cycles so simply coupled together. Included among these requirements are: that the swings of the contacts must be reliably constant; that to this end they must be free of interference by friction comparable in magnitude with the force of their actuation; that the stationary contacts shall be positioned correctly (adjustably) with reference to the swings of the moving members; that the stationary parts shall receive the impact of the vibrating members with some resilience; and that in their return strokes following the moving contacts they shall come sharply to accurately positioned stops.

Of the 2 vibratory forms discussed herein, the one of xylophone reeds satisfies these requirements when newly adjusted. The cantilever reed transmuter is not subject to this time limitation because it does

not contain the one imperfectly stable element included in the other, i. e., the reed supporting pivots, but has a solidly built reed system and a corresponding permanence of adjustment.

The Transmuter

A 60-cycle xylophone-reed transmuter is shown in figure 2, an assembly drawing appearing as an elevation in its lower half. The unit here illustrated is the commercial sized transmuter built as a developmental model. Its basic rating is that of the stated frequency, which mainly determines its space dimensions; it otherwise is rated one or more tens of kilowatts, based upon about 400 amperes of natural-cooled contact capacity and upon voltage determined by the transformer. In the middle of this transmuter is the electromagnetic actuator, an ordinary drum-wound armature with 3-phase supply leads, surrounded at a rather large air-gap distance by a flux-return ring of clamped transformer-steel laminations. The armature-like actuator has 30 teeth, while the flux ring is smooth. Midway across the gap and opposite each tooth of the actuator, and flatwise thereto, is a steel reed 0.125 inch (0.317 centimeter) thick, 0.312 inch (0.8 centimeter) wide, and 19.5 inches (49.5 centimeters) long, measured over the ends of its contacts. The double amplitude of the swing is 0.188 inch (4.8 millimeters); the resultant maximum stress is about $^1/_4$ of the fatigue limit of spring steel. The reed assembly resembles a squirrel cage, but with respect to an induction motor the analogy does not extend far beyond visual likeness. The bars are not permitted to have any rotatory urge, they being insulated to prevent torque-producing currents.

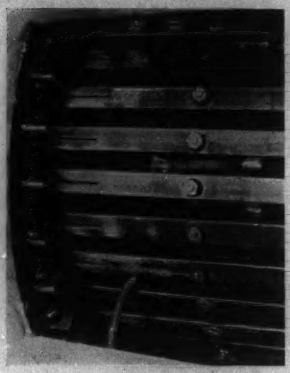

Fig. 3. View showing details of reeds, reed pivots, polarizer, and terminals of blade contactors of a "xylophone reed" transmuter

The reeds are designed for a natural periodicity close to the electric value, and in this form they are supported at the points where occur the nodes of the fundamental, i. e., at about 22.4 per cent of the total length from each end. The reed pivots are round-shouldered small studs with round-shouldered nuts. The studs are insulated electrically from their supports, and the nuts are cushioned from the reeds with washers of soft rubber. This mounting has little damping effect when perfectly adjusted, but, as aforementioned, it will not always remain so. The members upon which the reed pivots are mounted are also those which supply the polarizing flux to the reeds.

The polarizing structure appears in the middle isometric insert of figure 2 and in figure 3, both of which show the alternating arrangement of the teeth, as well as the reed pivots. Each polarizer consists of a pair of castellated plates of cast iron with their teeth interspersed and with a d-c coil placed between the 2 toothed plates to excite all of the odd numbered teeth with, say, north polarity and all of the even numbered teeth with south polarity. A given reed is excited with the same polarity at both of its nodal supports, and its neighbor on each side is excited with the opposite polarity.

In the xylophone reed form the movement of the outward or contactor ends of the reed naturally is opposite that in the actuator zone, and it is apparent that the movements of the 2 ends are exactly in mutual phase. As in the present example, there are 30 teeth on the actuator and 30 reeds; and since the actuator winding is bipolar, there will be at any instant approximately 15 contiguous actuator teeth having varying intensities of north polarity, according to sinusoidal ordinates, and 15 diametrically opposite teeth of correspondingly varying south polarity. In the actuator north zone, all of the north polarized reeds will be repelled and all of the south polarized reeds attracted, and the converse will be true in the south polar region. Thus as the poles of the actuator rotate intangibly, there are 2 interlaced and opposite pairs of waves of reed motion, harmonically controlled both electrically and mechanically with sinusoidal phase and amplitude. According to the alternate vibratory phasing, the mating stationary contacts are connected in zigzag fashion to the positive and negative busses. While it is not necessary that the polarization be alternately north and south from tooth to tooth, this arrangement is convenient and economical.

The contacts are divided into 2 sets, those of the transformer winding and those of the busses or positive and negative mains. Except for mechanical convenience, it is immaterial which are reed-mounted and which are stationary. In the present design the transformer contacts are the vibratory ones. In some earlier designs, including examples in the author's issued patent,[1] the line contactors are the vibratory ones. Coin silver is the contact metal preferred for ordinary use in the new converter. Contact materials are discussed further in the section "Commutation and Inductance," with references.[2-8]

For connection to the moving contactors the familiar shunt or "pigtail" is not employed, but is replaced by a stationary copper blade making with the reed contact what may be called a semi-sliding contact. In such action there is firm pressure be-

1. For all numbered references see list at end of paper.

tween the blade and its reed contact at, and only at, the end of the stroke. This gripping of the blade occurs during, and is caused by, the contact of the moving member with its mating V block; both pressures last only through the commutative period—about 15 per cent of the time. The interaction of the stationary blade, the moving contact, and the stationary V block results in a strong braking or snubbing of the vibratory swing at its extremity. The right-hand isometric inset of figure 2 shows this relatively important detail. The working part of the blade member is an extended keystone rising from the body of the arch shaped portion, and it should be plated with a noble metal. Figures 3 and 4 show this member from opposite ends. The whole blade member is made from rolled copper $^1/_{16}$ inch (1.6 millimeters) thick, with the arched portion thinned somewhat. The arch passes, with clearance to avoid friction, through the correspondingly slotted insulating coupling that supports the moving contact upon its reed.

The moving contact may be considered as a square prism set diamondwise with reference to its motion in such fashion as to mate with stationary contacts of the shape of 90 degree V blocks. By the slot provided for the internal contact with the blade member, each vibratory contact actually is divided into 2 triangular prisms, with axes parallel to the length of the reed. The triangular halves of the divided contact are mounted upon the reed by couplings of insulating material.

In the model, each reed was made into a fork of 2 prongs by running a fine slitting saw through the coupling and back into the reed for an indefinite distance—about 2.5 inches (6.4 centimeters) measured from the outer end of the reed contactor. This is one of the important elements of the resilient mounting of the contacting members, whereby the 2 half contacts are free to move separately in both the transverse and the torsional directions. In a further improvement they even are relieved of the springy torsion, by being slipped upon round forked ends of the reeds. The triangular moving members fit their blades loosely, until driven in upon them by their wedging impact with the stationary contacts. This arrangement makes the contacts readily replaceable, and leaves them fully exposed for ventilation.

Each stationary V block mates, when pressed, with the oblique faces of its split-square moving contact. Each block contact is mounted upon 2 small studs, and each stud is provided with a spring between the block and its insulating support and with a nut on the outside. In the transmuter under discussion, the nuts are made of pinion rod (see figure 3) and are provided with a locking arrangement. When at the beginning of its return stroke a moving contact starts to retreat from a V block, it is followed by the latter until the nuts return to their bearing. Thus the only element that is rigid is the desirably sharp limitation of this resilient return, for precision of parting time. The V blocks are connected to their busses, alternately positive and negative as aforesaid, by flexible leads. On the low voltage side there are 2 pairs of bus rings thus connected to 2 interspersed but independent commutative groups, for the 3 wire output of the machine.

All the stationary contacts, inner and outer, are mounted upon a single bakelite laminated ring or crown, which can be removed with these V blocks in place by withdrawing 3 screws. Each individual stationary contact merely is snapped into its place in this crown, and any one may be removed individually. As may be understood from figure 4, they are exposed on all sides for ventilative cooling. The crown ring is supported upon a platform plate of bakelite laminated which, being carried upon an end cage, supports the actuator shaft and the blade contacts. As a whole the transmuter structure resembles a motor, but there is no rotation except that of the magnetism. The actuator winding could be placed in the ring instead of the core.

The transmuter illustrated in figure 5 is improved over the xylophone reed form in respect to the mentioned tendency of the pivots, by their elimination, and the supporting of the reeds instead as cantilevers rooted at the middle of the structure. For the same thickness and loading of the reeds, their length to give the stated frequency is somewhat less than in the form supported at the nodes. There is only one node of the fundamental, at the clamped end; the length is computed from the formula:[9]

$$p = \frac{1}{2\pi}\sqrt{\frac{3EIg}{\left(W + \frac{33}{140}\,wl\right)l^3}}$$

where p is the periodicity or frequency of the loaded reed in cycles per second, l its length from the clamp to the mass center of the load (the contact), w the weight of the reed per unit length, W the weight of the load, E is Young's modulus of elasticity of the steel, I the moment of inertia of the reed section, and g the acceleration of gravity. Much simplification and a good approximation may be had by considering the concentrated weight W to be negligible, as it nearly is in the transmuter of figure 5 if l be measured over the end of the contactor. Overtones may be

Fig. 4. Closeup of assembled V blocks, reed contacts, and lead-in blades

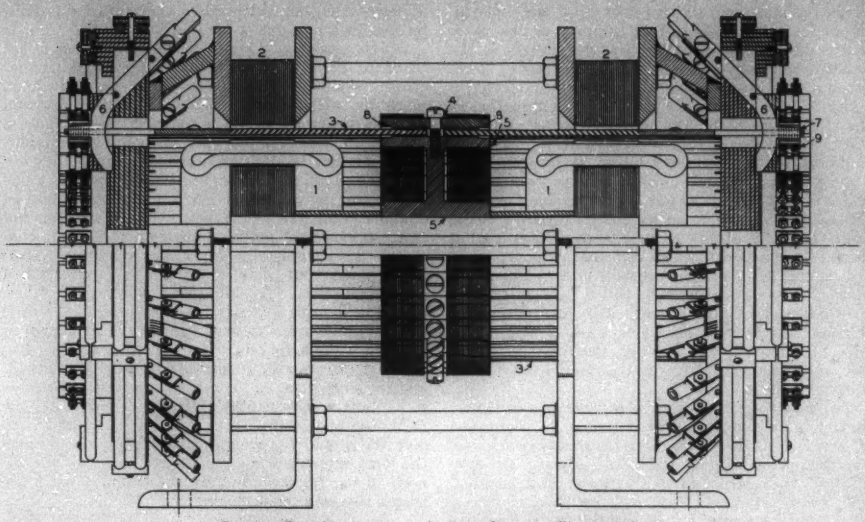

Fig. 5. Details of a 60 cycle "cantilever reed" transmuter
Over-all length, 18 inches. For part numbers see caption of figure 1

computed with coefficients, but their smaller energies can be suppressed successfully by damping and by lack of excitation at their frequencies.

The commutators of the cantilever form of transmuter are identical with those of the earlier form. Since the reeds may be divided where rooted at the middle of the structure, they are insulated there with thin material; and the insulating couplings at the contacts ordinarily become superfluous. Accordingly, the studs supporting the triangular halves of the vibratory contacts are made simple extensions of the forked reeds, as die-forged round prongs. The root-insulated reeds may be bare for electrolytic voltages, coated for distribution potentials, and for higher voltages coupling-insulated from the contacts.

In the cantilever form, the central polarizer is excited alternately north and south from tooth to tooth by separate small coils on each. The 2 actuators are essentially halves of the one in the xylophone reed design. The 2 are excited symmetrically from the power supply, so that the reed halves carrying the primary and secondary (left and right) contacts move in mutual phase relationship. The essence of the mechanical operation of the transmuter throughout is permanent precision in the timing of the metallic contacting, irrespective of electrical tolerance therein.

The Transformer

The transformer, which forms the major electromagnetic structure of this converter, is shown in the lower part of figure 6, an assembly drawing of the 10-kw model. The transmuter rests atop the transformer, and for convenience as an experimental unit the present outfit is provided with casters.

Viewed from the end, it may be seen that the transformer resembles a shell type of unit, and in the side elevation that the winding is subdivided into many (in this instance, 30) coil units. These units are interspersed with the teeth of the iron core in the same manner as are the coils of an armature winding. Each unit comprises both primary and secondary conductors, close coupled by their joint construction. In the illustrated model, the coupled construction is that of a cable of internal wires and an external copper tube, with intervening and external insulation. In this intimate relation, all of the lines of flux that link the high voltage wires link also the low voltage tubular conductor; and since for the load component current of the primary and secondary members the magnetomotive forces (ampere turns) are equal and opposite, there will be no magnetic flux caused by these load currents. The sole net flux is that of the primary exciting current.

The low-voltage secondary winding is connected in Gramme ring fashion. The high-voltage winding resembles a Gramme ring in that it is an assembly of coils that surround a central core; but the interconnection between these primary coils follows a diagram resembling that for the drum armature of a 3-phase bipolar rotary converter. The transformer is thus an extension of the conventional shell-type three-phase design, with the distinction that the windings being close coupled are especially adapted to the dual commutation.

As a convenience in building the model, its core had no air gaps in the lateral or tooth paths; and for

assurance of closeness of primary-secondary coupling the windings were formed of the mentioned concentric cable. These 2 design details have been altered by experience to a subsequent construction procedure comprising a joining of the ordinary practices in making transformers and induction motors. In motor fashion, the iron is provided with very thin air gaps in the teeth at their junctions with the central core, thus changing the coil holes to slots facing inward from the outer yokes and requiring one long slotted shape for the 2 sides and a plain strip for the center. In transformer fashion, the coils are form-wound as flat rectangles, and are slipped over the core as primary-secondary units, or couples, one for each core slot. Each of these couples is made of flat coils of the 2 windings, sheet-insulated and spaced so closely that the leakage path is negligible. The subdivision of the winding for the multiple phasing is in the nature of such large interspersing of the primary-secondary turns that, in combination with the closeness of the flat coils, there is attained a very small value of calculated flux leakage and reactance.

The everyday service of the perforating trade in punching desired rectilinear patterns in a widely tooled variety proved a boon in the construction of the model. It probably would be capital-saving and otherwise economical in manufacture, since the progressive punching method is applicable to making slots as well as holes. Figure 7 shows the partly completed model transformer, with the clamped core and the close coupled cables inserted, the inner layer connected into coils, and the outer layer ready for connection.

The transformer may be oil immersed, except where objectionable as a fire hazard as in some basements. With such oil immersion there may be combined the enclosure of the surmounted transmuter in a hood arranged as a "diving bell," for isolation of the commutators from dirt and moisture. The hood may be filled with inert gas such as nitrogen or helium, the latter as a powerful deionizing agent if needed for special high-voltage equipment.

Commutation and Inductance

Technically, the heart of this development has been the perfecting of the commutation, as in the history of generators and rotary converters. The means to that end differ in some very important essentials from those feasible in rotary commutation of noncoupled windings. Accordingly, the following analysis of the prevention of contact sparking relates largely to principles familiar in transformer design, in combination with only a portion of those that are dominant in ordinary commutation of self-inductive coils. The major omission is the resistive shunting by carbon brushes required in ordinary commutation. The important addition is an action borrowed from transformation, of which it is the core and essence. That action is the opposing by the load current in the primary winding of ampere-turns instantaneously equal to those of the load current in the secondary, so that if the 2 be coupled without leakage the only magnetism is the mutual flux caused by the primary exciting current. Since the exciting current is not commutated, the transformer action may be exploited through the dual contacting to give commutation of neutralized inductance, as discussed in other terms in succeeding paragraphs.

The causes of commutative sparking are mainly the following 3: First, there may be a breaking of substantial current in an inductive circuit, in which event there will be a spark whether the parting be quick or slow. Second, there may be a concentration of contact heating at points or edges (usually the trailing edge of a brush) whenever a large current remains until break and the final conduction is localized in the small areas of those points or edges, as distinguished from parting over nearly the whole surface of a but-

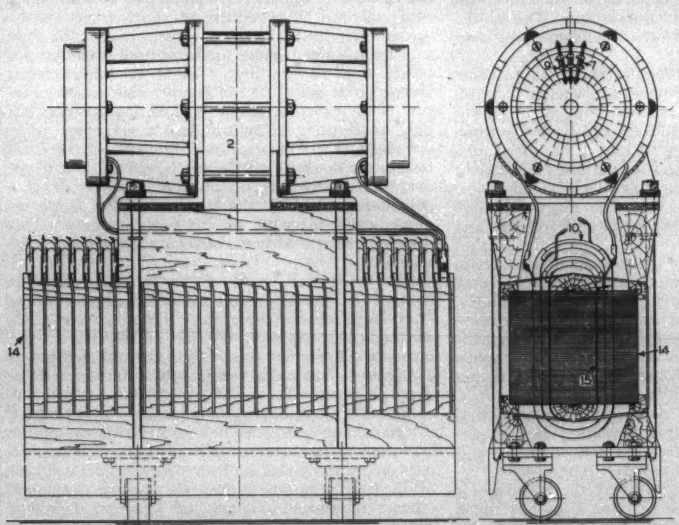

Fig. 6. Assembled converter with transmuter mounted directly over transformer

Over-all length, 25 inches; width, 10 inches. For part numbers see caption of figure 1

ton. In silver contacting, this concentration would have to be extreme in order alone to be deleterious.[2-8] Third, there may be heavy current interrupted, a slow separation of the contacts after their actual parting, and sufficient voltage to maintain an arc for a portion of the slow separation. During its persistence, the last is analogous to arc welding, and, of course, is aggravated if to it is added the first or inductive condition.

Among these potential causes of sparking, the second and third are countervailed in vibratory commutation by designing and adjusting the contacts to cause substantially full-faced parting at the right times, and rapid separation thereafter. By the means already described, such adjustment may be made accurately to maintain moderate surface concentrations of the currents, at full working pressures until the instants of parting.

For the inductive analysis it may be noted that by and during its commutative short circuit a coil in the secondary of the converter is shut out from series relation to its external circuit (that of the other coils in the winding) and that its local current falls and reverses without hindrance from external inductance. If the coil have practically zero flux leakage and there be negligible inductance in its commutator leads, then the only material inductive consideration is that of its own primary coil and of the circuits in which the latter may be included. By definition and construction the flux leakage of the primary coil is also nearly zero and its leads may be made of negligible inductance. Hence, if by short circuit it too can be isolated simultaneously from the inductance of its own external circuit (the other primary coils), no appreciable reactance will be left to influence the commutation. This is the dual commutation, with its dependence on close coupling.

These actions are functionally analogous to those in a motor-dynamo or dynamotor, wherein 2 windings are laid in the same armature slots, are tapped to input and output commutators, and have the same motion relative to the common field. Brief discussions of such rotary transformations and of their dual commutation are available in general electrical literature, to the effect that the magnetomotive forces of the 2 windings are equal and opposite and there is thus no armature reaction, that if the brushes are positioned so that the input and output coils in the same slots are short-circuited simultaneously the commutation is exceedingly good, and that low resistance brushes may be used and heavy currents delivered.[10-11] Mechanically, the new converter differs from a dynamotor in the all-important change from mass rotation to the intangible travel of flux poles. An interesting early proposal is described in "Edison's System of Continuous-Current Transformers."[12] While the transformation in that design was stationary, the dual commutation was still rotary; and the coupling was far from close.

Since armature reaction is absent, the opening of a secondary breaker on short-circuit does not cause the danger of flashover from voltage induction by sudden change of cross-magnetization as in generators,[13] or by distortion combined with hunting as in

Fig. 7. Model transformer partly assembled

some rotary converters.[14] As the new converter is a (commutating) transformer with no armature to restart, the breaker often may be placed on the primary side.

Concerning the precision of commutation, there is in the dual metallic method an important condition tolerant of some deviation from perfectly synchronous timing. If for a given primary-secondary coil couple the termination of short-circuit on either side lags that on the other, then the ending of the first not only will confirm the building of current in its own coil, but also because of short-circuit of the second coil will set the rise of current in it at the same rate by transformation, in the normal direction opposite that in the first. When the short-circuit thereupon is ended at the lagging contact, the current of its coil thus put in series with the others has only to adjust itself by a negligible difference, without material sparking. For similar reasons there will be little or no sparking if some bouncing of a single contact momentarily breaks the short-circuit of a coil on one side while the other coil of the couple remains short-circuited by its own contacts. This does not mean that bouncing can be permitted to be general.

The responsive travel of the spring-backed bus contact or V block is about one thread-pitch of its studs, i. e., about 0.02 inch or 0.5 millimeter. Accordingly, by whatever fraction of 360 degrees the nuts are adjusted in one setting, say 45 degrees or $12^1/_2$ per cent, by that precision the duration of the short-circuit easily may be regulated. With the elimination of commutative inductance as described, the remaining energy to be considered is the ohmic evolution. Each commutative cycle lasts about 15 per cent of the power half cycle; and practically all of this heating occurs in the coils, because of the low contact resistance. Hence, the foregoing figure of contact adjustment or deviation would affect the winding for 1.9 per cent of the total time or by about 1 per cent of the ohmic heating, the coil current being

constant except when commutating, and passing then through zero.

Reversing voltages may be employed in vibratory as in ordinary commutation, by slightly shifting the timing of the contacting. Except for higher potentials, their service and need are not important. In the absence of reactance voltage they have only to compensate the ohmic drop of each coil and its short leads. In generators and other such machines the value of this ohmic drop is about $^1/_{10}$ the reactive voltage per coil, i. e., as 0.15 to 1.5 volt in a typical 240 volt machine. Accordingly, if the reversing voltage were deficient by half or even entirely, this uncompensated ohmic voltage would be capable of only negligible sparking in the non-energy-storing operation.

Much information is now available on contact metals.[2–8] Only a limited portion of it is required directly for at least the moderate and lower voltage applications of the new converter. Since "It isn't commutation if there is substantial inductive sparking," superior ability to withstand arcing may be eliminated as a normal requirement of the contact material. Certain high grade contact alloys possess this property, but it is for other reasons that they are of important potential utility herein. The silver-tungsten and silver-molybdenum alloys combine durability with high surface conductivity. Except for its softness, prohibitive according to present indications, fine silver is the ideal material because of its high "contactivity" and stability thereof. In general coin silver is so satisfactory and economical that it seems to require little improvement for the semi-sliding contact. For the working faces of the copper blade contacts, palladium plating is indicated favorably.

Some Advantages of Vibratory Conversion

Experience with the model unit has suggested a simple method of performing routine tests of the converter, with only a small proportion of the rated input. As the divided secondary is served by independent halves of the same commutator, its 2 output voltages may be externally opposed to each other and connected in series with a low resistance source of low voltage, such as a storage battery. The system thus may be made to work at rated secondary current and with full input and output voltages, i. e., with normal primary excitation. Thus the iron and primary copper losses may be fed on the one side and the secondary copper loss measured on the other.

More important, it is now evident that the new converter has the benefit of an economic convenience peculiar to a few other classes of apparatus, of which the electrostatic precipitator is an example. That is the feasibility of prebuilding as a pilot to each new rating a group of about 3 full sized units of which the full number such as 30 would constitute the complete machine. This pilot group may be subjected to tests that demonstrate proportionately the realization of all the functions and faults of the particular design. If the full machine be assembled from these parts including those of the transmuter arranged straightaway, the leads can be made very short. In the transmuter the principal parts can be standardized for a few frequencies, voltage ranges, and current capacities for a wide variety of converter ratings.

Little mention has been made of higher-voltage applications, but these are within the possible range of service of the apparatus. As shown in the issued patent,[1] it is a peculiarity of vibratory as distinguished from rotatory commutation, that the winding of a converter can be subdivided into as many sections as there are pairs of poles and these sections connected in series rather than in parallel with each other. For low and medium voltages there seems to be no occasion to build the new converter in other than bipolar form.

The general economy of the vibratory converter has been the incentive to its development. From the manufacturing viewpoint, its design is unhampered by rotation, by centrifugal force, by the necessity for rigidity of the commutator therefor and for thermal stresses, by the visual isolation of rotation, by sliding friction and brush wear, by carbon and copper dusting, by bodily contagion of trouble from one segment to the next and corollary thereto in large and high voltage units, by the lurking flashover. As to operation, the new machine requires no attendance and promises to need little maintenance—in the nature of occasional conditioning or replacing of contactors. There is no lubrication dependent on either machine reliability or human vigilance and, as compared with the mercury vapor rectifier, no pumps or other auxiliaries to be maintained. Adjustments for correct performance can be made in the factory; but where field repair is required, its nature is simple. Since the converter is essentially a transformer practically unaffected by its commutation, it is evident that its over-all power efficiency is high.[14]

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A Generalized Infinite Integral Theorem

A generalized infinite integral theorem and its transform and applications are presented in this paper in such form that it becomes unnecessary to use Duhamel's theorem. The treatment embodies extensions to Heavisides methods of circuit analysis, thereby simplifying materially the mathematics of operational methods and giving a clearer insight into the connection between the physics and mathematics of transients. Extensions to Heavisides expansion theorem also are given.

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WHEN Oliver Heaviside developed his operational methods of solving differential equations, he devoted his attention primarily to circuits that:

1. *Are energized by a continuous electromotive force.*
2. *Are started from rest and have neither charge nor current.*
3. *Have constant parameters (characteristics) of such values that the roots of the operational equations representing the circuits are unequal.*

These are rather severe restrictions which limit the application of Heaviside's methods to a very few problems arising in practice. Hence workers in the field of operational analysis have endeavored to eliminate as many of these restrictions as possible—in a word, to generalize Heaviside's method. Let us see what generalizations are possible and desirable.

Applied Electromotive Force. The sources of electromotive force that engineers meet in practice may or may not be continuous. In fact, sine wave and non-sine wave periodic electromotive forces commonly are met with in practice. Can Heaviside's methods be extended to any source of electromotive force? The answer is yes. Indeed such extensions are so well known that they form a part of all textbooks on the subject. There is this, however, to be said about them: They lack elegance and are artificial and awkward. In fact, Heaviside's results for continuous electromotive forces (*the unit function*) generally are extended to other functions by a step-by-step process using the principle of superposition (Duhamel's theorem).[1,2,3]

A paper recommended for publication by the A.I.E.E. committee on electrophysics, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 28–31, 1936. Manuscript submitted May 31, 1935; released for publication Sept. 10, 1935.

1. For all numbered references, see list at end of paper.

In this paper a different mode of extending Heaviside's methods to other than continuous electromotive forces is proposed. The procedure is to disregard the unit function as the fundamental electromotive force and to derive relations that are general and with respect to which the unit functions as well as any other electromotive force function is but a special case. The mathematics of operational methods thus are simplified materially, and a clearer insight into the connection between the physics and mathematics of transients is attained.

Initial Conditions. Circuits met in practice rarely ever start from rest. Disturbances generally occur on circuits that already have been energized. Can Heaviside's methods be extended to circuits starting from any arbitrary condition whatever? Again the answer is yes. The extension is shown in this paper under heading "Extension to Nonindicial Circuits."

Circuit Parameters. Many circuits have variable parameters. Can Heaviside's operational methods be extended to such circuits? The answer is yes in some very special cases. The present paper, however, is not concerned with this problem.

In general the parameters of circuits encountered in practice are arbitrary and need not satisfy the relation that the roots of the operational equation are unequal. Can Heaviside's methods be extended to the cases where all the roots are equal, or where some of the roots are equal? The answer is yes. These extensions, however, have been known only for the case where the applied electromotive force is continuous. This paper gives extensions to the case where the electromotive force is of any form whatever (which may be met in practice) and specifically derives results for the exponential and sine wave electromotive forces.

Derivation of the Theorem

Consider the differential equation

$$[a_n p^n + a_{(n-1)} p^{(n-1)} + \ldots + a_0] i(t) = e(t) \tag{1a}$$

or

$$\sum_{k=0}^{n} a_k p^k \, i(t) = e(t) \tag{1b}$$

Multiply[4] both sides of equation 1*b* by $\epsilon^{-ut} dt$ and integrate between zero and infinity thereby obtaining

$$\int_0^\infty \sum_{k=0}^{n} a_k \epsilon^{-ut} p^k i(t) dt = \int_0^\infty \epsilon^{-ut} e(t) dt \tag{2}$$

where u is any complex number whose real part is positive and sufficiently large. Consider a typical term of the summation on the left of equation 2. Let this be the kth term and let it be integrated by parts giving

$$a_k \int_0^\infty \epsilon^{-ut} \{p^k i(t)\} dt = \left[a_k \epsilon^{-ut} \{p^{(k-1)} i(t)\} \right]_0^\infty + a_k u \int_0^\infty \epsilon^{-ut} \{p^{(k-1)} i(t)\} dt \tag{3}$$

If it be assumed that $i(t)$ and all its derivatives except the nth are zero when $t = 0$, then the first

term on the right of equation 3 vanishes at the lower limit; but it also vanishes at the upper limit because $\epsilon^{-ut}p^{(k-1)}\ i(t) \to 0$ as $t \to \infty$. Hence equation 3 reduces to

$$a_k\int_0^\infty \epsilon^{-ut}[p^k\ i(t)]\ dt = a_k u\int_0^\infty \epsilon^{-ut}\ [p^{(k-1)}\ i(t)]dt \tag{4}$$

Integrating successively by parts until the number of integrations is equal to k,

$$a_k\int_0^\infty \epsilon^{-ut}\ [p^k i(t)]\ dt = a_k u^k\int_0^\infty \epsilon^{-ut}\ i(t)\ dt \tag{5}$$

Each term on the left of equation 2 yields, after repeated integration, an expression similar to equation 5. Thus equation 2 becomes

$$\sum_{k=0}^{n} a_k u^k\int_0^\infty \epsilon^{-ut}\ i(t)dt = \int_0^\infty \epsilon^{-ut}e(t)dt \tag{6a}$$

or

$$\int_0^\infty \epsilon^{-ut}i(t)dt = Y(u)\int_0^\infty \epsilon^{-ut}\ e(t)dt \tag{6b}$$

where

$$Y(u) = 1\Big/\sum_{k=0}^{n} a_k u^k = 1/Z(u) \tag{6c}$$

Equation 6*b* is the generalized infinite integral theorem of equation 1. Its solution[5,6] is

$$i(t) = \frac{1}{2\pi j}\int_{b-j\infty}^{b+j\infty} [\epsilon^{ut}\ Y(u)\int_0^\infty \epsilon^{-ux}\ e(x)dx]du \tag{7}$$

Equation 7 gives the current in a circuit that, starting from rest, is energized by any electromotive force whatever. As an illustration of the use of equation 7 let it be required to find the current in a series circuit with resistance R and inductance L when such a circuit is established by impressing the unit function $\mathbf{1}$ on it. The differential equation for such a circuit is

$$Ri + Lpi = \mathbf{1} \tag{7a}$$

whence

$$Y(p) = 1/(R + pL);\ \ Y(u) = \mathbf{1}/(R + uL) \tag{7b}$$

Substituting equation 7*b* in equation 7

$$i(t) = \frac{1}{2\pi j}\int_{b-j\infty}^{b+j\infty} \frac{\epsilon^{-ut}}{u(R + ub)}\ du = \frac{1}{2\pi j}\int_{b-j\infty}^{b+j\infty} \frac{1}{R}\left[\frac{1}{u} - \frac{1}{u + (R/L)}\right]\epsilon^{ut}\ du \tag{7c}$$

Now it can be shown that

$$\frac{1}{2\pi j}\int_{b-j\infty}^{b+j\infty} \frac{u^m}{u}\epsilon^{ut}du = t^{-m}/\Gamma(1 - m) = t^{-m}/(-m)! \tag{7d}$$

Substituting equation 7*d* in equation 7*c*,

$$i(t) = \frac{1}{R}\,(1 - \epsilon^{-Rt/L}) \tag{7e}$$

Extension to Systems

The foregoing analysis may be extended readily to systems of differential equations such as:

$$Z_{11}(p)\ i_1(t) + Z_{12}(p)\ i_2(t) + \ldots + Z_{n1}(p)\ i_n(t) = e_1(t) \tag{8a}$$

$$Z_{12}(p)\ i_1(t) + Z_{22}(p)\ i_2(t) + \ldots + Z_{n2}(p)\ i_n(t) = e_2(t) \tag{8b}$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$Z_{1n}(p)\ i_1(t) + Z_{2n}(p)\ i_2(t) + \ldots\ Z_{nn}(p)\ i_n(t) = e_n(t) \tag{8n}$$

In equations 8 the functions $Z_{ks}(p)$ are polynomials in p and represent the operational impedances of the various branches in an electric circuit. The function $i_k(t)$ is the current in any branch k of the circuit, and it satisfies the "indicial" conditions stated following equation 3, namely, if N be the highest degree of Z_{ks} in any column k then $i_k(t)$ and all its derivatives up to the $(N - 1)$st shall be zero when $t = 0$. Finally $e_k(t)$ is the electromotive force in branch k and can be any function whatever provided that the integral on the right of equation 2 exists for each value of $e_k(t)$ in equations 8.

Multiplying each of equations 8 by $\epsilon^{-ut}dt$ and integrating between zero and infinity as was done in equations 1 to 5,

$$\sum_{k=1}^{n} Z_{k1}(u)\int_0^\infty \epsilon^{-ut}\ i_k(t)dt = \int_0^\infty \epsilon^{-ut}\ e_1(t)dt \tag{9a}$$

$$\sum_{k=1}^{n} Z_{k2}(u)\int_0^\infty \epsilon^{-ut}i_k(t)dt = \int_0^\infty \epsilon^{-ut}e_2(t)dt \tag{9b}$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$\sum_{k=1}^{n} Z_{kn}(u)\int_0^\infty \epsilon^{-ut}i_k(t)dt = \int_0^\infty \epsilon^{-ut}e_n(t)dt \tag{9c}$$

Equations 9 now can be solved as any set of linear equations by means of determinants, the unknowns being the integrals in $i_k(t)$. Thus:

$$\int_0^\infty \epsilon^{-ut}i_k(t)dt = \sum_{s=1}^{n}(\Delta_{ks}/\Delta)\int_0^\infty \epsilon^{-ut}e_s(t)dt \tag{10}$$

where

$$\Delta = \begin{vmatrix} Z_{11}Z_{21}\ldots\ldots\ldots\ldots Z_{n1} \\ Z_{12}Z_{22}\ldots\ldots\ldots\ldots Z_{n2} \\ \\ Z_{1n}Z_{2n} \qquad\qquad Z_{nn} \end{vmatrix} \tag{11a}$$

Δ_{ks} = the minor [with the correct sign $(-1)^{(k+s)}$] of Δ obtained by omitting column k and row s (11b)

Observe that equation 10 is of the same form as 6*b*. Hence its transform is

$$i_k(t) = \sum_{s=1}^{n}\frac{1}{2\pi j}\int_{b-j\infty}^{b+j\infty} \left[\epsilon^{ut}\ (\Delta_{ks}/\Delta)\int_0^\infty \epsilon^{-ux}e_s(x)dx\right] du \tag{12}$$

The expression Δ_{ks}/Δ is the quotient of 2 polynomials. Moreover Δ_{ks} is of lower degree than Δ because Δ_{ks} is a minor of Δ.

Extension to Nonindicial Circuits

The foregoing treatment applies only to indicial circuits, that is, to circuits starting from rest and containing neither charge nor current. Mathematically 6 and 7, and 10 and 12 apply to the case where $i_k(0) = i'_k(0) = \ldots = i_k^{(n-1)}(0) = 0$

where for equations 6 and 7 n is the order of the differential equation 1, and for equations 10 and 12 n is the highest degree (see equations 8) of all the values of Z_{ks} in any column k of the determinant Δ. When these conditions are not satisfied the circuit is nonindicial.

It is the object here to derive infinite integrals and their transforms for nonindicial circuits, that is, for circuits in which $i_k(0)$, $i'_k(0)$ ..... $i_k^{(n-1)}(0)$ are not necessarily zero. Consider equation 1. Multiply each side by $\epsilon^{-ut}dt$ and integrate between zero and infinity thereby obtaining expressions similar to equations 3. Since by assumption $p^{(k-1)}\, i(0)$ is not necessarily equal to zero, the first term in equation 3 does not neeessarily vanish at the lower limit but gives some definite constant. Let

$$a_k\epsilon^{-ut}\{p^{(k-1)}\, i(t)\}_0 = A_{k1} \tag{13}$$

Then equation 3 becomes

$$a_k\int_0^\infty \epsilon^{-ut}\,[p^k i(t)]dt = A_{k1} + a_k u\int_0^\infty \epsilon^{-ut}\,[p^{(k-1)}\, i(t)]dt \tag{14}$$

Integrating successively by parts until the number of integrations is equal to k,

$$a_k\int_0^\infty \epsilon^{-ut}\,[p^k i(t)]dt = A_{k1} + A_{k1}\, u + \ldots\ldots A_{kk}u^{(k-1)} + a_k u^k\int_0^\infty \epsilon^{-ut}\, i(t)dt \tag{15}$$

Each term on the left of equation 2 yields an expression similar to equation 15. Hence equation 2 becomes

$$\sum_{k=0}^{n}\left[A_{k1} + A_{k2}u + \ldots\ldots + A_{kk}u^{(k-1)}\right] + \sum_{k=0}^{n} a_k u^k\int_0^\infty \epsilon^{-ut}\, i(t)dt = \int_0^\infty \epsilon^{-ut}\, e(t)dt \tag{16a}$$

or

$$A(u) + Z(u)\int_0^\infty \epsilon^{-ut}\, i(t)dt = \int_0^\infty \epsilon^{-ut}\, e(t)dt \tag{16b}$$

Thus equation 16b and its transform are

$$\int_0^\infty \epsilon^{-ut}\, i(t)dt = Y(u)\left[\int_0^\infty \epsilon^{-ut}\, e(t)dt + A(u)\right] \tag{17a}$$

$$i(t) = \frac{1}{2\pi j}\int_{b-j\infty}^{b+j\infty} \epsilon^{ut}Y(u)\left[\int_0^\infty \epsilon^{-ux}\, e(x)dx - A(u)\right] du \tag{17b}$$

Similarly for a nonindicial circuit involving a system of n differential equations the infinite integral theorem and its transform are:

$$\int_0^\infty \epsilon^{-ut}\, i_k(t)dt = \sum_{s=1}^{n}(\Delta_{ks}/\Delta)\left[\int_0^\infty \epsilon^{-ut}\, e(t)dt - A_k(u)\right] \tag{18a}$$

$$i_k(t) = \sum_{s=1}^{n}\frac{1}{2\pi j}\int_{b-j\infty}^{b+j\infty}\left\{\epsilon^{ut}(\Delta_{ks}/\Delta)\left[\int_0^\infty \epsilon^{-ux}e(x)dx - A_k(u)\right]\right\} du \tag{18b}$$

Outline of the Problem

The treatment will be confined to indicial circuits for 2 reasons: (1) They are easier to treat; and (2) the generalization from indicial to nonindicial circuits is obvious. The results of the first 2 sections of the paper may be summarized in the following 2 sets of equations which are identical with equations 6b, 7, 10, and 12, respectively:

$$\int_0^\infty \epsilon^{-ut}\, i(t)dt = Y(u)\int_0^\infty \epsilon^{-ut}\, e(t)dt \tag{19a}$$

$$i(t) = \frac{1}{2\pi j}\int_{b-j\infty}^{b+j\infty}\left[\epsilon^{ut}\, Y(u)\int_0^\infty \epsilon^{-ux}\, e(x)dx\right] du \tag{19b}$$

$$\int_0^\infty \epsilon^{-ut}\, i_k(t)dt = \sum_{k=1}^{n}(\Delta_{ks}/\Delta)\int_0^\infty \epsilon^{-ut}e_s(t)dt \tag{20a}$$

$$i_k(t) = \sum_{s=1}^{n}\frac{1}{2\pi j}\int_{b-j\infty}^{b+j\infty}\left[\epsilon^{ut}\,(\Delta_{ks}/\Delta)\int_0^\infty \epsilon^{-ux}e_s(x)dx\right] du \tag{20b}$$

Hereafter equations 19a and 20a will be referred to as the infinite integrals and 19b and 20b as their transforms for indicial circuits. Here are 2 separate cases: (1) a single differential equation 1 whose infinite integral is equation 19a and whose transform is equation 19b; and (2) a system of differential equations 8 whose infinite integral is equation 20a and whose transform is equation 20b. In each of these cases 2 distinct types of problems arise from the reciprocal relation between the infinite integrals and their respective transforms: (a) given $Y(u)$ or Δ_{ks}/Δ, required $i(t)$; and (b) given $i(t)$, required $Y(u)$ or Δ_{ks}/Δ.

Problems of the first type (a) are solved by the use of equations 19b and 20b, respectively. They have been treated in articles and textbooks[1,2,3,6] for the unit function. Such treatments, however, have not been extended to other electromotive force functions. In other words, no theorem has been given corresponding to Heaviside's expansion theorem, which applies, for example, to the exponential or the sine electromotive force. One object of this paper is actually to develop such theorems.

Problems of the second type (b) are solved by the use of equations 19a and 20a, respectively. Such problems apparently have received no attention whatever. This type of problem will not be treated in the present paper because the process, in its most general form, is important and involved enough to be the subject of a separate paper. The remainder of the paper is concerned with only the first type of problem.

Application to Exponential Electromotive Forces

Consider a circuit having exponential sources of electromotive force of the form

$$e(x) = E_c\epsilon^{cx}\,\mathbf{1} \text{ or } e_s(x) = E_{cs}\epsilon^{c_s x}\,\mathbf{1} \qquad c \neq 0 \tag{21}$$

Substituting equation 21 in 19 and 20, respectively,

$$\frac{Y(u)}{u-c} = \int_0^\infty \epsilon^{-ut}\, i(t)dt \tag{22a}$$

$$i(t) = \frac{1}{2\pi j}\int_{b-j\infty}^{b+j\infty}\frac{Y(u)}{u-c}\,\epsilon^{ut}\, du E\,\mathbf{1} \tag{22b}$$

$$\sum_{s=1}^{n}\Delta_{ks}/(u-c_s)\,\Delta = \int_0^\infty \epsilon^{-ut}\, i(t)dt \tag{23a}$$

$$i_k(t) = \sum_{s=1}^{n} \frac{1}{2\pi j} \int_{b-j\infty}^{b+j\infty} \frac{\Delta_{ks}}{(u - c_s)\Delta} e^{ut} du \, E_s \, 1 \tag{23b}$$

Expressions 22 and 23 are special forms of 19 and 20. The former are used for simple differential equations such as 1, while the latter are applicable to systems such as 8. Now a single differential equation is but a special case of a system of such equations. Hence a discussion of equations 23 is all that would be required to cover the general case. Therefore, equations 22 will not be discussed at length, but their use will be illustrated by solving a problem.

Let it be required to find the current $i(t)$ in a circuit, with R and L, which is subjected suddenly to any electromotive force, $e(t) = e^{ct}E\,1$. By Kirchoff's law,

$$(R + pL)i = e^{ct} E\,1 \text{ or } i = \frac{1}{R + pL} e^{ct} E\,1 \tag{24}$$

whence

$$Y(u) = \frac{1}{R + uL} \tag{25}$$

Substituting equation 25 in 22*b* and integrating,

$$i(t) = \frac{E\,1}{Lc + R} [e^{ct} - e^{-Rt/L}] \tag{26}$$

Extension of Heaviside's Expansion Theorem

Heaviside's expansion theorem may be extended readily to any form of electromotive force for which equations 19*b* and 20*b* exist, by the use of these equations. However, it will be extended here only to the exponential electromotive force. The problem may be stated as follows: Given a circuit with constant parameters having exponential electromotive forces of the form indicated by equation 21, which circuit moreover is at rest and satisfies the "indicial" conditions; what is the value of any current $i_k(t)$? For convenience the following 4 cases will be considered, which naturally yield 4 separate extensions of Heaviside's expansion theorem.

Case a. The determinant Δ (see equations 11) has no repeated roots and no roots equal to any c_s in equation 21. It can be shown[7] that under these conditions

$$\frac{\Delta_{ks}}{\Delta} = \sum_{r=1}^{m} \frac{b_{rs}}{u - u_r} \qquad b_{rs} = \frac{\Delta_{ks}(u_r)}{\Delta'(u_r)} \tag{27}$$

where m is the degree of the polynomial Δ and u_r is any of its roots. Substituting equation 27 in 23*b* and integrating,

$$i_k(t) = \sum_{s=1}^{n} \sum_{r=1}^{m} b_{rs} E_s \, (e^{u_r t} - e^{c_s t})/(u_r - c_s) \tag{28}$$

Equation 28 is the first extension of Heaviside's expansion theorem and applies to indicial circuits with constant parameters, subjected to exponential electromotive forces of the type designated by equation 21. Moreover, the parameters of the circuits are so related that the determinant Δ (see equation 11) has neither repeated roots nor any roots equal to c_s.

Case b. The determinant Δ has no repeated roots but some of its roots are equal to some of the values of c_s in equation 21. Hence

$$\frac{\Delta_{ks}}{\Delta} = \sum_{r=1}^{h} \frac{b_{rs}}{u - c_{sr}} + \sum_{r=h+1}^{m} \frac{b_{rs}}{u - u_r} \tag{29a}$$

where

$$b_{rs} = \frac{\Delta_{ks}(c_{sr})}{\Delta'(c_{sr})} \qquad 1 \leq r \leq h \tag{29b}$$

$$b_{rs} = \frac{\Delta_{ks}(u_r)}{\Delta'(u_r)} \qquad h + 1 \leq r \leq m \tag{29c}$$

c_{sr} = that c_s which is equal to u_r (29d)

Substituting equation 29*a* in 23*b* and integrating

$$i_k(t) = \sum_{r=1}^{h} \sum_{\substack{s=1 \\ c_{sr} \neq c_s}}^{n} b_{rs} E_s \frac{e^{c_{sr}t} - e^{c_s t}}{c_{sr} - c_s} + \sum_{r=h+1}^{m} \sum_{s=1}^{n} b_{rs} E_s \frac{e^{u_r t} - e^{c_s t}}{u_r - c_s} + \sum_{r=1}^{h} b_{rs} E_{sr} t e^{c_{sr} t} \tag{30}$$

In equation 30 the summation of c_{sr} is to be carried only over r (not over s). Equation 30 is the second extension of Heaviside's expansion theorem and applies to indicial circuits subjected to exponential electromotive forces. The parameters of the circuits are so related that the determinant Δ, while not having any repeated roots, may have roots equal to some of the c_s's.

Case c. The roots of the determinant Δ are such that u_k is repeated m_k times and none of the roots is equal to any c_s. Here if m is the degree of Δ and if Δ has g distinct roots that are repeated $m_1, m_2 \ldots m_g$ times, respectively,

$$\frac{\Delta_{ks}}{\Delta} = \sum_{r=1}^{g} \sum_{v=1}^{m_r} \frac{b_{vrs}}{(u - u_r)^v} \tag{31a}$$

where

$$m_1 + m_2 + \ldots + m_g = m \tag{31b}$$

Substituting equation 31*a* in 23*b* and integrating,

$$i_k(t) = \sum_{r=1}^{g} \left\{ \sum_{v=1}^{m_r} \sum_{s=1}^{n} b_{vrs} E_s \frac{e^{u_r t}}{(c_s - u_r)^v} R_v[(c_s - u_r)t] \right\} \tag{32a}$$

where

$$R_v[(c_s - u_r)t] = e^{(c_s - u_r)t} - \sum_{q=1}^{v} [(c_s - u_r)t]^{(q-1)}/(q - 1)! \tag{32b}$$

Now in equations 31*a* and 32*a* the values of b_{vrs} may be expressed as follows:

$$b_{vrs} = \frac{\phi_r^{(m_r - v)}(u_r)}{(m_r - v)!} \tag{33a}$$

where

$$\phi_r(u) = \frac{[\Delta_{ks}(u)](u - u_r)^{m_r}}{\Delta(u)} \tag{33b}$$

Equation 32*a* is the third extension of Heaviside's expansion theorem and applies to indicial circuits subjected to exponential electromotive forces. The parameters of the circuits are so related that Δ has roots $u_1, u_2 \ldots u_g$ which are repeated $m_1, m_2 \ldots m_g$ times, respectively.

Case d. The determinant Δ has repeated roots some of which are equal to c_s. Here the decomposition yields:

$$\frac{\Delta_{ks}}{\Delta} = \sum_{p=1}^{m_1} \frac{b_{p1s}}{(u - c_{p1})^p} + \sum_{p=1}^{m_2} \frac{b_{p2s}}{(u - c_{p2})^p} + \ldots + \sum_{p=1}^{m_w} \frac{b_{pws}}{(u - c_{pw})^p} + \sum_{p=1}^{m(w+1)} \frac{b_{p(w+1)s}}{(u - u_{w+1})^p} + \ldots + \sum_{p=1}^{m_g} \frac{b_{pgs}}{(u - u_g)^p} \quad (34)$$

Substituting equation 34 in 23*b* and integrating,

$$i_k(t) = \sum_{r=1}^{w} \left[\sum_{p=1}^{m_r} \frac{b_{prs} E_{sr} t^p \epsilon^{c_{sr} t}}{p!} \right] + \sum_{\substack{r=1 \\ c_s \neq c_{sr}}}^{w} \left\{ \sum_{p=1}^{m_r} \sum_{s=1}^{n} \frac{b_{prs} E_s \epsilon^{c_{sr} t}}{(c_s - c_{sr})^p} R_p \left[(c_s - c_{sr})t\right] \right\} + \sum_{r=w+1}^{g} \left\{ \sum_{p=1}^{m_r} \sum_{s=1}^{n} \frac{b_{prs} E_s \epsilon^{u_r t}}{(c_s - u_r)^p} R_p \left[(c_s - u_r)t\right] \right\} \quad (35)$$

Equation 35 is the fourth extension of Heaviside's expansion theorem and applies to indicial circuits subjected to exponential electromotive forces. The parameters of the circuits are so related that Δ has roots $u_1, u_2 \ldots u_g$ which are repeated $m_1, m_2 \ldots m_g$ times, respectively. Moreover, some (say w) of these roots have values equal to some values of c_s. Thus u_r is equal to c_{sr} for $r = 1,2,\ldots w$.

This concludes all the possible extensions of Heaviside's expansion theorem. The exponential electromotive force has been chosen not only because of the facility with which it can be handled, but also because of its practical application in actual engineering problems. Indeed all the trigonometric functions are reducible to the exponential; moreover, most electromotive force functions encountered in engineering practice are expressible as Fourier series and hence are also reducible to exponential functions.

Extension of Heaviside's Expansion Theorem to Sine Wave Electromotive Forces

The extension of Heaviside's expansion theorem to sine wave electromotive force functions follows directly from its extension to exponential functions. Thus let the electromotive force $e_s(t)$ be

$$e_s(t) = E_{msi} \sin(\omega t + \alpha_s) \mathbf{1} = E_{ms} \left[\frac{\epsilon^{j(\omega t + \alpha_s)} - \epsilon^{-j(\omega t + \alpha_s)}}{2j} \right] \mathbf{1} \quad (36a)$$

$$= \epsilon^{j\omega t} \left[\frac{E_{ms} \epsilon^{j\alpha_s}}{2j} \right] \mathbf{1} - \epsilon^{-j\omega t} \left[\frac{E_{ms} \epsilon^{-j\alpha_s}}{2j} \right] \mathbf{1} \quad (36b)$$

Now observe that each term on the right of equation 36*b* has a form similar to equation 21. Thus $c_s \sim \pm j\omega$, $E_s \sim E_{ms} \epsilon^{\pm j\alpha_s}/2j$. The extensions, equations 28, 30, 32, and 35, therefore, may be written directly for sine wave electromotive forces by performing the necessary algebraic substitutions. Thus the first extension of Heaviside's expansion theorem to sine wave electromotive forces is (see equations 28 and 36)

$$i_k(t) = \sum_{s=1}^{m} \sum_{r=1}^{m} \frac{b_{rs} E_{ms}}{2j} \left[\frac{\epsilon^{j\alpha_s} (\epsilon^{u_r t} - \epsilon^{j\omega t})}{u_r - j\omega} - \frac{\epsilon^{-j\alpha_s} (\epsilon^{u_r t} - \epsilon^{-j\omega t})}{u_r + j\omega} \right] \quad (37)$$

Similarly expressions may be written corresponding to equations 30, 32, and 35.

Equation 37 gives the current in a circuit in which the parameters are such that none of the roots of its operational equation are equal. Moreover the circuit, starting from rest, is energized by a sine wave electromotive force. As an illustration, let it be required to determine the current in a series circuit with resistance R and inductance L which is subjected suddenly to the sine wave electromotive force of equations 36*a* and 36*b*. The differential equation for such a circuit is

$$Ri + Lpi = E_m \sin(\omega t + \alpha) \mathbf{1} \quad (37a)$$

whence

$$Y(u) = R + Lu, \text{ and therefore } u_r = -R/L \quad (37b)$$

Now equation 37 cannot be used in this instance because $\Delta = 0$ (in other words, here is an example where a single differential equation rather than a system of differential equations is involved). Hence equation 22*b* is resorted to. Substituting $\pm j\omega$ for c_s and $E_m \epsilon^{\pm j\alpha}/2j$ for E_s and integrating,

$$i = \left[\frac{E_m \epsilon^{j\alpha}}{2j(R + j\omega L)} \left\{ \epsilon^{j\omega t} - \epsilon^{-Rt/L} \right\} - \frac{E_m \epsilon^{-j\alpha}}{2j(R - j\omega L)} \left\{ \epsilon^{j\omega t} - \epsilon^{-Rt/L} \right\} \right] \mathbf{1} \quad (37c)$$

$$= \left[\frac{E_m}{2j} \left\{ \frac{\epsilon^{j(\omega t + \alpha)}}{Z\epsilon^{j\phi}} - \frac{\epsilon^{-j(\omega t + \alpha)}}{Z\epsilon^{-j\phi}} \right\} - \frac{\epsilon^{-Rt/L} E_m}{2j} \left\{ \frac{\epsilon^{j\alpha}}{Z\epsilon^{j\phi}} - \frac{\epsilon^{-j\alpha}}{Z\epsilon^{-j\phi}} \right\} \right] \mathbf{1} \quad (37d)$$

$$= \left[\frac{E_m}{Z} \sin(\omega t + \alpha - \phi) - \frac{E_m \epsilon^{-Rt/L}}{Z} \sin(\alpha - \phi) \right] \mathbf{1} \quad (37e)$$

Notations

a_k—a constant coefficient of the differential equation 1.
A_{ks}—a constant defined by equation 13.
$A(u)$—a polynomial in u defined by equation 16.
b—any positive real number.
b_{rs}—a constant obtained by expanding the function Δ_{ks}/Δ and defined by equation 29*b*.
b_{prs}—a constant obtained by expanding the function Δ_{ks}/Δ and defined by equation 33.
c or c_s—coefficient of t in the exponential electromotive force function.
c_{sr}—that c_s which is equal to u_r.
$e(t)$—any instantaneous electromotive force such that the integral of equation 2 exists.
$e_s(t)$—exponential electromotive force defined by equation 21.
E_s—value of $e_s(t)$ corresponding to $t = 0$.
E_{sr}—that E_s whose exponent has for its coefficient c_{sr}.
E_{msi}—amplitude of the sine wave electromotive force $e_s(t)$.

g—number of roots of Δ that are repeated.
$z_{hs}(u)$—operational impedance of branch h on branch s.
$i(t)$—instantaneous current.
r—any integer.
$i', i'' \ldots i^{(n-1)}$—1st, 2d . . . (n − 1)th derivatives of $i(t)$.
k—any integer.
s—any integer.
h—number of roots of Δ that are equal to some values of c_s (see equation 30).
$m_1, m_2 \ldots m_g$—the number of times that the distinct roots ($u_1, u_2 \ldots u_g$) of the polynomial Δ are repeated.
p—differential operator d/dt.
m—degree of the polynomial Δ.
n—number of sources of electromotive force in a circuit (see equations 28 and 30).
t—time.
u—any complex number whose real part is positive.
u_r—any root of the determinant Δ.
w—number of roots u_r that are equal to some of the values of c_s (see equations 34 and 35).
$Y = Y(u)$—operational admittance.
$Z = Z(u)$—operational impedance.
$i_k(t)$—current in branch k of a circuit.
Δ, Δ_{hs}—impedance determinant and its minor defined by equation 11.
α_s—initial angle of the sine wave electromotive force $e_s(t)$.
ω—angular velocity of the sine wave electromotive force $e_s(t)$.

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Parallel Inverter With Resistance Load

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Calculation of inverter performance and analysis of the circuit apparently have not been treated to any great extent in technical literature. This paper presents a method of calculating in terms of 2 parameters the characteristics of an inverter supplying a pure resistance load, and discusses the various modes of operation, including that in which the direct current supplied to the inverter flows in pulses.

THE APPLICATION of inverters has become of noticeably greater interest during recent years. A number of papers[1] of a descriptive nature have been written but no papers, with the exception of several[2,3,4] in Germany, have been published, to the author's knowledge, which deal with the analysis of the circuit and the calculation of the inverter performance. It is the purpose of this paper to present a method of calculating the characteristics of an inverter with a pure resistance load and to discuss the different modes in which inverters may operate. The treatment differs from that of previous investigators in that different parameters are used, the results are plotted in more usable form, and the case is discussed in which the direct current flows in pulses starting from zero each half cycle. It is shown that parallel inverters with resistance load can operate in 2 different fashions depending upon the relative values of the constants. The relations between the constants are conveniently expressed in terms of 2 parameters K and J which represent respectively the ratio of capacitor to load volt-amperes and the ratio of ballast reactance to load resistance.

The circuits under consideration are intended to operate with any of the grid-controlled mercury-vapor discharge tubes or the conventional grid-controlled rectifier. In these devices current conduction may be initiated at any instant that the anode-cathode voltage has the proper polarity, but current extinction must be accomplished through some function of the circuit.

Description of Operation

In figure 1 is shown a schematic diagram for a single-phase inverter with a resistance load. The constant potential E is applied from the d-c source and tubes A and B are alternately made conducting through the functioning of their control devices, the frequency of the a-c load being determined by the

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1. For all numbered references, see list at end of paper.

frequency of the control. Assume for the moment that tube A is conducting. Capacitor C assumes a potential of approximately $2E$, the right-hand side being positive. Now if tube B is rendered, conducting capacitor C tends to discharge through the 2 tubes, causing the current in tube A to decrease to zero. Tube A thus becomes open-circuited. The anode-cathode potential across tube A is then equal to the potential across the condenser minus the arc drop in tube B. Since the left-hand side of the capacitor is negative in potential relative to the right-hand side, the anode becomes negative relative to the cathode. With the new conduction paths, the capacitor tends to charge with the opposite polarity and as it becomes charged the anode-cathode potential increases from a negative value to a positive value as shown by the curve in figure 2. When tube A is made conducting, the capacitor discharges in the reverse direction extinguishing the arc in tube B. In this manner tubes A and B alternately are made to conduct current, and pulses of current are made to pass alternately through the 2 sides of the transformer which produce an alternating current in the secondary of the transformer and in the load resistance. The other curves in figure 2 show how other quantities vary with time. The symbol T represents one period of the control frequency.

Modes of Operation

In the foregoing explanation of operation of the circuit it was assumed tacitly that the ballast inductance was sufficiently large that the current in the d-c circuit did not reach zero at any instant. As the ballast inductance is made smaller and smaller the variations in the direct current become greater until finally a condition is reached in which the direct

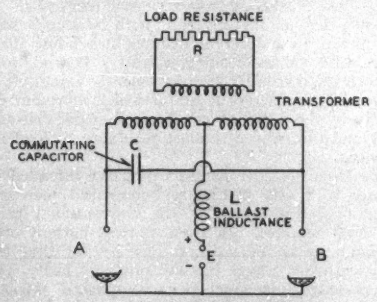
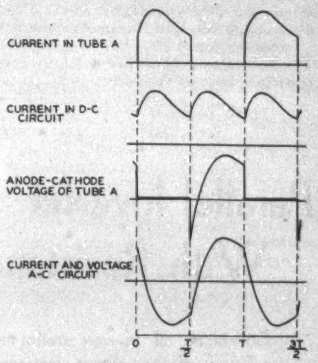


Fig. 1. Schematic diagram of parallel inverter with resistance load

current flows in pulses. The variations in the principal quantities for this condition are shown in figure 3.

In the development which follows it will be found that the results can be expressed conveniently in terms of 2 dimensionless parameters, namely, $K = 4YR$ and $J = X/R$. The former gives approximately the ratio of the kilovolt-ampere capacity of the commutating capacitor to the load kilowatts. Thus, assuming that all 3 transformer windings have the same number of turns, for the fundamental component of voltage across the load the load in watts is E^2/R. Similarly, since the voltage across the capacitor is twice that across the load, the volt-amperes of the capacitor are $2\pi fC\ (2E)^2$. The ratio is thus $\frac{2\pi fC4E^2}{E^2/R} = 2\pi fC\ 4R = 4YR = K$. The other parameter J is equal to the ratio of the reactance of the ballast inductance at *control* frequency ($2\pi fL$)

Fig. 2. Current and voltage relations when inductance in d-c side is large



to the load resistance. Expressed as a function of these 2 parameters, the division between the 2 modes of operation exemplified by the curves of figures 2 and 3 is given by the line OA in figure 4. The derivation of this division line will be given later.

Part or all of the capacitance of C in figure 1 can be placed in parallel with the load. In some instances it may also be desirable to arrange that capacitance be switched in simultaneously with additional load.

Outline of Method of Calculation

The general plan of attack will be to set up the differential equations of the circuit with one tube operating and the other tube open-circuited. This circuit is shown in figure 5*a*. It will be assumed that all 3 windings of the transformer have the same number of turns. If this is not so, R can be reduced readily to an equivalent resistance. The further assumption will be made that the transformer leakage reactance and magnetizing current are negligibly small. Calculations in which these quantities were not neglected have shown these assumptions to be justifiable. The circuit can be simplified further to that shown in figure 5*b*. All circuit resistances except the load will be assumed to be equal to zero. Since the tube arc drop is essentially constant, inde-

pendent of the current, it may be subtracted from the applied continous voltage and the difference regarded as the actual applied voltage.

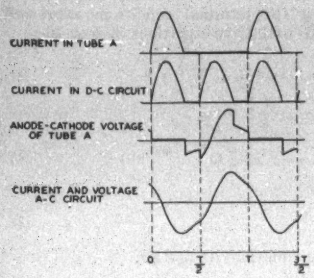


Fig. 3. Current and voltage relations when the direct current flows in pulses

For the figure shown, the following 3 differential equations may be written:

$$Ri_2 - \frac{q}{4C} = 0 \tag{1}$$

$$L\frac{di_1}{dt} + \frac{q}{4C} = E \tag{2}$$

$$-\frac{dq}{dt} = i_2 - i_1 \tag{3}$$

in which

i_1 = current in the circuit connected to the supply
i_2 = current in the load
q = charge on the capacitor of such sign as to make the right-hand side positive

Now let

$$i_1 = I_1 e^{mt} \tag{4}$$

$$i_2 = I_2 e^{mt} \tag{5}$$

$$q = Qe^{mt} \tag{6}$$

and substitute in equations 1 to 3, letting the right-hand member of equation 2 be zero. Then

$$R\,I_2 - \frac{Q}{4C} = 0 \tag{7}$$

$$mL\,I_1 + \frac{Q}{4C} = 0 \tag{8}$$

$$-mQ = I_2 - I_1 \tag{9}$$

From the determinant of equations 7 to 9 the following auxiliary equation is obtained:

$$4CR\,m^2 + m + \frac{R}{L} = 0 \tag{10}$$

The roots of this equation give the values of m which when used in connection with equations 4 to 6 give the complementary functions. These roots are

$$m = \frac{1}{2(4CR)}\left[-1 \pm \sqrt{1 - 4(4CR)\frac{R}{L}}\right] \tag{11}$$

Now introducing the parameters $Y = 2\pi fC$ and $X = 2\pi fL$, there results

$$m = \frac{\pi f}{K}\left[-1 \pm \sqrt{1 - \frac{4K}{J}}\right] \tag{12}$$

It is evident from this equation that 2 distinct (if the special boundary case between the 2 be neglected) solutions result: first, the case in which the 2 roots are real, the transient terms then consisting of 2 exponentials; and second, the case in which the 2 roots are complex, the transient terms then consisting of 2 damped sinusoids. The division between these 2 cases is obtained by equating the quantity under the radical to zero. Thus

$$K = \frac{J}{4} \tag{13}$$

The straight line in figure 4 shows graphically the division between these 2 cases.

Solution With Roots Real

Let the roots of equation 12 for this case be $-a$ and $-b$ where

$$a = \frac{\pi f}{K}\left[1 + \sqrt{1 - \frac{4K}{J}}\right] \tag{14}$$

$$b = \frac{\pi f}{K}\left[1 - \sqrt{1 - \frac{4K}{J}}\right] \tag{15}$$

The complete solution for the current i_1 may be written

$$i_1 = I_1' e^{-at} + I_1'' e^{-bt} + \frac{E}{R} \tag{16}$$

in which I_1' and I_1'' are integration constants and E/R is the particular integral. Similarly, the charge on the capacitor may be written

$$q = Q' e^{-at} + Q'' e^{-bt} + 4CE$$

in which Q' and Q'' are integration constants related to I_1' and I_1'' through equation 8. Thus

$$q = 4CaL\,I_1' e^{-at} + 4CbL\,I_1'' e^{-bt} + 4CE \tag{17}$$

The instantaneous voltage across the capacitor in figure 5*b* is

$$e = q/4C \tag{18}$$

so that from equation 17

$$e = aL\,I_1' e^{-at} + bL\,I_1'' e^{-bt} + E \tag{19}$$

The integration constants may be obtained by applying the terminal conditions to equations 16 and 19. Calling $T = 1/f$, the full period of the control frequency, it may be seen from figure 2 that

$$i_{1(\text{for } t = 0)} = i_{1(\text{for } t = T/2)} \tag{20}$$

and

$$e_{(\text{for } t = 0)} = -e_{(\text{for } t = T/2)} \tag{21}$$

After applying equations 20 and 21 to equations 16 and 19

$$\left(1 - e^{\frac{-aT}{2}}\right) I_1' + \left(1 - e^{\frac{-bT}{2}}\right) I_1'' = 0 \tag{22}$$

$$aL(1 + \epsilon^{\frac{-aT}{2}}) I_1' + bL(1 + \epsilon^{\frac{-bT}{2}}) I_1'' = -2E \tag{23}$$

From equations 14 and 15, since $fT = 1.0$

$$k = \frac{aT}{2} = \frac{\pi}{2K}\left[1 + \sqrt{1 - \frac{4K}{J}}\right] \tag{24}$$

$$h = \frac{bT}{2} = \frac{\pi}{2K}\left[1 - \sqrt{1 - \frac{4K}{J}}\right] \tag{25}$$

and

$$aL = \frac{2gL}{T} = \frac{2g2\pi fL}{2\pi fT} = \frac{gJR}{\pi} \tag{26}$$

$$bL = \frac{2hL}{T} = \frac{2h2\pi fL}{2\pi fT} = \frac{hJR}{\pi} \tag{27}$$

Rewriting equations 22 and 23

$$(1 - \epsilon^{-g}) I_1' + (1 - \epsilon^{-h}) I_1'' = 0 \tag{28}$$

$$g(1 + \epsilon^{-g}) I_1' + h(1 + \epsilon^{-h}) I_1'' = -\frac{2\pi}{JR} E \tag{29}$$

Solving for I_1' and I_1'',

$$I_1' = \frac{1}{\Delta}(1 - \epsilon^{-h}) \frac{2\pi}{JR} E \tag{30}$$

$$I_1'' = -\frac{1}{\Delta}(1 - \epsilon^{-g}) \frac{2\pi}{JR} E \tag{31}$$

in which

$$\Delta = h(1 - \epsilon^{-g})(1 + \epsilon^{-h}) - g(1 - \epsilon^{-h})(1 + \epsilon^{-g}) \tag{32}$$

Therefore

$$\frac{i_1 R}{E} = \frac{2\pi}{J\Delta}(1 - \epsilon^{-h}) \epsilon^{\frac{-2g}{T}t} - \frac{2\pi}{J\Delta}(1 - \epsilon^{-g}) \epsilon^{\frac{-2h}{T}} + 1 \tag{33}$$

Also, from equations 19, 26, 27, 30, and 31,

$$\frac{e}{E} = \frac{2g}{\Delta}(1 - \epsilon^{-h}) \epsilon^{\frac{-2g}{T}t} - \frac{2h}{\Delta}(1 - \epsilon^{-g}) \epsilon^{\frac{-2h}{T}t} + 1 \tag{34}$$

Solution With Roots Complex

Let the roots of equation 12 for this case be

$$m = -\alpha \pm j\beta \tag{35}$$

where

$$\alpha = \frac{\pi f}{K} \tag{36}$$

$$\beta = \frac{\pi}{K}\sqrt{\frac{4K}{J} - 1} \tag{37}$$

The complete solution for the current i_1 may be written

$$i_1 = I_1' \epsilon^{(-\alpha + j\beta)t} + I_1'' \epsilon^{(-\alpha - j\beta)t} + \frac{E}{R} \tag{38}$$

Since the complex integration constants I_1' and I_1'' will be conjugate, this equation may be written, if the factor E/R is absorbed in the integration constant, as

$$\frac{i_1 R}{E} = \text{real part } I_1 \epsilon^{(-\alpha + j\beta)t} + 1 \tag{39}$$

The integration constant Q can be evaluated in terms of I_1 from equation 8, after which e/E can be written by the aid of equation 18 as

$$\frac{e}{E} = -\text{ real part } (-\alpha + j\beta) \frac{L}{R} I_1 \epsilon^{(\alpha + j\beta)t} + 1 \tag{40}$$

Again applying the terminal conditions expressed by equations 20 and 21 to equations 39 and 40,

$$\text{real part } I_1 + 1 = \text{real part } I_1 \epsilon^{(-\alpha + j\beta)\frac{T}{2}} + 1 \tag{41}$$

$$-\text{ real part } (-\alpha + j\beta) \frac{L}{R} I_1 + 1 = \text{real part } (-\alpha + j\beta) \frac{L}{R} I_1 \epsilon^{(-\alpha + j\beta)\frac{T}{2}} - 1 \tag{42}$$

Let

$$I_1 = m + jn \tag{43}$$

then expanding equations 41 and 42,

$$\left[1 - \epsilon^{-\frac{\alpha T}{2}} \cos \beta \frac{T}{2}\right] m + \left[\epsilon^{-\frac{\alpha T}{2}} \sin \beta \frac{T}{2}\right] n = 0 \tag{44}$$

$$\text{real part } (-\alpha + j\beta) \left\{\left[1 + \epsilon^{\frac{-\alpha T}{2}} \cos \beta \frac{T}{2}\right] + j \epsilon^{\frac{-\alpha T}{2}} \sin \beta \frac{T}{2}\right\} \frac{L}{R}(m + jn) = 2 \tag{45}$$

To simplify the notation, let

$$s = \frac{\alpha T}{2} = \frac{\pi}{2K} \tag{46}$$

$$\gamma = \frac{\beta T}{2} = \frac{\pi}{2K}\sqrt{\frac{4K}{J} - 1} \tag{47}$$

$$k = \epsilon^{-s} \tag{48}$$

Equation 44 may then be written as

$$(1 - k \cos \gamma) m + (k \sin \gamma) n = 0 \tag{49}$$

and equation 45 as

$$\text{real part } \frac{2}{T}(-s + j\gamma)[(1 + k \cos \gamma) + j k \sin \gamma] \frac{X}{2\pi fR}(m + jn) = 2$$

or

$$[s(1 + k \cos \gamma) + \gamma k \sin \gamma] m + [\gamma(1 + k \cos \gamma) - s k \sin \gamma] n = -\frac{2\pi}{J} \tag{50}$$

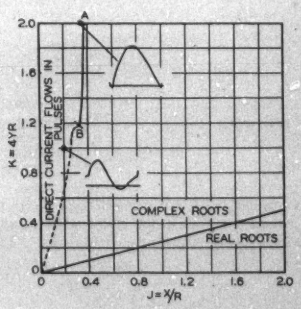


Fig. 4. Division of solutions according to relative values of J and K

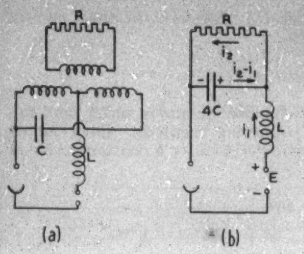


Fig. 5. Equivalent circuits for parallel inverter with resistance load

Solving for m and n in equations 49 and 50, there results

$$m = \frac{2\pi k \sin\gamma}{J[\gamma(1-k^2) - 2sk\sin\gamma]} \tag{51}$$

$$n = \frac{-2\pi[1 - k\cos\gamma]}{J[\gamma(1-k^2) - 2sk\sin\gamma]} \tag{52}$$

From equation 39

$$\frac{i_1 R}{E} = \epsilon^{\frac{-2s}{T}t}\left(m\cos\frac{2\gamma}{T}t - n\sin\frac{2\gamma}{T}t\right) + 1 \tag{53}$$

and from equation 40

$$\frac{e}{E} = -\text{ real part }\frac{L}{R}\frac{2}{T}[(-sm-\gamma n)+j(\gamma m - sn)]\epsilon^{(-\alpha+j\beta)t} + 1$$

$$= \frac{J}{\pi}\epsilon^{\frac{-2s}{T}t}\left[(sm+\gamma n)\cos\frac{2\gamma}{T}t + (\gamma m - sn)\sin\frac{2\gamma}{T}t\right] + 1 \tag{54}$$

Thus for any value of K or J it is possible to solve for the variation of i_1 or e by the use of equations 46 to 48 and 51 to 54. In figure 7 is shown an oscillogram and test results for a case in which the constants lie in the region which requires this type of solution.

In a large number of cases the transient terms reduce to a very small value at the end of a half cycle. Thus for $K = 0.5$, the exponential has reduced to $\epsilon^{-\frac{\pi}{3\times 0.5}}$ or 0.043. For the special case in which the exponential has reduced to zero at the end of the half cycle ($k = 0$), the solution simplifies to the following: In equations 51 and 52

$$m = 0 \tag{55}$$

$$n = -\frac{2\pi}{J\gamma} \tag{56}$$

and equations 53 and 54 become

$$\frac{i_1 R}{E} = \frac{2\pi}{J\gamma}\epsilon^{\frac{-2s}{T}t}\sin\frac{2\gamma}{T}t + 1 \tag{57}$$

$$\frac{e}{E} = \epsilon^{\frac{-2s}{T}t}\left[-2\cos\frac{2\gamma}{T}t + \frac{2s}{\gamma}\sin\frac{2\gamma}{T}t\right] + 1 \tag{58}$$

Failure of Solutions to Comply With Physical Requirements of Tubes

It was explained previously that as L decreases the variations in i_1 become so great that the current is extinguished before the end of the half cycle. A general analytical expression to determine the limits at which this phenomenon occurs is difficult to obtain. However, for the special case just considered in which the transient components reduce to zero at the end of a half cycle, it is possible to obtain a simple relation between the parameters at which the phenomenon first appears. The limiting condition occurs when the minimum value of current just touches zero. This may be determined mathematically by obtaining the point at which minimum occurs and substituting this value in the expression for current and equating to zero. Equating the differential of equation 57 to zero

$$\frac{2\gamma}{T}\epsilon^{\frac{-2st}{T}}\cos\frac{2\gamma}{T}t - \frac{2s}{T}\epsilon^{\frac{-2st}{T}}\sin\frac{2\gamma}{T}t = 0 \tag{59}$$

Calling the time which satisfies this equation t'',

$$t'' = \frac{T}{2\gamma}\left[\tan^{-1}\frac{\gamma}{s} + \pi\right] \tag{60}$$

the π is added to obtain the first minimum; without it, the expression gives the first maximum.

Substituting this value of t'' in equation 57 and equating i_1 to zero,

$$\frac{i_1 R}{E} = 0 = \frac{2\pi}{J\gamma}\epsilon^{-\frac{2s}{T}\frac{T}{2\gamma}\left(\tan^{-1}\frac{\gamma}{s}+\pi\right)}\sin\left[\frac{2\gamma}{T}\frac{T}{2\gamma}\left(\tan^{-1}\frac{\gamma}{s}+\pi\right)\right] + 1$$

$$= -\frac{2\pi}{J\gamma}\epsilon^{\frac{-s}{\gamma}\left(\tan^{-1}\frac{\gamma}{s}+\pi\right)}\frac{\gamma}{\sqrt{s^2+\gamma^2}} + 1$$

or

$$\epsilon^{-\frac{s}{\gamma}\left(\tan^{-1}\frac{\gamma}{s}+\pi\right)} = \frac{J}{2\pi}\sqrt{s^2+\gamma^2} \tag{61}$$

From equations 46 and 47

$$\frac{\gamma}{s} = \sqrt{\frac{4K}{J} - 1}$$

$$s^2 + \gamma^2 = \frac{\pi^2}{4K^2} + \frac{\pi^2}{4K^2}\left(\frac{4K}{J} - 1\right) = \frac{\pi^2}{KJ}$$

On substituting these values in equation 61,

$$\epsilon^{-\frac{\tan^{-1}\sqrt{\frac{4K}{J}-1}+\pi}{\sqrt{\frac{4K}{J}-1}}} = \frac{1}{\sqrt{\frac{4K}{J}}} \tag{62}$$

It will be observed that equation 62 is a function of $4K/J$ alone. By a cut-and-try process it was established that a value of $4K/J$ equal to 12.96 satisfies this equation. Thus the relation

$$K = \frac{12.96}{4}J = 3.24\,J \tag{63}$$

expresses the relation between K and J for small values of K. The relation between K and J for somewhat larger values of K which would just prevent negative values of direct current from appearing were obtained by a cut-and-try process and the results plotted by the line OB in figure 4. Below the point

B the solution fails to comply with the physical requirements of tube conduction by the appearance of a negative current at the point in the curve where the slope is zero (see the wave shape plotted for point $K = 1.0$). Above the point B the solution fails by the appearance of negative current at the 2 ends of the curve. The mathematical requirements are still satisfied but the physical requirements are not. To the left of the line OA, therefore, the direct current must flow in pulses.

Summary of Results

Figure 6 shows families of curves which were calculated by the foregoing methods. Each family represents the characteristics for a constant value of

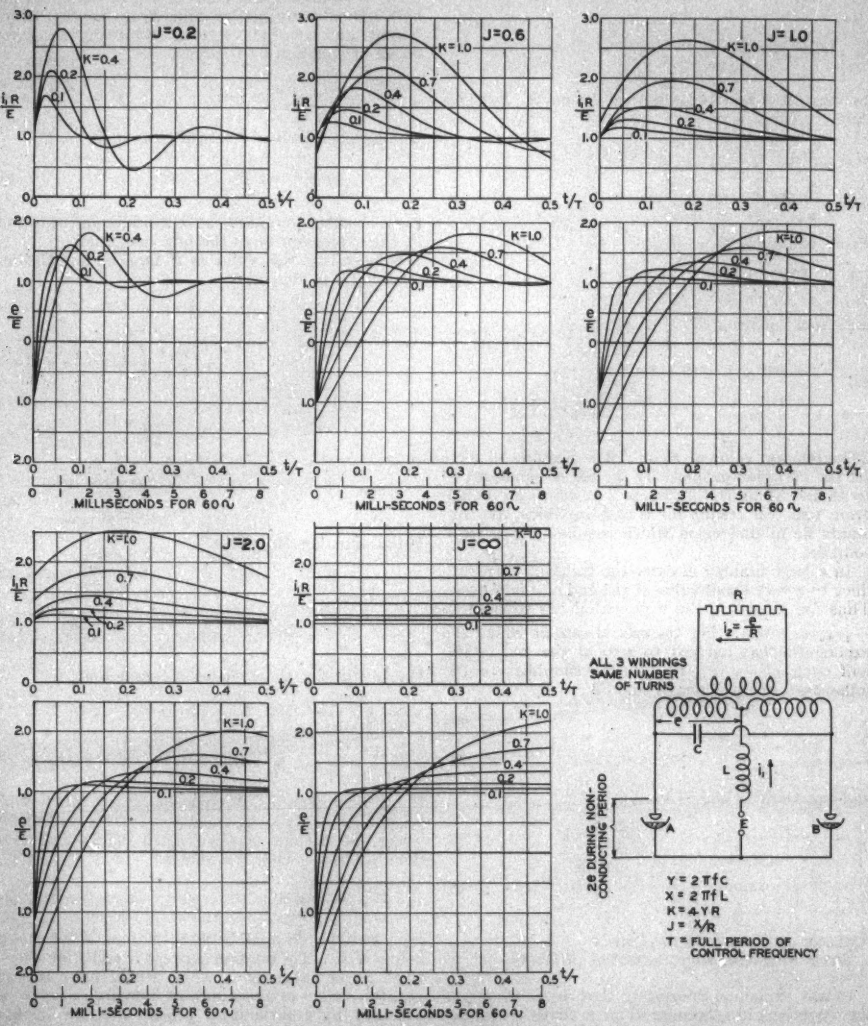


Fig. 6. Current and voltage relations for single phase inverter with resistance load

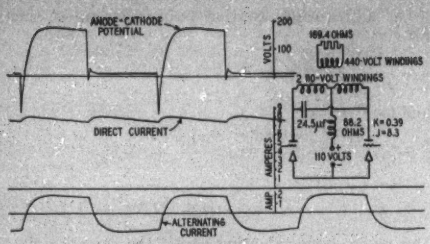


Fig. 7. Oscillogram of 60 cycle inverter operation for K = 0.39 and J = 8.3

J or X/R and different values of K or $4YR$. The abscissa in all cases is the ratio t/T, which extends to only 0.5, representing a half period. The load current, i_2R/E, varies cyclically, the next half cycle being the negative of the particular half cycle plotted, thus forming a continuous alternating current. The transformer voltage curves, e/E, vary in a similar manner. It must be remembered that this is the voltage across the capacitor and also across the load in the equivalent circuit. To get the voltage across the actual capacitor connected between the outside terminals of 2 windings and which is also, except for the arc drop, the anode-cathode voltage during the nonconducting period of the tube, it is necessary to multiply the function e/E by $2E$.

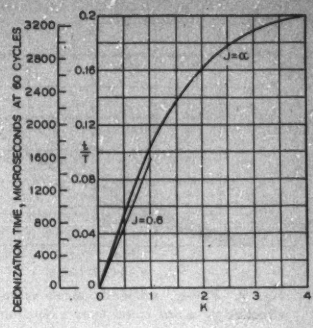
Plotted in the manner indicated, the results may be used for any frequency. In addition to the time scale t/T, a corresponding time scale for the 60 cycle case is also plotted.

To approximate the effect of arc drop, E in this development should represent the actual continuous voltage minus the arc drop which is essentially constant. This will give correct values for i_1, i_2, and capacitor voltage. To get the anode-cathode voltage it is necessary to multiply $2\ e/E$ by the actual continuous voltage minus the arc drop and then to add the arc drop to the product. Figure 7 shows an oscillogram of anode-cathode potential, load current, and direct current for the case in which the parameters are $J = 8.3$ and $K = 0.39$.

Deionization Time

A knowledge of the deionization characteristics of the particular tube used is a prerequisite to the design of any inverter circuit. Actually this is not a constant but depends upon the magnitude and the rate of decay of the tube current just prior to current zero and also upon the rate of rise of anode-cathode voltage. As a measure of the circuit characteristics the time from current zero to the time positive current first appears may be taken conveniently. For satisfactory operation of the inverter it is, therefore, necessary that the actual deionization time of the tube be smaller than this quantity. The deionization time defined in this manner and taken from the curves of figure 6 is plotted in figure 8. It will be observed that this quantity is proportional to the

Fig. 8. Deionization time as a function of K and J



capacitance for a large range of values, but varies little with change in J.

For a given commutating capacitor, if the load current is decreased by increasing the load resistance, then $K = 4YR$ increases. From the curve it may be seen that the deionization time also increases. It follows then that if the constants of the circuit are adjusted so that sufficient deionization time is obtained at full load the deionization time for fractional loads will be greater.

Power and Effective Value of Load Voltage

The power P taken by the load is obtained most readily from the arithmetic mean, I_{1a}, of the direct current. Thus

$$P = EI_{1a}$$

The power taken by the load may also be expressed in terms of the effective value E_e^2 of the load voltage. Thus

$$P = \frac{E_e^2}{R} = EI_{1a}$$

Multiplying through by R/E^2, there is obtained

$$\frac{PR}{E^2} = \frac{E_e^2}{E^2} = \frac{RI_{1a}}{E} \tag{64}$$

By integrating the analytical expression for Ri_1/E it is thus possible to obtain values from which E_e^2 and P may be obtained directly.

For the case in which the roots are real, after integrating equation 33 and dividing by $T/2$, there results

$$\frac{RI_{1a}}{E} = \frac{2\pi}{J\Delta}(1 - \epsilon^{-g})(1 - \epsilon^{-h})\frac{h - g}{gh} + 1 \tag{65}$$

For the case in which the roots are complex, a similar operation on equation 53 gives

$$\frac{RI_{1a}}{E} = \frac{k}{s^2 + \gamma^2}[(-ms + n\gamma)\cos\gamma + (m\gamma + ns)\sin\gamma] + \frac{ms - n\gamma}{s^2 + \gamma^2} + 1 \tag{66}$$

The results obtained by applying equations 65 and 66 are plotted in figure 9. These curves should

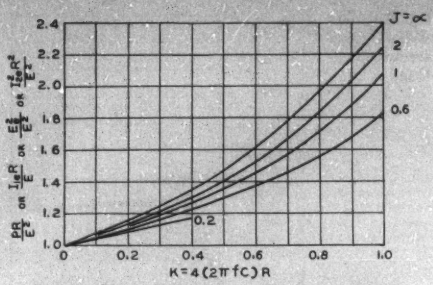


Fig. 9. Power, arithmetic mean value of i_1, and effective values of e and i_2 as a function of J and K

be useful for the determination of regulation at half load, obtained by doubling the load resistance, K is doubled and J is halved. The effect upon the voltage may be read from the curves.

Solution When Direct Current Flows in Pulses

This problem of direct current flowing in pulses is complicated by the fact that 2 circuit conditions must be considered: first, the period during which a tube is conducting, and second, the period during which no tube is conducting. During the latter period the capacitor discharges through the load resistance. The integration constants must be so chosen that the capacitor potentials match on at the boundaries of these 2 periods to form a continuous function. Because of the particular manner in which the transcendental functions are involved it is impossible to obtain a straightforward solution for this case. A cut-and-try process is necessary to determine one of the integration constants. During the conducting period the natural oscillation constants of the circuit are given by equations 46 to 48, and the expression for i_1 may be written in the form of equation 53 as

$$\frac{i_1R}{E} = \epsilon^{\frac{-2s}{T}t}\left(M\cos\frac{2\gamma}{T}t - N\sin\frac{2\gamma}{T}t\right) + 1 \qquad (67)$$

and e may be written in the form of equation 54 as

$$\frac{e}{E} = \frac{J}{\pi}\epsilon^{\frac{-2s}{T}t}\left[(sM + \gamma N)\cos\frac{2\gamma}{T}t + (\gamma M - sN)\sin\frac{2\gamma}{T}t\right] + 1 \qquad (68)$$

in which M and N are the integration constants.

The integration constant M may be determined by applying the terminal condition $i_1 = 0$ for $t = 0$ in equation 67. Thus,

$$M = -1 \qquad (69)$$

Now designate the time at which i_1 again reaches zero by t'. Then from equation 67

$$N = \frac{\epsilon^{\frac{2s}{T}t'} - \cos\frac{2\gamma t'}{T}}{\sin\frac{2\gamma t'}{T}} \qquad (70)$$

On substituting equation 69 in equation 68, then for $t = 0$

$$\frac{e}{E} = \frac{J}{\pi}(-s + \gamma N) + 1 \qquad (71)$$

and for $t = t'$,

$$\frac{e}{E} = \frac{J}{\pi}\epsilon^{\frac{-2st'}{T}}\left[(-s + \gamma N)\cos\frac{2\gamma t'}{T} - (\gamma + sN)\sin\frac{2\gamma t'}{T}\right] + 1 \qquad (72)$$

During the nonconducting period the capacitor discharges through the load resistance with a time constant equal to $4RC$ or $K/2\pi f$ or $1/2\alpha$ or $T/4s$. The total decrease in capacitor voltage during this period is then

$$\epsilon^{\frac{-4s}{T}\left(\frac{T}{2} - t'\right)} \text{ or } \epsilon^{-2s + \frac{4st'}{T}}$$

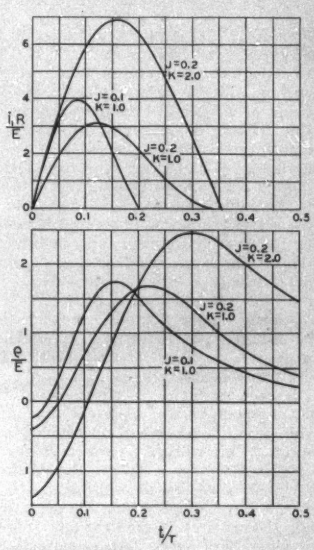
Multiplying equation 72 by this factor gives the value of e/E at the end of the half cycle as

$$\frac{e}{E} = \frac{J}{\pi}\epsilon^{-2s\left(1 - \frac{t'}{T}\right)}\left[(-s + \gamma N)\cos\frac{2\gamma t'}{T} - (\gamma + sN)\sin\frac{2\gamma t'}{T}\right] + 1 \qquad (73)$$

A value of t' must be arbitrarily chosen until N calculated from equation 70 gives equal but negative values of e/E when inserted in equations 71 and 73.

Equations 67 and 68 then give the instantaneous values of i_1 and e for the conducting period. During

Fig. 10. Calculated curves for current and voltage relations when direct current flows in pulses



the nonconducting period $i_1 = 0$ and e decreases exponentially with a time constant equal to $T/4s$. In figure 10 are shown the results of calculation for 3 sets of constants which fall within this region.

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Capacitor Motors With Windings Not in Quadrature

Quite often the design of a split phase induction motor is such that the so-called quadrature winding is displaced at some angle other than 90 degrees from the main winding, in which event the motor behaves differently when run in opposite directions. It is the purpose of this paper to indicate a method by which the designer can predict the performance of such a motor. While the emphasis is placed upon the capacitor motor, the treatment is applicable also to motors of other types.

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IN the design of split-phase induction motors, the number of stator slots and poles may frequently be such that the so-called quadrature winding is, in reality, other than 90 degrees from the main winding. Under such a condition the operating characteristics of the motor are modified; the torque chiefly, being different from that predicted by the usual analyses. Deliberate adjustment of the winding displacements may be used to modify the torque characteristics of the motor. In all such cases the motor displays different behavior when run in opposite directions; this is frequently a desirable characteristic.

It is the purpose of this paper to indicate a method of determining such effects for a motor of the split-phase type so as to enable the designer to predict the characteristics for those cases in which the windings are not in quadrature, and accurate torque calculations are necessary. Emphasis is placed upon the capacitor motor calculations as they represent a slightly more general case, although, as indicated later, the equations developed are suitable for the plain single phase, plain split-phase, capacitor, 2-phase, and shaded pole motors, with windings equal or unequal, and displaced any number of electrical degrees. The work is an extension of that given by Wayne J. Morrill,[1] whose analysis of the capacitor motor, based upon the revolving field theory, was found to be adaptable to these further generalizations. To aid in cross reference, the symbols used here will follow (for the most part) those given in his paper.

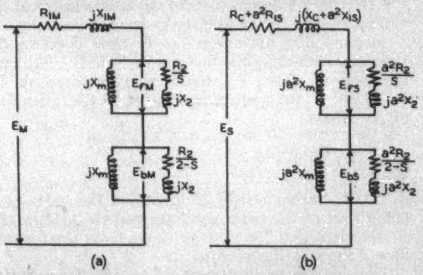

Fig. 1. Equivalent networks of the single phase motor

The method shown in this paper covers a more general process than that hitherto available for presenting the theory and calculations of a 2-phase machine in which the 2 stator windings are unequal with respect to the number of turns and distribution, are not 90 degrees apart in space, and are supplied by unequal impressed voltages not 90 degrees apart in time. The ability to displace windings other than

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1. For reference see end of paper.

90 degrees and then calculate the machine characteristics, gives the designer an additional tool to meet the multiplicity of difficult industrial specifications.

Theory

In the revolving field theory of the single phase induction motor, the alternating flux produced by the stator winding is resolved into a pair of sinusoidal waves revolving in opposite directions at synchronous speed. The effect upon the stator, produced by

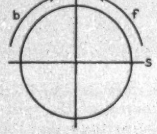

Fig. 2. Relative positions of the fields

each of these fluxes, can be represented by the network of figure 1*a*. If the starting phase *S* is operating alone, the equivalent network is as shown by figure 1*b*.

If both the main, *M*, and the starting, *S*, phases are excited simultaneously, their fluxes superimpose without distortion and the equivalent circuit of each phase is the same as before, except that in addition to the forward and backward voltages (self-induced in each phase) there is present in each phase a forward and backward voltage due to the fluxes of the other phase.

Referring to figure 2, since *M* is 90 electrical degrees ahead of *S*, the voltage generated in *M* by the *S* forward flux must lag, by 90 time degrees, the voltage which the same flux produces in *S*; and since the ratio of effective turns of the windings, or T_M to T_S, is $1/a$, the voltage in *M* must be $1/a$ times that of *S*. Then

$$\underset{Sf}{E_M} = -j\frac{E_{fS}}{a} = \epsilon^{-j\frac{\pi}{2}}\frac{E_{fS}}{a} \tag{1}$$

in which the subscript *M* identifies the voltage as being that of the main winding, and the underscript *Sf* indicates that the voltage arises from the forward flux of the starting winding.

The voltage generated in *M* by the *S* backward flux must lead by 90 time degrees the voltage which the same flux produces in *S*. Then

$$\underset{Sb}{E_M} = j\frac{E_{bS}}{a} = \epsilon^{j\frac{\pi}{2}}\frac{E_{bS}}{a} \tag{2}$$

The voltage generated in *S* by the *M* forward flux must lead by 90 time degrees the voltage which the same flux produces in *M*, and since the ratio of effective turns of $T_S/T_M = a$, this *S* voltage must be *a* times that of *M*. Then

$$\underset{Mf}{E_S} = jaE_{fM} = \epsilon^{j\frac{\pi}{2}}aE_{fM} \tag{3}$$

The voltage generated in *S* by the *M* backward flux must lag by 90 time degrees the voltage which this same flux produces in *M*. Then

$$\underset{Mb}{E_S} = -jaE_{bM} = \epsilon^{-j\frac{\pi}{2}}aE_{bM} \tag{4}$$

The equivalent networks then become those shown in figure 3. The divided circuits of figures 1*a* and 1*b* have been replaced by series impedances of equivalent values.

If the *M* and *S* windings are not 90 degrees apart in space, equations 1 to 4, respectively, become

$$\underset{Sf}{E_M} = \epsilon^{-j\alpha_1}\frac{E_{fS}}{a} \tag{1a}$$

$$\underset{Sb}{E_M} = \epsilon^{j\alpha_1}\frac{E_{bS}}{a} \tag{2a}$$

$$\underset{Mf}{E_S} = \epsilon^{j\alpha_1}aE_{fM} \tag{3a}$$

$$\underset{Mb}{E_S} = \epsilon^{-j\alpha_1}aE_{bM} \tag{4a}$$

wherein α_1 is the angle in degrees between *M* and *S*.

In the stator there is a transformer action between *M* and *S* which, it will be assumed, produces the same effects as do these 2 forward and backward moving fluxes. This transformer action, in either direction, is not the same as that which would be produced by a transformer action between *M* and *S* if it were of equal value but outside the machine.

Examination of the circuits of figure 3 indicates the following voltage and current relationships, all values being considered vectorially:

$$E_M = E_{1M} + E_{fM} + E_{bM} + \underset{Sb}{E_M} + \underset{Sf}{E_M} \tag{5}$$

$$E_S = E_{1S} + E_{fS} + E_{bS} + \underset{Mb}{E_S} + \underset{Mf}{E_S} \tag{6}$$

$$E_{1M} = I_M(R_{1M} + jX_{1M}) \tag{7}$$

$$E_{fM} = I_M(R_f + jX_f) \tag{8}$$

$$E_{bM} = I_M(R_b + jX_b) \tag{9}$$

$$\underset{Sf}{E_M} = I_S a\epsilon^{-j\alpha_1}(R_f + jX_f) \tag{10}$$

$$\underset{Sb}{E_M} = I_S a\epsilon^{j\alpha_1}(R_b + jX_b) \tag{11}$$

$$E_{1S} = I_S a^2(R_{1S} + jX_{1S}) \tag{12}$$

$$E_{fS} = I_S a^2(R_f + jX_f) \tag{13}$$

$$E_{bS} = I_S a^2(R_b + jX_b) \tag{14}$$

$$\underset{Mf}{E_S} = I_M a\epsilon^{j\alpha_1}(R_f + jX_f) \tag{15}$$

$$\underset{Mb}{E_S} = I_M a\epsilon^{-j\alpha_1}(R_b + jX_b) \tag{16}$$

Expanded, the equations of total voltage become

$$E_M = I_M[(R_{1M} + jX_{1M}) + (R_f + jX_f) + (R_b + jX_b)] + I_S[a(R_b + jX_b)\epsilon^{j\alpha_1} + a(R_f + jX_f)\epsilon^{-j\alpha_1} \doteq j\omega M] \tag{17}$$

$$E_S = I_S[a^2(R_{1S} + jX_{1S}) + a^2(R_f + jX_f) + a^2(R_b + jX_b)] + I_M[a(R_b + jX_b)\epsilon^{-j\alpha_1} + a(R_f + jX_f)\epsilon^{j\alpha_1} \doteq j\omega M] \tag{18}$$

Referring to equation 17, let the first expression in the brackets be represented by Z_I; let the second be Z_{II}. In equation 18 let the first expression be Z_{III}; and the second expression be Z_{IV}. Note the quantity $j\omega M$. This is to take care of the coupling caused by local mutual leakage fluxes which link both

stator windings but do not link with the rotor windings. It can readily be measured and possibly calculated but it will, in general, be small enough to neglect here. Using the impedances, equations 17 and 18 reduce to

$$I_M Z_I + I_S Z_{II} = E_M \tag{17a}$$

$$I_M Z_{IV} + I_S Z_{III} = E_S \tag{18b}$$

Solving these 2 equations simultaneously for currents,

$$I_M = \frac{E_M Z_{III} - E_S Z_{II}}{Z_I Z_{III} - Z_{II} Z_{IV}} = A + jB \tag{19}$$

$$I_S = \frac{E_S Z_I - E_M Z_{IV}}{Z_I Z_{III} - Z_{II} Z_{IV}} = g + jh \tag{20}$$

$$\frac{I_S}{I_M} = \frac{E_S Z_I - E_M Z_{IV}}{E_M Z_{III} - E_S Z_{II}} = \frac{Z_I - Z_{IV}}{Z_{III} - Z_{II}} \tag{21}$$

The starting currents, with windings 90 degrees apart, are

$$I_M = \frac{E_M}{Z_I} \tag{22}$$

$$I_S = \frac{E_S}{Z_{III}} \tag{23}$$

The torque equation per inch of rotor periphery can be set up for the condition of $\alpha_1 \leqq 90$ degrees,

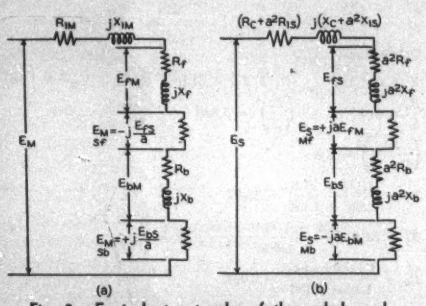

Fig. 3. Equivalent networks of the unbalanced 2 phase motor

and integrated to determine the average torque. This yields (after a long integration) the following expression for average torque in synchronous watts:

$$T_{avg.} = (I_M^2 + a^2 I_S^2)(R_f - R_b) + 2aI_S I_M[R_f \cos(\alpha_1 - \varphi) - R_b \cos(\alpha_1 + \varphi)] \tag{24}$$

If α_1 equals 90 degrees this reduces to:

$$T_{avg.} = (I_M^2 + a^2 I_S^2)(R_f - R_b) + 2a(Ah - Bg)(R_f + R_b) \tag{25}$$

$$Ah - Bg = I_M I_S \sin \varphi$$

where φ is the angle between I_M and I_S.

The starting torque for any displacement becomes

$$T_{avg.}\,(\text{starting}) = 2aI_S I_M[R_f \cos(\alpha_1 - \varphi) - R_b \cos(\alpha_1 + \varphi)] \tag{26}$$

Constants Required for Calculation

1. The ratio $a = \dfrac{T_{SkwS}}{T_{MkwM}}$ in which k_w represents the winding factor and T the number of series turns
2. X_m = magnetizing reactance, which is half of the test or design value. (The double-field theory assumes that the motor is replaced by one stator and 2 oppositely rotating rotors, each with half constants)
3. R_{1M} = resistance of the main stator winding
4. R_{1S} = resistance of the starting stator winding divided by a^2
5. R_2 = rotor resistance (half of design or test value)
6. X_{1M} = leakage reactance of stator main winding M
7. X_{1S} = leakage reactance of stator starting winding S divided by a^2
8. X_2 = leakage reactance of rotor (half of design or test value)
9. X_c = reactance of the capacitor used with S winding. It requires the minus sign
10. R_c = resistance of the capacitor

Calculate the following combinations of terms for a slip S:

11. $R_f = \dfrac{X_m^2\left(\dfrac{R_2}{S}\right)}{\left(\dfrac{R_2}{S}\right)^2 + (X_2 + X_m)^2}$ At synchronism $S = 0$ and $R_f = 0$

12. $X_f = X_m \dfrac{\left(\dfrac{R_2}{S}\right)^2 + X_2(X_2 + X_m)}{\left(\dfrac{R_2}{S}\right)^2 + (X_2 + X_m)^2}$ At synchronism $S = 0$ and $X_f = X_m$

13. $R_b = \dfrac{X_m^2\left(\dfrac{R_2}{2 - S}\right)}{\left(\dfrac{R_2}{2 - S}\right)^2 + (X_2 + X_m)^2}$

    At synchronism $R_b = \dfrac{X_m^2 R_2}{R_2^2 + (X_2 + X_m)^2}$

14. $X_b = X_m \dfrac{\left(\dfrac{R_2}{2 - S}\right)^2 + X_2(X_2 + X_m)}{\left(\dfrac{R_2}{2 - S}\right)^2 + (X_2 + X_m)^2}$

    At synchronism $X_b = X_m \dfrac{R_2^2 + X_2(X_2 + X_m)}{R_2^2 + (X_2 + X_m)^2}$

15. $R_{1M} = R_{1M} + R_f + R_b$
16. $X_{1M} = X_{1M} + X_f + X_b$
17. $R_{1S} = R_c + a^2(R_{1S} + R_f + R_b)$
18. $X_{1S} = X_c + a^2(X_{1S} + X_f + X_b)$
19. $R = R_f - R_b$
20. $X = X_f - X_b$

Referring to equations 17 and 18,

21. $Z_I = R_{1M} + jX_{1M}$
22. $Z_{II} = a(R_f + jX_f)\epsilon^{-j\alpha_1} + a(R_b + jX_b)\epsilon^{j\alpha_1} \doteq j\omega M$
    $= -ja[(R_f - R_b) + j(X_f - X_b)]$ when $\alpha_1 = 90$ degrees

Note that in items 22 and 24 with M considered, the plus sign is used when the magnetomotive forces are prevailingly additive, and the minus sign is used when the magnetomotive forces are prevailingly opposite.

23. $Z_{III} = R_{1S} + jX_{1S}$

24. $Z_{IV} = a(R_f + jX_f)e^{j\alpha_1} + a(R_b + jX_b)e^{-j\alpha_1} = j\omega M$

$= j\omega[(R_f - R_b) + j(X_f - X_b)]$ when $\alpha_1 = 90$ degrees

25. Capacitor voltage:

$E_c = I_s\sqrt{R_c^2 + X_c^2}$

Theoretically a capacitor is usually represented as an ideal capacitance with a shunted resistance. The capacitors utilized in practice have a comparatively high foil resistance which gives the effect of a series circuit.

Applications of Equations

The equations given here can be applied to the analysis of the following:

(*a*) Plain single-phase induction motor

(*b*) Split-phase induction motor, windings 90 degrees apart

(*c*) Capacitor induction motor, windings 90 degrees apart

(*d*) Split-phase induction motor, windings not 90 degrees apart

(*e*) Capacitor induction motor, windings not 90 degrees apart

(*f*) Shaded pole induction motor

(*g*) Two-phase induction motor, windings equal and 90 degrees apart

(*h*) Two-phase induction motor, windings equal and not 90 degrees apart

(*i*) Two-phase induction motor, windings unequal and 90 degrees apart

(*j*) Two-phase induction motor, windings unequal and not 90 degrees apart

In *g*, *h*, *i*, and *j* the terminal voltages are assumed to be 90 degrees apart in time, but the voltage of the second phase can be taken as $E_1(\cos\alpha_2 + j\sin\alpha_2)$ if such is not the case. It should also be pointed out that the shaded pole motor for which this analysis is applicable is the continuous-iron distributed-winding type, and not the usual construction.

Taking up each of these analyses separately, the equations for I_M, I_S, and T_{avg} are:

(*a*). Mutual inductance M (as here used) and ratio of transformation become zero, I_S equals zero, Z_{II} and Z_{IV} become zero, and

$$I_M = \frac{E}{Z_I} \qquad T_{avg} = I_M^2(R_f - R_b)$$

(*b*). I_M, I_S, and T_{avg} are as in equations 19, 20, and 25 with the impedances (Z terms) modified by R_c and X_c being equal to zero.

(*c*). I_M, I_S, and T_{avg} are as in equations 19, 20, and 25.

(*d*). R_c and $X_c = 0$. I_m, I_S, and T_{avg} are as in equations 19, 20, and 24.

(*e*). I_M, I_S, and T_{avg} are as in equations 19, 20, and 24.

(*f*). Z_I, Z_{II}, Z_{III}, and Z_{IV}, from items 21, 22, 23, and 24, are modified by the capacitor constants being equal to zero. Then

$$I_M = E_M\left(\frac{Z_{III}}{Z_IZ_{III} - Z_{II}Z_{IV}}\right)$$

$$I_S = -E_M\left(\frac{Z_{IV}}{Z_IZ_{III} - Z_{II}Z_{IV}}\right)$$

$$\frac{I_S}{I_M} = -\frac{Z_{IV}}{Z_{III}} \qquad E_S = 0$$

T_{avg} is obtained from equation 24.

(*g*). $E_S = jE_M$, $\alpha_1 = 90$ degrees, and $\varphi = 90$ degrees. The following assumptions are made:

$a = 1 \quad R_f = R_b \quad X_f = X_b$

$Z_I = (R_{1M} + 2R_f) + j(X_{1M} + 2X_f)$

$Z_{II} = 0$

$Z_{III} = Z_I$

$Z_{IV} = 0$

$$I_M = \frac{E_M}{Z_I}$$

$$I_S = \frac{jE_M}{Z_I}$$

$$T_{avg} = 4I_M I_S R_f$$

(*h*). $E_S = jE_M$, $\alpha_1 \gtrless 90$ degrees, $a = 1$, $R_f = R_b$, and $X_f = X_b$, with Z_I, Z_{II}, Z_{III}, and Z_{IV} from items 21, 22, 23, and 24.
$T_{avg} = 4I_M I_S R_f$

(*i*). $E_S = jE_M$, $\alpha_1 = 90$ degrees, $a \lessgtr 1$, $R_f = R_b$, and $X_f = X_b$, with Z_I, Z_{II}, Z_{III}, and Z_{IV} from items 21, 22, 23, and 24.
$T_{avg} = 4aI_M I_S \sin\varphi$

(*j*). $E_S = jE_M$, $\alpha_1 \gtrless 90$ degrees, $a \gtrless 1$, $R_f = R_b$, and $X_f = X_b$, with Z_I, Z_{II}, Z_{III}, and Z_{IV} from items 21, 22, 23, and 24.
$T_{avg} = 4aI_M I_S \sin\varphi$

Appendix I

To aid in identifying the terms and to show the influence of winding displacement, the detailed calculations on the capacitor motor used by Morrill with some additional items will be considered.

$R_{1M} = 2.02$	$X_{1M} = 2.79$
$R_2 = 2.06$	$X_2 = 1.06$
$R_{1S} = 5.12$	$X_{1S} = 2.31$
R_c at start $= 3$	X_c at start $= -14.5$
R_c running $= 9$	X_c running $= -172$
Syn. speed $= 1{,}800$ rpm	Running speed $= 1{,}740$ rpm
$X_m = 33.4$	$E = 110$
$a = 1.18$	slip $= 1/30$
$a^2 = 1.39$	

Calculations:

$X_m^2 = 1{,}115 \qquad X_2 + X_m = 34.46 \qquad (X_2 + X_m)^2 = 1{,}186$

$\frac{R_2}{S} = 61.8 \qquad \left(\frac{R_2}{S}\right)^2 = 3{,}820 \qquad \frac{R_2}{2 - S} = 1.047$

$\left(\frac{R_2}{2 - S}\right)^2 = 1.10$

$$R_f = \frac{1{,}115 \times 61.8}{3{,}820 + 1{,}186} = 13.77$$

$$X_f = 33.4\,\frac{3{,}820 + 1.06 \times 34.46}{5{,}006} = 25.72$$

$$R_b = \frac{1{,}115 \times 1.047}{1.10 + 1{,}186} = 0.984$$

$$X_b = 33.4\,\frac{1.10 + 1.06 \times 34.46}{1.10 + 1{,}186} = 1.057$$

(*a*). With the running capacitor,

$Z_I = (2.02 + 13.77 + 0.984) + j(2.79 + 25.72 + 1.057) = 16.77 + j29.57$

$Z_{II} = j1.18(0.984 + j1.057) - j1.18(13.77 + j25.72) = 29.1 - j15.1$

$Z_{III} = 9 + 1.39(5.12 + 13.77 + 0.984) + j[-172 + 1.39(2.31 + 25.72 + 1.057)]$
$= 36.7 - j128$

$Z_{IV} = -Z_{II}$ (when $\alpha_1 = 90$ degrees)

$$I_M = 110\,\frac{(36.7 - j128) - (29.1 - j15.1)}{(16.77 + j29.57)(36.7 - j128) + (29.1 - j15.1)^2}$$

$= 2.31\,\underline{|64^\circ\ 59'}$ or $0.975 - j2.10$.

Similarly,

$I_S = 0.978\,\underline{|3^\circ\ 40'}$ or $0.976 + j0.0626$

$I = I_M + I_S$ or $2.82\,\underline{|46^\circ\ 20'}$

Table I

	$\alpha_1 = 90°$		$\alpha_1 = 60°$		$\alpha_1 = 120°$	
Starting						
I_M	14.2	$\angle 40° 50'$	13.35	$\angle 19° 40'$	15.64	$\angle 4° 50'$
I_S	6.28	$\angle 27° 40'$	4.26	$\angle 62° 10'$	8.54	$\angle 54° 10'$
I_1	17.5		14.56		21.3	
Torque (syn. watts)	760		446		908	
Torque per ampere	43.5		30.7		42.6	
Capacitor voltage	93.0		63.0		126.4	
Running (slip $^1/_{30}$)						
I_M	2.31	$\angle 64° 59'$	2.661	$\angle 67° 7'$	2.068	$\angle 56° 52'$
I_S	0.978	$\angle 3° 40'$	0.678	$\angle 20° 28'$	1.116	$\angle 6° 16'$
I_1	2.82		2.77		2.905	
Torque (syn. watts)	138.6		154.1		112.1	
Capacitor voltage	168.0		116.0		192.0	

$$T_{avg} = (2.31^2 + 1.39 \times 0.978^2)(13.77 - 0.984) + 2 \times 1.18(0.975 \times 0.0626 + 2.10 \times 0.976)(13.77 + 0.984)$$
$$= 138.6 \text{ synchronous watts}$$

(*b*). Considering next the same windings displaced so that $\alpha_1 = 60$ degrees, with slip $= {}^1/_{30}$, R_f, X_f, R_b, X_b, Z_I, and Z_{III} as before, and $M = 0$,

$$Z_{II} = 1.18(13.77 + j25.72)(0.5 - j0.866) + 1.18(0.984 + j1.057)(0.5 + j0.866)$$
$$= 33.9 + j2.74$$
$$Z_{IV} = -16.52 + j28.88$$
$$I_M = 2.661 \angle 67° 7' \qquad \varphi = 87° 35'$$
$$I_S = 0.678 \angle 20° 28'$$
$$T_{avg} = (2.661^2 + 1.39 \times 0.678^2)(13.77 - 0.984) + 2 \times 1.18 \times 0.678 \times 2.661[13.77 \times 0.886 + 0.984 \times 0.844]$$
$$= 154.1 \text{ synchronous watts}$$

(*c*). Considering $\alpha_1 = 120$ degrees, slip $= {}^1/_{30}$, etc.

$$Z_{II} = 1.18(13.77 + j25.72)(-0.5 - j0.866) + 1.18(0.984 + j1.057)(-0.5 + j0.866)$$
$$= 16.52 - j28.88$$
$$Z_{IV} = -33.9 - j2.74$$
$$I_M = 2.068 \angle 56° 52'$$
$$I_S = 1.116 \angle 6° 16'$$
$$T_{avg} = 112.1 \text{ synchronous watts}$$

(*d*). The effect of winding displacement upon starting torque, using starting capacitor, is shown as follows:

$M = 0$ Slip $= 100$ per cent $R_f = 1.93$ $R_b = 1.93$ $X_f = 1.14$

$$X_b = 1.14$$
$$\alpha_1 = 90 \text{ degrees}$$
$$Z_I = 5.88 + j5.07$$
$$Z_{II} = j1.18(1.93 + j1.14) - j1.18(1.93 + j1.14) = 0$$
$$Z_{III} = 15.5 - j8.12$$
$$Z_{IV} = -j1.18(1.93 + j1.14) + j1.18(1.93 + j1.14) = 0$$
$$I_M = 14.2 \angle 40° 50'$$
$$I_S = 6.28 \angle 27° 40'$$
$$\varphi = 68° 20'$$

The torque equation reduces to $2aI_MI_S[2R_f \cos(\alpha_1 - \varphi)]$

$$T_{avg} = 2 \times 1.18 \times 14.2 \times 6.28(2 \times 1.93 \times 0.9304)$$
$$= 760 \text{ synchronous watts}$$

Voltage across the capacitor $= I_S\sqrt{R_c^2 + X_c^2}$
$= 93$ volts

Starting current $= 17.5$ amperes

Starting torque, synchronous watts per ampere $= 43.5$

(*e*). With $\alpha_1 = 60$ degrees, Z_I and Z_{III} are unchanged.

$$Z_{II} = 1.18(1.93 + j1.14)(0.500 + j0.866) + 1.18(1.93 + j1.14)(0.500 - j0.866)$$
$$= 2.28 + j1.345$$
$$Z_{IV} = 2.28 + j1.345$$
$$I_M = 13.35 \angle 19° 40'$$
$$I_S = 4.26 \angle 62° 10'$$
$$T_{avg} = 2 \times 1.18 \times 13.35 \times 4.26 \times 1.93(0.929 + 0.781)$$
$$= 446 \text{ synchronous watts}$$
$$E_c = 63.0 \text{ volts}$$

(*f*). For $\alpha_1 = 120$ degrees the contrasted results are given in table I.

Losses and efficiency can be calculated by the usual methods. It should be noted that the equivalent circuit includes no resistance by which iron loss is considered. An iron loss current can be added to the in-phase component of the total current and the iron loss added to the input.

Appendix II

An analysis of the shaded pole motor, with continuous iron and distributed shaded winding, is given in the following:

Partial design data for $^1/_{20}$ hp =

X_m	= 93.8 ohms	R_S	= 18.2 ohms
X_1	= 5.47 ohms	T_M	= 1,112 series turns
X_2	= 5.47 ohms	T_S	= 1,112 series turns
R_M	= 9.3 ohms	$k_{WM} = k_{WS}$	= 0.772
R_2	= 6.45 ohms	E_M	= 110 volts

Shaded winding and main windings are identical (except for wire size) with relative displacements of 60 degrees. Values for diagram or equations are:

a	= 1	X_m	= 46.9
α_1	= 60°	X_{1M}	= 5.47
R_{1M}	= 9.3	X_{1S}	= 5.47
R_{1S}	= 18.2	X_2	= 2.735
R_2	= 3.225	M	= 0

Starting conditions, slip = 100 per cent,

$$R_f = R_b = \frac{46.9^2 \times 3.225}{3.225^2 + (2.735 + 46.9)^2} \text{ or } 2.87$$

$$X_f = X_b = 46.9\,\frac{3.225^2 + 2.735(2.735 + 46.9)}{3.225^2 + (2.735 + 46.9)^2} \text{ or } 2.775$$

$$R_{1M} = 9.3 + 2.87 + 2.87 \text{ or } 15.04$$
$$X_{1M} = 5.47 + 2.775 + 2.775 \text{ or } 11.02$$
$$Z_I = 15.04 + j11.02$$
$$Z_{II} = 1(2.87 + j2.775)(0.5 - j0.866) + 1(2.87 + j2.775)(0.5 + j0.866) + 0$$
$$= 2.87 + j2.775$$
$$Z_{III} = 23.94 + j11.02$$
$$Z_{IV}' = 2.87 + j2.775$$
$$I_M = 110 \times \frac{23.94 + j11.02}{(15.04 + j11.02)(23.94 + j11.02) - (2.87 + j2.775)(2.87 + j2.775)}$$
$$= 6.06 \angle 35° 18'$$
$$I_S = -0.921 \angle 16° 1' \text{ or } 0.921 \angle 163° 59'$$
$$\varphi = 199° 17'$$

Average starting torque:

$$T = 2 \times 1 \times 0.921 \times 6.06[2.87 \times (-0.7579) - 2.87 \times (-0.1859)]$$
$$= -18.35 \text{ synchronous watts.}$$

The minus sign indicates rotation opposite from that which would be brought about by separate excitation of the so-called starting winding.

Reference

1. The Revolving Field Theory of the Capacitor Motor, W. J. Morrill. A.I.E.E. Trans., v. 48, April 1929, p. 614–29.

The "Comet"—A Diesel Electric Unit Train

The electrical equipment and performance of an articulated light-weight streamlined Diesel-electric train are described in this paper. Particular attention is given to the control, which provides full utilization of the available engine power for driving the train over a wide range of train speeds. Generators, motors, and auxiliary equipment are considered briefly, and the estimated train performance is given.

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In a Diesel electric rail vehicle, the electric power transmission system which conveys the power from the engine to the driving wheels is 1 of the 5 essential component parts which must be co-ordinated in design and location. These 5 parts are the body and running gear; the motive power plant; the transmission system; the auxiliaries; and the braking apparatus. The electrical transmission equipment and other details of the "Comet," a light weight stream-lined Diesel electric unit train now being operated by the New York, New Haven and Hartford Railroad, are described in the present paper, and calculated data on the performance of this train are given.

In the electrical system of power transmission, each engine drives a generator and power is transmitted by electrical conductors to motors geared to the driving wheels. A system of control is provided for regulating the engine output and for insuring correct generator voltage for the varying propulsion needs. For the sake of simplicity and ease of regulation, the electrical power is generated and used as direct current rather than as alternating current.

Duplicate Power Plants

In this unit train, there are 2 duplicate power plants, one located at each end of the train, with duplicate sets of control and auxiliaries, both being controlled simultaneously from either of the 2 operating stations, which also are located one at each end of the train. Operation at full train speed in either direction is thereby facilitated. These power plants are housed in engine rooms which are likewise in duplicate, except that the single storage battery for the train is located in one engine room while the single train heating boiler is located in the other engine room. Two traction motors are mounted on each car truck immediately under the engine rooms, these motors receiving electrical energy from the plant above.

The main items of the transmission equipment consist of:

2 d-c generators.
2 d-c auxiliary generators.
4 railway type traction motors.
2 controllers.
6 pneumatically operated contactors for motor circuits.
2 pneumatically operated reversers for motors.
2 load regulating relays.
2 sets of contactors and resistors for fields, load regulation, motor field shunting, and engine starting.
1 storage battery for engine starting.

The auxiliary equipment includes 4 radiator blower motors, 2 airbrake compressor motors, 2 air conditioning compressor motors, motors for car circulating fans, and such miscellaneous equipment.

Generators, Auxiliary Generators, and Traction Motors

Each generator is of the railway type, being built with a single bearing bracket at the commutator end. The armature is carried by a ball bearing in this bearing bracket and by the engine crankshaft bearings, the armature shaft being coupled solidly to the crankshaft. The generator frame is a rolled steel ring to which are welded the supporting feet. The bearing bracket is bolted onto one end of this ring. Class *B* (high temperature) insulation is used for windings, thus permitting high rating with a minimum of weight and space. The characteristic curve of this generator when coupled to a 400 horsepower engine operating at 900 rpm is shown in figure 1. This machine has 3 field windings: a separately excited winding for voltage control; a series winding

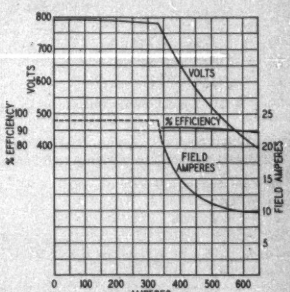

Fig. 1. Characteristic curves of generator coupled to 400 horsepower engine at 900 rpm

Load of auxiliary generator on same shaft, at 140 volts: 12 amperes for control and battery, 75 amperes for 2 radiator blowers

A paper presented before a meeting of the Institute's Connecticut Section, New Haven, May 22, 1935; recommended for publication by the A.I.E.E. committee on transportation; and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 28–31, 1936. Manuscript submitted July 3, 1935; released for publication Sept. 23, 1935.

used for engine starting purposes; and a commutating field winding.

The auxiliary generator has no bearings, the armature being carried on an extension of the main generator shaft and the field frame being bolted to the bearing bracket of the main machine. This generator is used for auxiliary purposes only, supplying power at 110 volts (nominal voltage) for battery charging, lighting, air brake compressor operation, air conditioning operation, main generator field excitation, and cooling fans, as will be described more in detail later. This generator is also built with class *B* insulation for weight and space economy.

The series type traction motors are of standard railway construction, being supported by a spring support at the motor nose and by bearings on the axle. The armature is geared to the axle with a 24 to 47 ratio and its performance with this gear ratio and with 36 inch wheels is shown by figure 2. The windings are insulated with class *B* insulation.

Performance Curves

Figures 1 and 2 show the performance of one generator and of one motor. The performance of the train, with 2 400 horse power engines, each driving a generator and each generator supplying power for 2 traction motors, is shown by figure 3. The dotted curve shows the available power at the engine shaft, the difference between this and the actual power at the rims of the driving wheels representing power consumed by the auxiliary devices and losses in the transmission equipment. The performance curve includes series connections of the motors, parallel connections of the motors, and motor field shunting to obtain successively higher speed conditions under the limitation of maximum generator voltage. It may be noted that the curve up to 100 miles per hour is approximately hyperbolic in shape, whereas above 100 miles per hour, the curve breaks to a different slope. This is due to the fact that the generator voltage has reached its maximum at 100 miles per hour and above that speed the voltage on the motors is constant.

The sequence of operations during the acceleration

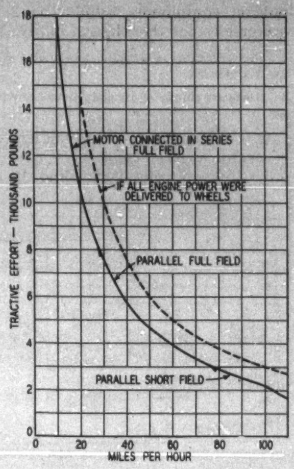

Fig. 3. Performance of New Haven "Comet"

2 Diesel engines each rated 400 horsepower, 900 rpm

2 railway generators

4 railway motors

24 to 47 gear ratio

36 inch wheels

of a train consists of first connecting the motors in series relation across their respective generators with the engine turning over at an idling speed (slightly below 400 rpm), then bringing the engine speed up gradually until it is operating at full speed. This operation is with relatively low generator voltage. With the engine at full speed, the voltage of the generator is automatically raised gradually to keep the engines fully loaded until the maximum generator voltage is reached. With maximum generator voltage across 2 motors in series, further advance in train speed is made by reconnecting the traction motors in parallel relation, this reconnection automatically reducing the generator voltage to approximately half of full voltage, with its subsequent gradual increase to full voltage with further increase in train speed. The shunting of the traction motor field again reduces the generator voltage, which again increases automatically, reaching full voltage at 100 miles per hour.

Torque Control

The "torque control" system described in the following paragraphs is used for obtaining full utilization of engine power and for insuring an adequate supply of power for the auxiliary devices. The application of propulsion power is governed by the movement of a control lever located at the engineman's position at either end of the train, and the motor connections may be selected by the same lever. A second lever controls the direction of movement of the train by the remote control of reversing drums to reverse the direction of current flow through the traction motor fields. Both engines operate simultaneously and may be started or stopped individually from these control stations. The engines are accelerated from idling to full speed in 6 steps.

Torque control of internal combustion engine pro-

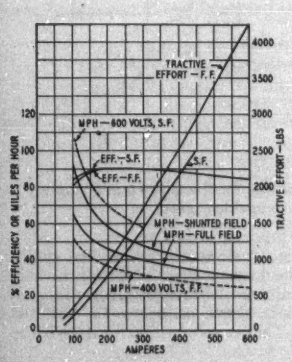

Fig. 2. Performance curves of series type railway traction motors

24 to 47 gear ratio

36 inch wheels

500 volts

pulsion equipments fulfills the 2 fundamental requirements for this class of motive power, namely:

1. Full utilization of available power over as wide a range of train speed as possible.

2. Adequate supply of auxiliary power at relatively constant voltage.

It is obvious from a study of figure 1 that the main generator voltage must vary over a wide range in order to keep from overloading the engine under the

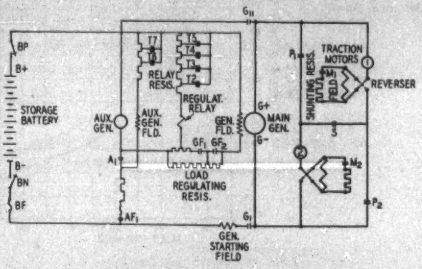

Fig. 4. Schematic diagram of torque control

widely varying current demands of the traction motors. Thus, with the traction motors requiring a total of 600 amperes for acceleration or for climbing a grade, the generator voltage must be limited to 430 volts in order to keep from overloading the engine, yet with the motors requiring only 350 amperes total, the voltage may rise to 743 volts, still within the limits of engine power. Such variable voltage regulation may be approximated by the use of a

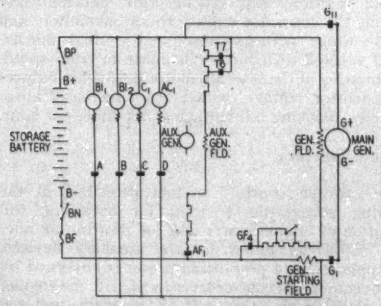

Fig. 5. Schematic diagram of auxiliary power supply with engine idling

differentially connected series field winding in the generator, but full utilization of the available power may be secured only over a relatively small range of operating speeds, and such a scheme has other disadvantages. Torque control, however, regulates by means of a sensitive, yet substantially constructed relay which is responsive to very slight variations in engine speed.

Power Application by Torque Control

Figure 4 shows the general scheme of power control for one power plant with its 2 motors. The main power circuits are indicated by heavy lines, while the auxiliary generator circuits, field circuits, and regulating circuits are shown by lighter lines. Engines are started by closing contactors G_1 and G_{11}, which causes power to flow from the storage battery through the main generator armature and the starting field, which causes the generator to act as a motor and spin the engine until it fires. With the engine firing, power is applied to the traction motors by closing switch S for series connections of the traction motors or switches P_1 and P_2 for parallel connections of the motors. Contactor AF_1 is also closed to energize the auxiliary generator field from the storage battery. The auxiliary generator then develops a voltage for supplying excitation current for the main generator field, this current flowing through the load regulating resistance.

The engine speed is advanced step by step by means of a governor operator which resets the engine governor for higher speed operation. This governor operator is controlled by the engineman's operating lever (circuits not shown). Contacts T_2 to T_7 are carried by this governor operator, these various contacts being closed for various positions of the governor operator.

As a matter of fact, the engine governor, as set by the governor operator, does not actually control the engine speed except when idling. Correct engine speeds are maintained automatically slightly below the governor speed setting by varying the generator

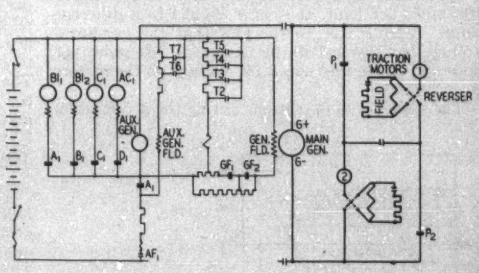

Fig. 6. Schematic diagram of auxiliary power supply with propulsion power on

load to hold the engine down to the selected speed, which is accomplished by varying the main generator field to load or unload the engine according to whether its speed is above or below the selected operating speed. This is accomplished through the regulating relay.

With the auxiliary generator field excited from the battery, its generated voltage is directly proportional to engine speed. As soon as the engine speed is raised by the operation of the engineman's controller, the auxiliary generator voltage comes up to a point where its voltage is sufficient to operate the regulating relay. When this relay closes its contacts, the field regulating contactors GF_1 and GF_2 close to reduce the resistance in the main generator field circuit, thus resulting in a higher main generator field and voltage and an increase in the current flowing through the traction motors. Thus the increase in power delivery from the main machine causes the engine to slow down slightly, resulting in a corresponding reduction in auxiliary generator voltage which causes the regulating relay and field regulating contactors to open. The reduction of engine load then results in an increase in engine speed. This cycle is repeated rapidly, resulting in practically constant engine speed as determined by the speed setting selected.

Higher Speed Steps With Torque Control

In order to raise the engine speed for the next higher speed setting, the contact T_2 is opened by the advancement of the engine governor operator. The opening of T_2 inserts additional resistance in the relay circuit and insures that the relay and regulating contactors remain open. Thus, with minimum generator field and load, the engine speed advances rapidly until the auxiliary generator voltage reaches a new value sufficiently high to again cause the regulating relay to go into action and control the engine speed. This procedure is repeated step by step until all resistance is in the relay circuit and the auxiliary generator voltage is in the neighborhood of 130 volts (sufficient to charge the battery fully). Further increases in engine speed are then accomplished by opening contacts T_6 and T_7 successively to reduce the auxiliary generator voltage. As this voltage is reduced, the effect on the regulating relay is the same as the insertion of resistance in its circuit, thus unloading the engine to allow its speed to rise until the auxiliary generator voltage is again back to 130 volts. Thus, on the last 3 controller notches the auxiliary generator is generating practically constant voltage.

The control system of the "Comet" keeps the engines fully loaded over the operating speed range. As the train speeds up and the current demand of the traction motors reduces, the regulating system automatically increases the generator voltage to keep the engines fully loaded. Any change in the traction motor connections which increases the current demand instantly reflects in reduced generator voltage to maintain full load.

The power supply for the auxiliary equipment is obtained from the main generator when the engine is idling and from the auxiliary generator when the main generator is delivering propulsion power. Figure 5 shows the connections when idling and figure 6 shows the running connections. Under idling conditions, contactors G_1 and G_{11} are closed and the main generator field is energized from the battery to

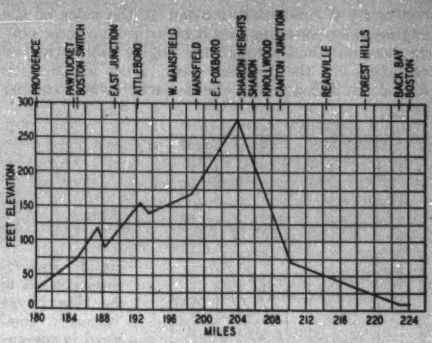

Fig. 7. Condensed profile of line of New York, New Haven and Hartford Railroad Between Providence, R. I., and Boston, Mass.

Maximum curve, high speed zone, 1 degree 31 minutes (curve resistance negligible)

give the correct generator voltage for battery charging. The auxiliary equipment is then connected to this main machine to operate at normal auxiliary voltage. When propulsion power is required, however, the main generator voltage is too high and too variable for auxiliary operation, so the auxiliary equipment is connected across the auxiliary generator which operates at the correct voltage for battery charging and auxiliary circuits. Contactor A_1 shown in figures 4 and 6 is a reverse current switch, closing when the auxiliary generator voltage reaches battery voltage, and dropping out at lower voltages.

Auxiliary Equipment

The auxiliary requirements of the "Comet" are unusually heavy. Among the auxiliaries which must be supplied with power are:

1 battery.
2 airbrake compressor motors.
2 air conditioning compressor motors.
12 air conditioning fan motors.
2 engine fuel pump motors.
4 radiator cooling fan motors.
1 heating boiler blower motor.
2 regulated lighting systems.
1 control system.

Air for the braking system is supplied by 2 air compressors requiring an estimated average of 4.5 horsepower during train operation. Air from the braking system is used for the operation of electro-pneumatic contactors, traction motor reversers, engine trip and reset devices, door control, and similar devices.

Two compressor and condensing sets are provided for air conditioning purposes. Each compressor is of 2 cylinder construction using di-chloro di-fluoro methane as a refrigerant. The compressed gas is

cooled by 2 condensers located at the sides of the engine room, air being first drawn through these condensers and then through the engine lubricating oil radiators by the radiator fans, after which it is forced out through the engine jacket water cooling

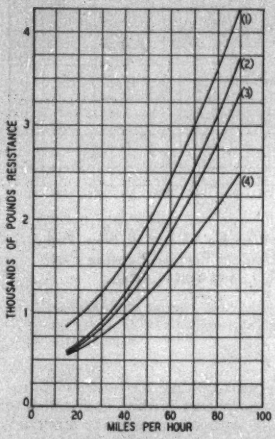

Fig. 8. Train resistance values of the New Haven "Comet" compared to conventional train

Based upon Davis formula

3 car train, 2 power plants, one at each end

Cross sections, 125 and 107.5 square feet

Streamlining to 65 per cent of "K"

Curve 1—Conventional cars, 210 ton train, 12 axles
Curve 2—Conventional cars, 136 ton train, 8 axles
Curve 3—Cars with reduced cross section, 136 ton train, 8 axles
Curve 4—Cars with reduced cross section, 136 ton train, streamlined

radiators located in the roof of the engine room. The liquid refrigerant is then carried through the train to 6 air conditioning units, 2 of which are located in each power car and 2 in the center car (over the vestibules), and returns to the compressor as a gas. Each unit consists of finned tube cooling (and also steam heating) coils with 2 motor driven fans for circulating air through these coils, this air then being forced through the upper tubular members of the passenger compartment structure and discharged uniformly along the car in a horizontal direction through slots at the base of the tubular members. These air conditioning units include expansion valves and electrically operated fluid valves used for control. The units in the power car are each of 2 tons capacity, and those in the center car are of 2.5 tons capacity each. They will maintain the inside temperature 15 degrees Fahrenheit below outside temperatures if desired, with full passenger load.

The lighting of this train constitutes a marked improvement over any passenger train installation to date, and is the result of considerable study and many tests. Of the indirect type, it is arranged to diffuse the light evenly so as to minimize glare and create a restful illumination. Designed to give a light intensity of approximately 8 foot candles on a 45 degree plane 33 inches from the floor, the ultimate results were even more satisfactory than had been anticipated. The lighting load amounts to approximately 8.3 kw, exclusive of the headlights and vertical beam headlight.

Ample room is provided to insure proper inspection and maintenance of the various items of equipment. This presented a problem, since the low floor height and shrouding below the floor for the reduction of air resistance necessitated locating the bulk of the equipment above the car floor. With the power plant located in the forward center section of the engine room, the space above the generator is occupied by the engine cooling water reservoir and a control cabinet. The radiators and radiator fans are located at the rear of the engine room on each side, with the air compressor under one fan housing and the air conditioning compressor under the other. The air-brake equipment is in one of the forward corners.

Estimate of Train Performance

The first step in the determination of any proposed train performance is a study of the physical characteristics of the proposed run—grades, curves, speed restrictions, necessary stops, and similar pertinent data. Figure 7 is a condensed profile of the line between Providence, R. I., and Boston, Mass., over which the "Comet" is scheduled to operate. The specification was to stop at Pawtucket (4.51 miles out of Providence) and at Back Bay (1.28 miles out of South Station, Boston) with the following time limits: 10 minutes from Providence to Boston Switch (4.9 miles out of Providence), including the stop time at Pawtucket; and 4 minutes from South Station to Back Bay, including stop time at Back Bay. A speed limit of 90 miles per hour was effective over the whole line.

There have been a vast number of tests made to determine the resistance of trains of various weights and types and at various speeds. Out of this mass of data, the application engineer has generally accepted

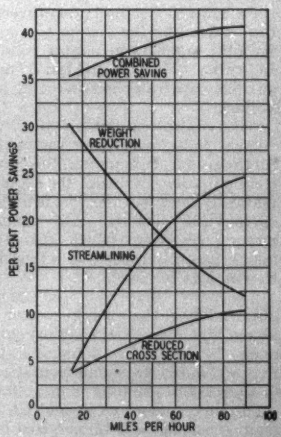

Fig. 9. Effect on power requirements of car alterations (weight reduction, reduced cross section, reduction of wind resistance) on level track

3-car train, 210 ton conventional type, 2 engines, 125 square feet cross section, 12 axles, altered to 136 tons streamlined type, 107.5 square feet cross section, 8 axles

(Streamlining to "K" = 65 per cent, Davis formula)

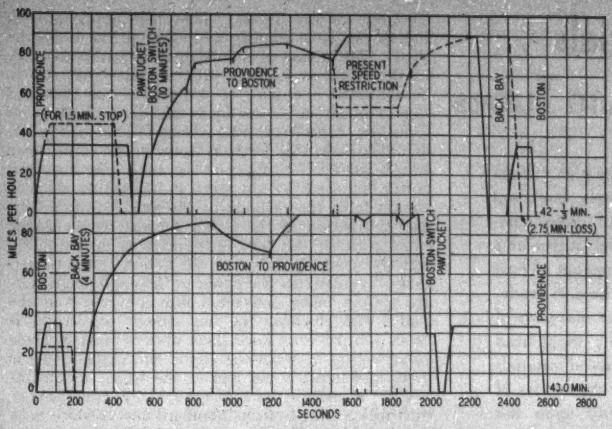

Fig. 10. Continuous speed-time curves of the "Comet" between Providence and Boston

Calculated performance of high-speed 3-car unit train, 136 tons loaded, 2 400 horsepower Diesel engines

the Davis formula as representing reasonable values of resistance, and, from frequent use of this formula, has been possible to prognosticate a train performance within reasonable accuracy. This formula, however, has been confirmed only for conventional types of equipment and up to 60 or 70 miles per hour. This formula is:

$$\text{Resistance} = \underset{\text{(Journal friction)}}{1.3 + \frac{20}{W}} + \underset{\text{(Flange resistance)}}{0.045V} + \underset{\text{(Windage)}}{\frac{K}{WN} A V^2}$$

where

W = tons per axle
V = speed in miles per hour
N = number of axles
A = frontal area of train in square feet
K = windage constant
= 0.0024 for head car (conventional type)
= 0.00034 for trail cars (conventional type)

No verified information is available for the close determination of high speed train performance where the train exterior has been rounded and smoothed for the purpose of minimizing the air resistance. Various wind tunnel tests and computations have been made with varying results. It was felt, therefore, that a closer determination of results would be possible by the use of the known and tried formula with adjustments in the factor K to compensate for the reduced air resistance. An examination of existing data indicated that the value of K would range from 40 to 60 per cent of the values for conventional cars. To be on the safe side, the actual value used was 65 per cent.

The estimated weight of the "Comet" was 136 tons loaded, on 8 axles. Since this train has no "head car" and "trailer cars," the front portion and the rear portion, which have slightly greater cross section than the center, were assumed to equal a "head car" and the balance constituted the "trailer car." From this segregation, a resistance for the complete train was calculated to be as shown by curve 4 on figure 8. As a matter of interest, the resistance of a conventional train of 210 tons and 125 foot cross section with 12 axles is shown by curve 1, while this same train reduced to 136 tons (the estimated weight of the "Comet") would have a resistance as shown by curve 2. Reducing both the weight and cross section of the conventional train would give curve 3 and the further reduction in resistance by aerodynamic design of exterior gives curve 4. Expressed in another way, figure 9 shows the power savings which may be effected by the various alterations from a conventional train to a unit train such as the "Comet."

Using line 4 of figure 8 as a basis of train resistance, a continuous speed-time curve was prepared covering the run from Providence to Boston and from Boston to Providence, calculating the performance on each grade section. This is shown by figure 10. From this, it may be determined that the run may be made within the time specified, i. e., 43.78 miles in 44 minutes.

Road tests have shown that the calculated performance is on the safe side and that there is a reasonable margin to insure maintenance of schedule, the actual run between Providence and Boston without stops having been made in 37 minutes.

Reasons for Diesel Motive Power

A great many railroad men wonder why the Diesel engine is used for propulsion of fast trains such as the "Comet" instead of using steam. The answer is economy of operation.

The "Comet" is 207 feet, 4 inches in length, with engine room space of approximately 37 feet. A rough estimate of the train weight increase by the inclusion of Diesel propulsion equipment is 50 tons. A steam locomotive for this purpose would add approximately 85 feet to the train length and 200 tons to its weight. This would require very considerably more power for the run.

The round trip between Providence and Boston requires 50 gallons of Diesel fuel at a cost of approximately $2.50 and the total expense of operation is less than half of that of a steam hauled train. In addition, considerable time is saved at terminals because of the fact that the "Comet" may operate in either direction without turning.

Anode Materials for High Vacuum Tubes

Continued development of the high vacuum tube has played an extremely important part in the development of radio communication. Since the power output of a tube is proportional to the amount of heat that may be dissipated safely from its anode, the anode is one of the most vital parts of high vacuum tubes especially those used for transmitting purposes. Several materials have been found suitable for the anodes of transmitting tubes, depending upon the requirements of specific applications and the type of cooling adopted; these materials and their characteristics are discussed in this paper.

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DEVELOPMENT of radio communication has been marked by a series of periods, each of which has been the result of the application of some new device or devices. Without any question, the high vacuum tube is the device that has affected most profoundly every branch of the art. Development of the high vacuum tube has been continuous from the time the triode first was used. Today there are available in the United States tubes of all sizes ranging from the "acorn tube" to tubes capable of delivering 100 kw of radio frequency power. Tubes have been developed for many special applications to permit the desired results to be accomplished better, more easily, or more cheaply. To attempt even a hasty review of these developments would require far more space than is available here. For this reason the discussion will be limited to a more detailed consideration of one phase of the development of transmitting tubes, namely, the advances that have been made in the design and construction of anodes.

As is well known, in one of its simpler forms the vacuum tube consists of a filament or cathode which serves as a source of electrons, a plate or anode, and a grid consisting of a wire mesh or grating surrounding the cathode so that it may control the flow of electrons to the anode. The chief application of this device is to amplify a-c power to the levels desired. The action of the vacuum tube amplifier may be described as follows: The electrical impulse to be amplified is applied to the grid of the tube and thus controls electrostatically the flow of electrons from the cathode to the anode. The energy required to draw the electrons to the anode comes from a high voltage d-c supply in the anode circuit. The power required by the grid to vary this electron stream from the cathode to the anode ordinarily is only a fraction of the power flowing in the anode circuit; hence the tube is regarded as an amplifier. Strictly speaking, however, the action of the tube is that of a valve, the d-c power of the anode high voltage supply being converted into a-c power in the load. The efficiency of this energy conversion is never 100 per cent since there always must be some voltage drop between the anode and cathode of the tube, and hence some loss in the tube. Quantitatively, the energy loss is equal to the average energy with which the electrons bombard the anode. As a result of this bombardment the anode becomes heated and assumes some temperature at which the thermal loss by radiation, convection, and conduction equals the energy dissipated in the anode.

For any given tube there is a maximum amount of power that can be dissipated safely by the anode, if reasonable tube life is to be obtained. Then, as the conversion efficiency is determined fairly well by the mode of operation, it is seen that the a-c power output of the tube is proportional to the safe anode dissipation. Thus, in transmitting tubes, the anode dissipation rating is one of the most important factors in determining the amount of power the tube will deliver.

Anodes may be classified according to the principal method of cooling employed. In some types of tubes the anodes are cooled almost entirely by radiation, in others by convection, and in the third type by conduction.

Radiation Cooled Anodes

Historically, radiation cooled anodes were the first developed. In this type of construction, the anode is operated at some fairly high temperature and heat is radiated directly by the anode to and through the glass walls of the bulb. It has been necessary to design such anodes to operate at fairly high temperatures in order to dissipate reasonable amounts of power in anodes of the size demanded by the electrical characteristics desired of a tube. With some types of anode materials it has been desirable to operate at temperatures as high as 1,000 degrees centigrade.

Operation of anodes at such high temperatures immediately brought up a host of problems. One of the most important was that presented by the liberation of gases from the anode. All materials suitable for anodes contain gases in the raw state. These gases are mainly hydrogen, nitrogen, carbon monoxide, and carbon dioxide. They are present throughout the body of the material. When the material is heated in a vacuum, these gases are liber-

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ated at a varying rate, depending on the temperature and the time of heating. The major portion of these gases must be driven out of the anode during the manufacture of the tube so that in subsequent normal operation no appreciable amounts of gases are liberated. Residual gases in vacuum tubes become ionized under impact by electrons. If enough ions are generated in this way they partially neutralize the electron space charge that limits the flow of electron current between the cathode and anode. Increased current then flows through the tube, resulting in greater anode heating and more rapid gas liberation. This process quickly may become cumulative and lead to an arc discharge between the cathode and anode. If the tube be not protected by overload devices, such a discharge may result in an abrupt termination of the life of the tube by the melting of the cathode, grid, and anode.

The gases contained in anodes commonly are driven off by heating during one of the last stages of manufacture. The assembled tube is sealed to a vacuum system where the glass bulb can be baked out to free it of adsorbed gases. The anodes are heated by 2 processes. One method is to apply a high positive voltage to the anode and bombard it with electrons from the cathode. Another method is to place a coil carrying high frequency currents around the glass bulb in such a way that the anode acts as the short-circuited secondary of a transformer. The induced currents then heat the anode.

Another factor that is important in the choice of anode materials for radiation cooled tubes is the total heat radiation emissivity. It is desirable to have this approach as nearly as possible the ideal of a black body, since for a given anode and anode operating temperature (determined by gas liberation) it permits the highest dissipation rating. At first thought it would appear that the size of the anode could be increased to get the desired dissipation rating in the event that a material of low emissivity were used. However, this would result in an increase in the electrostatic capacitances to the other electrodes of the tube. Because of the definite trend to higher frequencies in radio communication, it is absolutely necessary to keep interelectrode capacitances to a minimum so that capacitance charging currents, which of course entail losses, can be limited to reasonable values.

A third set of factors in the choice of anode material consists of the mechanical properties. The material must be capable of being worked into the desired shapes without undue difficulty or expense. It must maintain these shapes at the highest temperatures necessary during the manufacture of the tube. Only a very small amount of warping can be tolerated at the normal anode temperature as warping results in a change of electrical characteristics.

A fourth factor is the vapor pressure of the anode material. This must be low enough to avoid noticeable metallic deposits in the tube during manufacture. Deposits on insulators in a tube may result in excessive interelectrode leakage or excessive radio frequency losses in the insulators. Deposits on the glass bulb result in higher glass temperatures, because of increased radiation absorption and radio frequency losses, and may lead to gas evolution and strain cracks.

One of the first materials used for anodes in radiation cooled transmitting tubes was tungsten. A typical 250 watt tube made commercially about fifteen years ago had an anode in the form of 2 sheets of tungsten about $1^3/_4$ by $2^1/_2$ inches arranged about the grid. From the standpoint of gas content, ease of degassing, vapor pressure, and maintenance of mechanical shape at high temperatures, tungsten is a fairly desirable material for anodes. It has been found that the initial gas content of tungsten is of the order of 0.6 per cent by volume. The main constituent of the evolved gas is nitrogen, although there is considerable carbon monoxide and some carbon dioxide and hydrogen. The absence of oxygen undoubtedly is attributable to the ease with which this element combines with other elements, such as carbon. The major portion of the gas is liberated by heating to 2,200 degrees centigrade; no further gas is evolved by raising the temperature to 2,600 degrees. Such high anode temperatures, however, would be difficult to realize in actual manufacture of tubes.

Tungsten has 2 serious disadvantages: It is essentially a very hard metal and consequently difficult to machine and work into the desired shapes, and its cost is high. Because of these disadvantages it soon was displaced by molybdenum.

A study of the gases evolved when molybdenum is heated in vacuum has shown that to degas this material completely, it is necessary to heat it to a temperature of 1,760 degrees centigrade, as compared with 2,200 degrees for tungsten. In a typical experiment the total gas evolved was 5.6 per cent by volume, that is, approximately 10 times the volume gas content of tungsten. The various constituent gases are evolved at varying rates. Thus when degassing is carried at 800 degrees centigrade the major portion of the gas liberated is carbon monoxide, while at higher temperatures the gas evolved is

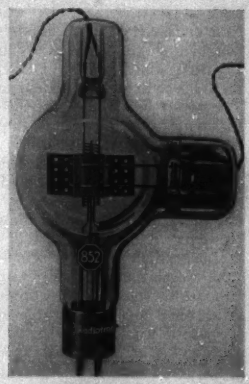

Fig. 1. A 75 watt tube with carborundum blasted molybdenum anode formed with integral cooling fins

mostly nitrogen. In heating at 800 degrees only about 15 per cent of the total gas in the sample is driven off. Further heating at 1,000 degrees contributes another 15 per cent. By raising the temperature to 1,200 degrees it is possible to drive off about 95 per cent of the gas in the sample.

In actual manufacture it is usually not desirable to use such high temperatures as the foregoing indicates are necessary for complete degassing of the anode, as the rate of evaporation of the molybdenum becomes high enough to cause deposits on the glass bulb and on insulators. Fortunately, complete degassing is not necessary because, regardless of the temperature at which degassing is carried on, the rate of gas evolution can be reduced to a negligible value by operating the anode at a sufficiently lower temperature. Long manufacturing experience has shown that molybdenum anodes that have been degassed at a brightness temperature of 1,300 to 1,400 degrees centigrade subsequently can be operated safely at temperatures as high as 1,000 degrees. Furthermore, a small amount of gas evolution can be tolerated if the tube contains active "getter" which will combine with or absorb the gases as fast as they are generated.

With molybdenum anodes ways and means soon were sought to decrease the temperature for the desired power dissipation. One way adopted was by the addition of fins which would increase the radiating area of the anode. It was found desirable to make the fins out of the same piece of metal as the anode because of the poor heat conductance between 2 pieces of metal brought together by some process such as riveting. Later it was found that the radiation emissivity of the anode could be increased by roughening the surface by carborundum blasting. Figure 1 shows a 75 watt tube in which both these methods to decrease anode temperature are employed. The anode is made of 2 strips of molybdenum folded to form radiating wings integral with the anode. The whole anode assembly then is carborundum blasted. This anode is shown at the left in figure 2.

By these means, the safe dissipation of molybdenum anodes was increased, thereby partly overcoming the low radiation emissivity characteristic of the metal. However, it is still desirable to operate the anodes at fairly high temperatures, sometimes as high as 1,000 degrees centigrade, in order to keep the anode dimensions small. These higher temperatures result in another and undesirable effect, largely in tubes employing a flat type of construction. The appearance of hot spots on the anode is common in such tubes, even when the construction is perfectly symmetrical, and is attributable to the fact that electrons attempt to travel from the cathode to the anode in lines normal to the anode surface. With anode thicknesses commonly used when the material is molybdenum, the center of the anode usually operates at a visibly higher temperature than the edges. This temperature difference produces warping or buckling, and consequently the electrical characteristics of the tube are subject to change. To overcome this in anodes of flat construction, it sometimes has been necessary to resort to elaborate constructions using channel pieces to give additional strength to those sections of the anode operating at higher temperatures. In anodes of circular construction, the heating produced is much more uniform, as the electrons flow from the central cathode in radial lines. In such anodes, the problem of warping generally is solved adequately by ridges pressed into the metal when the sections of the anodes are formed.

From a mechanical standpoint, molybdenum is a fairly satisfactory material. It does not soften or anneal even at much higher temperatures than are used during degassing.

Another material that has wide application to radiation cooled transmitting tubes is graphite. In comparison with molybdenum and tungsten, typical graphite samples suitable for use as anodes contain comparatively large amounts of adsorbed gases. The volume content of gases may be of the order of 10 times that of molybdenum; this is exclusive of the gas trapped in the cavities of the graphite. In addition, the volume of a graphite anode may be of the order of 10 times that of an equivalent metal anode, resulting in a 100-fold increase in gas that must be removed from the anode in the exhaust of the tube. By suitable pretreatment, the gas content of the anode can be reduced very greatly. One method consists among other processes of heating the anode to a high temperature in a vacuum furnace. It has been found that at 2,100 degrees centigrade it is possible to degas graphite so that subsequent heating at a higher temperature gives no further gas. As with molybdenum, the gas evolved, especially at the higher temperatures, is mainly nitrogen. An anode that has been degassed completely, reabsorbs only a fraction of the gas it originally contained if stored under proper conditions. In actual exhaust of a tube containing such a pretreated anode, the time

Fig. 2. Anode of tube shown in figure 1 (left) and a typical graphite anode used in a 50 watt tube (right)

required for completion of the degassing is not much different from that required by a molybdenum anode. Again it is found that if the anode is degassed at some given temperature, the rate of gas evolution can be reduced to a negligible value by dropping the temperature to some lower value. In a typical test the degassing was carried on at 1,300 degrees centigrade; on dropping the temperature to 1,000 de-

grees no further gas was evolved, although on increasing the temperature to 1,600 degrees considerably more gas was liberated. The total radiation emissivity of graphite depends on the treatment the surface has received. In comparison with molybdenum, graphite anodes operate at a visibly lower temperature for the same power radiation. At first thought this would seem to make graphite a much better anode material, because the energy radiated varies as the fourth power of temperature, and by operating at the same temperature as permissible with molybdenum much greater anode dissipation could be obtained. One factor militates against this, however. Glass is nearly opaque for the major portion of the radiations from anodes at the usual operating temperatures. Thus, regardless of whether the anode be metal or graphite, most of the radiated energy is absorbed by the glass and then is removed from the bulb mainly by convection air currents and reradiation. Any increase in the dissipation rating of a tube with a given bulb size must result in an increase in bulb temperature and consequent decrease in safety factors.

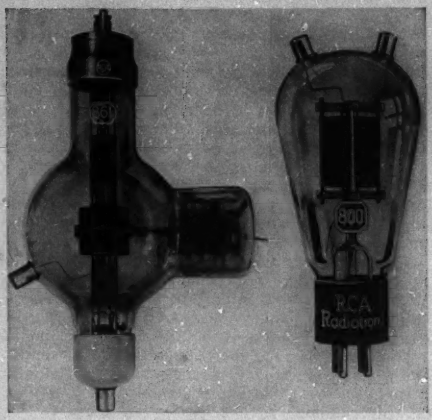

Fig. 3 (left). A typical tube with graphite anode

Fig. 4 (right). A typical tube with carbonized nickel anode

The fact that graphite anodes operate at a lower temperature than tungsten or molybdenum has been criticized. It seems that some users of transmitting tubes judge the operating efficiency of tubes by observing the color temperature of the anode. With tungsten or molybdenum anodes this is easily possible because at the normal operating temperature the anodes are distinctly orange-red in color. With graphite, however, practically no color can be seen in normal operation so that it is very difficult to judge how much energy is being lost in the anode.

One of the disadvantages of graphite as an anode material is its low tensile strength. In order to compensate for this weakness, the minimum wall thickness has been made at least $^1/_{16}$ inch. Consequently, graphite anodes are heavier than equivalent metal anodes. A typical graphite anode as used in the so-called "50 watt tube" is shown at the right in figure 2. Usually, more rigid supporting means are required, which may have to be rather elaborate for some kinds of service where there is a great deal of vibration such as in aircraft communication. There is also an advantage in the heavier wall thickness needed with graphite anodes. The heat conductance in the plane of the anode surface is so good that the entire anode operates at practically uniform temperature. The warping that occurs with metal anodes thus is avoided, and consequently the electrical characteristics of a graphite anode tube are more nearly constant. The absence of hot spots when graphite anodes are used means that the anode loss is radiated more uniformly over the anode surface. The glass bulb also operates at a more uniform temperature.

Mechanically, graphite does not present any serious problems. It is a soft material and therefore readily permits machining operations such as milling, grinding, and drilling.

The vapor pressure of graphite is low enough so that bulb blackening can be avoided during the exhausting of the tube. Careful selection of grades of graphite appears necessary here, because what ordinarily is termed graphite is in reality a complex mixture of a wide variety of forms of carbon, ranging from amorphous carbon to true graphite. Some of these forms produce undesirable effects, which can be eliminated partly by suitable treatment of the anodes. A typical tube with graphite anode is shown in figure 3.

Another metal that has found considerable application as an anode material, particularly in transmitting tubes of smaller sizes, is nickel. Nickel lends itself readily to a process called carbonizing. The nickel anodes are heated to a medium temperature in a hydrocarbon vapor such as natural gas. This treatment deposits a well-adhering layer of amorphous carbon or soot on the nickel. The radiating property of this layer approaches that of a black body—hence the desirability of this material.

The gas content of nickel is of the same order of magnitude as that of molybdenum. However, since it has a melting point of 1,450 degrees centigrade compared with 2,600 degrees for molybdenum, nickel anodes must be degassed at a lower temperature. The vapor pressure limits the degassing temperature to about 1,000 degrees centigrade, as this is the highest temperature at which nickel can be maintained without noticeable evaporation.

Nickel is formed very readily into the shapes desired for anodes. Care must be given to strengthening the anodes with ridges and the like in order to avoid warping during exhaust. Like other metals, nickel anodes have the advantage over graphite that they can be made very light in weight, so that elaborate supporting structures are not needed. Figure 4 shows a typical tube in which a carbonized nickel anode is used.

Other materials have found some application in transmitting tubes, resulting in some special characteristics; but the materials already mentioned have been used most widely.

Convection Cooled Anodes

So far attention has been given only to radiation cooled tubes. Anodes can be cooled also by convection air currents. In order to accomplish this, the anode is made part of the vacuum envelope. This imposes further requirements on the anode material. Obviously it must be impervious to gases, that is, vacuum tight. Since the anode can form only part of the vacuum enclosure because leads to the various electrodes must be brought through insulating seals, it must be possible to make a vacuum tight seal between the insulating material and the anode material. Copper has been found to be a very convenient anode material because it readily can be sealed to glass. In designing such a seal, the characteristics of glass and copper are taken into consideration. Two important factors are the higher coefficient of thermal expansion of copper compared with that of glass, and the fact that a copper to glass seal has a greater strength in compression than in tension. If the seal be so designed that the copper is on the outside and the glass inside, then as the seal cools from the temperature at which it is made the boundary between copper and glass is subjected to compression. In order to reduce this compressional stress, the copper is thinned out so that its thickness in the region where the copper and glass join is only a few thousandths of an inch. If the copper is thinned in this way it can stretch and thus relieve some of the stress on the seal. In making such a seal the thinned edge of the anode is heated in flames to oxidize it. At the same time the glass is heated until it is soft. The glass and copper then are brought into intimate contact and more heat is applied until the glass has dissolved the copper oxide. This solution has the characteristic orange color associated with copper to glass seals. The glass now is left in intimate contact with the copper. Such seals, when properly made, are perfectly vacuum tight.

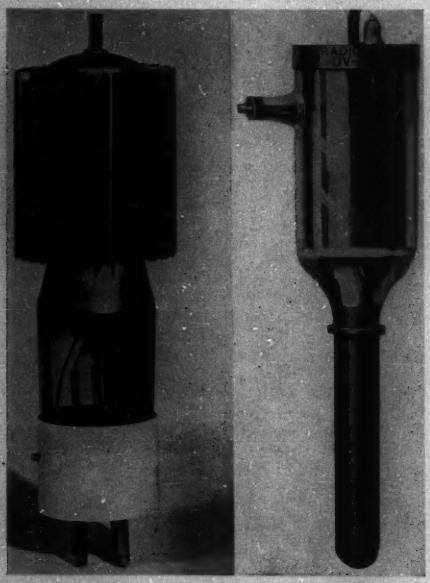

Fig. 5 (left). A typical tube with convection cooled anode

Fig. 6 (right). A typical tube with conduction cooled anode

In degassing the anodes of tubes made in this way, considerably lower temperatures are permissible than can be used in degassing the radiation cooled anodes previously described. In the first place, copper has a melting point of only 1,083 degrees centigrade. Secondly, since the anode is now part of the vacuum enclosure, it cannot be heated to temperatures too near the softening point or there will be danger that the pressure of the atmosphere might collapse it. Keeping the temperature of the anode below this point, the degassing of a tube readily is accomplished, so that subsequent operation at temperatures as high as 300 degrees centigrade is possible.

The dissipation of heat from such an external anode tube is largely by convection currents. In order to increase the safe allowable dissipation, more area can be added to the anode by attaching fins. In order to be effective, these fins should have adequate heat conductivity and be in intimate contact with the anode. Further increase in dissipation can be secured by the use of forced cooling. It really is surprising to find how much heat can be removed from such a fin structure by means of an air stream supplied by an ordinary fan. A typical tube with a convection cooled anode is shown in figure 5.

Conduction Cooled Anodes

A third method of cooling anodes is by conduction. In order to accomplish this, the anode again is made part of the vacuum enclosure. The portion of the anode that becomes heated during operation of the tube is inserted in a water jacket, which is so constructed that a high velocity water stream can play over the anode. Heat then is conducted by the anode directly to this water stream and is carried off. It is important to have a high water velocity because otherwise steam pockets may form and result in dangerous overheating of the anode at those points. By proper design of water jacket and adequate flow of water, it is possible to carry off as much as 250 watts per square inch of anode surface.

Because of the large amounts of heat that can be carried off by conduction cooling, this method is used exclusively in high power tubes, those with ratings of a few kilowatts or more. The construction of conduction cooled anodes is the same as that

described for a convection cooled anode. The anode usually is made of drawn copper, and the open end is turned to a thin edge and sealed directly to the glass portion of the tube. A typical conduction cooled tube is shown in figure 6.

Choice of Material Depends on Requirements

In concluding this discussion, it can be seen that several materials are suitable for use in constructing transmitting tube anodes. The final choice of material must depend on all the limitations involved. For example, if the physical dimensions of the anode must be very small for operation at very high frequencies, it is helpful to construct the anodes of tungsten, as they then may be operated at high temperatures where they can radiate fairly high amounts of power. Again, if an inexpensive construction is required, carbonized nickel is a satisfactory material. Where weight must be kept at a minimum, with a high degree of strength, molybdenum is very useful. Where uniformity of characteristics is desired, graphite is a very suitable material. If high heat dissipation is required, forced convection or conduction cooled copper anodes are most satisfactory. With such a variety of materials and designs available, the engineer is enabled to make a choice that best fits the purpose at hand.

Present Status of Ferromagnetic Theory

Even though progress in the theory of ferromagnetism still lags far behind experimental progress, advances in theory have been particularly rapid during the past 5 or 10 years. The salient points brought out in these most recent advances are summarized here.

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DISCOVERY of the loadstone and some of its magnetic properties is now reputed to be some 3,000 years old. During these many years ferromagnetism has resisted very successfully the attack of theorists, and even at the present time theory lags far behind experiment. But advances in theory have been particularly rapid during the last 5 or 10 years; the author describes in this paper what he regards as the high points of this progress.

Not until the last quarter of the last century was any considerable work done on magnetic materials. During this period data were gathered rapidly until, just before the close of the century, an excellent book[2] of 400 pages, containing practically all of the important experimental and theoretical facts, was written by J. A. Ewing, now Sir James Ewing. The shape of the magnetization curves of iron, cobalt, and nickel, the existence of magnetic saturation and the magnetic transformation temperature, the existence and some of the laws of hysteresis, the simpler effects of stress and of magnetostriction, together with the important methods of measurement, all were known then, and silicon steel had just been invented.

Strangely enough, during the next 15 years there was but little advance in knowledge of magnetic materials, but there were many applications of existing knowledge by engineers to electrical machinery, including that used in electrical communication. During this period also the Heusler alloys (nonferrous alloys exhibiting ferromagnetic properties) were invented; and although these served to stimulate those interested in the theoretical aspects of ferromagnetism, still there was little progress.

Beginning between 1915 and 1920 and extending to the present, there has been a rapid development on both the experimental and theoretical sides of ferromagnetism. To illustrate the progress that has been made in the improvement of magnetic materials, table I has been prepared. The improvements made during the last 20 years have resulted from new methods of purification of the materials, new compositions (alloys), and new methods of heat treatment. Some of these figures refer only to laboratory specimens, and not to materials available in commercial quantities.

But the chief topic of this paper is the theoretical side of ferromagnetism. How is one to explain the different values of magnetic permeability, ranging from 1 to 600,000 for various materials? Or, to consider first the more fundamental questions, what is the elementary magnetic particle, and why is ferromagnetism associated with so few elements?

Origin of Ferromagnetism

It was suggested by Ampére about 100 years ago that molecules might behave as magnets because of the electric currents circulating in them. Today,

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The author wishes to acknowledge the assistance of K. K. Darrow and O. E. Buckley, both of the Bell Telephone Laboratories, New York, N. Y., in the preparation of the paper.

2. For all numbered references see list at end of paper.

Table I—Some Extremes in the Properties of Magnetic Materials Available in 1915, and in 1935

Material	Property	Value 1915	Value 1935
Iron	Maximum permeability	45,000[11]	340,000[12]
	Initial permeability	300	20,000[13]
	Coercive force in oersteds	0.3[11]	0.03[13]
Iron-nickel[13]	Maximum permeability	2,800[14]	600,000[15]
	Initial permeability	700[16]	12,000[17]
	Coercive force in oersteds	1.5[14]	0.01[15]
Silicon-iron	Initial permeability	400	2,000[13]
Iron	Hysteresis at $Bx = 100$ gausses, in ergs per cu cm per cycle	20	0.1[13]
Iron-cobalt-nickel "perminvar"	Hysteresis at $Bx = 100$ gausses, in ergs per cu cm per cycle	[illegible]	0.00003[18]
Iron-cobalt	Saturation value[19]	25,800	25,800
	Permeability at $B = 18{,}000$ gausses	2,100	19,000[18, 19]
Tungsten steel	Coercive force[4] in oersteds	80	80
New K. S. steel	Coercive force[21] in oersteds		900

Superior numerals refer to references at end of paper.

with the advance in knowledge of atomic structure, the origin of ferromagnetism can be discussed in more specific terms. Strangely enough, the spectroscopists have supplied, so to speak, the elementary magnetic particle. It is the spinning electron. In order to explain their extensive observations on spectral lines, they found it necessary to revise the picture of the atom. For some time it has been supposed that an atom is made of a heavy nucleus with a positive charge and of electrons moving in circular or elliptical orbits around the nucleus. To this picture now must be added the idea that each electron itself is spinning about an axis that passes through its center. Each electron in an atom is then a small gyroscope, possessing a definite magnetic moment on account of its moving electrical charge and a definite angular momentum on account of its moving mass. The ratio of these 2 quantities is known from various independent lines of reasoning and evidence to possess a particular value. Electrons revolving *in orbits* also exhibit both magnetic moments and angular momenta due to their orbital motions, but for these the ratio is just half what it is for the spinning electron.

The Barnett experiment[22] shows in a very direct way the existence of these magnetic and mechanical moments of the electron and confirms the ratio between them in ferromagnetic materials (figure 1). A rod of iron is hung from a fine suspension and then is magnetized suddenly, whereupon the rod is observed to turn, twisting the suspending fiber a minute but measurable amount. The spinning electrons responsible for ferromagnetism have been turned by the applied field so that they are more nearly parallel to it; but the mechanical moment, which is also a property of those same electrons, causes the whole rod to rotate in just the way that a gyroscope would. Or, to put it differently: When the elementary magnets, pointing originally in all directions, are turned more nearly into parallelism with the axis of the rod by the applied field, they acquire a net angular momentum parallel to that axis. By the principle that action must be balanced by a corresponding reaction, the rod itself now must recoil with an equal and opposite momentum; it is this last that manifests itself by the sudden twist of the rod and may be calculated from the measured value of the twist. Its sign shows that the spinning magnetic particle is charged negatively, and its magnitude is what would be expected from the hypothesis that that particle is a spinning electron. Thus a change in magnetization is fundamentally a change in the direction of the spin of the electrons in the atom, and not a change in orientation of the whole electron orbit.

The next question is: Why is not every substance ferromagnetic? The picture of the atom of iron as now envisioned by the experts in this field, is represented by the diagram in figure 2. The 26 electrons in iron are divided into 4 principal "shells," each shell a more or less well defined region in which the electrons move in their orbits, and some of these shells are subdivided. The first (inner) shell contains 2 electrons, the next shell 8, the next 14, and the last 2. As the periodic system of the elements is built up from the lightest element, hydrogen, the formation of the innermost shells begins first. When completed, the number of electrons in the first 4 shells are 2, 8, 18, and 32, counting outward, but the *maximum* number in each shell is not always reached before the next shell begins to be formed. For example, when formation of the fourth shell begins, the third shell contains only 8 electrons instead of 18; it is the subsequent building up of this third shell that is believed to be connected intimately with ferromagnetism. The inserted numbers show how many electrons having positive and negative spins are present in each shell, and it may be noticed that in all the shells but one there are as many electrons spinning in one direction as in the other. This means that such shells are magnetically neutral and cannot have magnetic polarization. In the third shell, however, which is not yet filled to this extent,

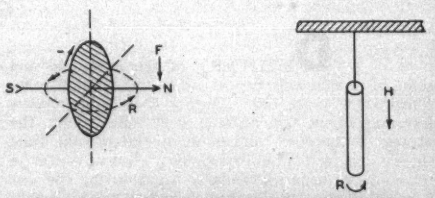


Fig. 1. Gyroscopic action (left), force F produces rotation R. Gyromagnetic effect (right), field H produces rotation R

there are 5 electrons with a positive spin and 1 with a negative spin, leaving an unbalance of 4 units of spin in one direction. If 1 more positive charge and its associated mass be added to the nucleus and 1 more electron in an outer shell, the iron is transformed into cobalt; and by repeating the process, the cobalt is transformed into nickel. These addi-

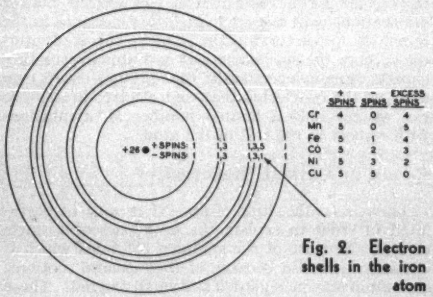
tional electrons in iron and their spins are so oriented that there is what may be called an excess spin of 4 units in iron, 3 in cobalt, and 2 in nickel. In manganese, the element just preceding iron in the periodic table, there is an excess of 5 spins. Only in incomplete shells such as this, shells that are being filled as new and heavier atoms are made, is there such excess spin. The completed shells are magnetically neutral because the spins are balanced.

The outermost electrons are those responsible for the ordinary chemical properties, and they are influenced by chemical combination. They do not contribute to ferromagnetism for reasons that will appear later.

Exchange Forces

Only in certain parts of the periodic table are electrons being added to *inner* shells, and one of these places is in the iron group; but since there are other parts, notably those occupied by the palladium, platinum, and rare earth metals, where these inner groups are being filled, there arises the further question: Why are not these other elements also ferromagnetic?

For an element to be ferromagnetic, it is necessary not only that there be uncompensated spin in the electron orbits, but also that the spins in neighboring atoms be parallel. Calculation of the energies of the electrons indicates that to align the spins in all the atoms in a small region, the diameter of an atom must bear the proper ratio to the diameter of the electron shell that has the uncompensated spin[23] (figure 3). This proper ratio is required because the electron spins and charges influence each other to an amount depending upon the distance between them; and it is only when this influence, which is known technically as the "exchange," has the right value that



	+ SPINS	- SPINS	EXCESS SPINS
Cr	4	0	4
Mn	5	0	5
Fe	5	1	4
Co	5	2	3
Ni	5	3	2
Cu	5	5	0

Fig. 2. Electron shells in the iron atom

the spins all can be aligned in the same direction,[24] that is, that the material can become ferromagnetic.[25]

The forces of "exchange," the existence of which has been realized only in the last few years, act to keep the spins parallel, while thermal agitation tends, obviously, to disturb this alignment. When the temperature is high enough, the temperature agitation prevails and the material ceases to be ferromagnetic. This temperature is the familiar Curie point, or magnetic transformation point, 770 degrees centigrade (or 1,043 degrees absolute) for iron. It is seen then that the height of the Curie point, θ (on the absolute temperature scale) is an indica-

In ferromagnetic substances, D/d is greater than 1.5 (Slater)

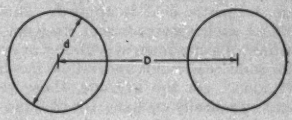


Fig. 3. "Incomplete" shells in neighboring atoms

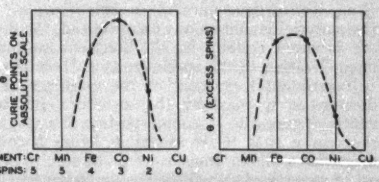


Fig. 4. Iron-cobalt alloys have the highest value of saturation magnetization

tion of the strength of the forces of exchange, which cannot yet be calculated theoretically except as to order of magnitude. These Curie points are plotted in figure 4 for the elements near iron in the periodic table; if a continuous curve be drawn through the points, it has a maximum near cobalt. Now the saturation value of magnetization depends both on the exchange and on the number of effective electron spins, that is, upon the number of electrons that can be oriented parallel to the field and the strength of the forces that hold them parallel. In a very rough way, it may be said to depend on the product of the exchange and the number, S, of uncompensated spins in the atom. Adopting θ as a measure of the exchange forces and forming the product θS, the right-hand curve in figure 4 is obtained, which indicates that the highest saturation should be attained in an iron-cobalt alloy, and that under certain appropriate conditions manganese might be ferromagnetic. Both these indications are substantiated by the data: The only known alloys having a higher saturation value than pure iron are the iron-cobalt alloys; and compounds and alloys of manganese are more magnetic than any others that do not contain iron, cobalt, or nickel. The Heusler alloys, composed of manganese, aluminum, and copper, have a saturation almost as high as nickel, and numerous compounds of manganese are ferromagnetic in a less degree.

The forces of exchange are purely electrostatic in origin. But they are not electrostatic in the classical sense of the word, they are the result of electric charges distributed in space in a definite way. It does not seem to be possible to describe them easily in words,

for it takes a great many mathematical equations to derive the result, which is a consequence of the assumptions of quantum mechanics. These forces account for the fact that it is easy to align the excess spins of neighboring atoms of some materials. In fact, when the forces of exchange are large (positive) as they are in ferromagnetic materials, the stable situation is one in which the spins are parallel, even when no magnetic field is applied. But the parallelism under such circumstances does not extend over the whole of a specimen of ordinary or even of visible size; for some reason not understood it is limited to smaller regions. On the average, those regions are found experimentally to have the volume of a cube about 0.001 inch on an edge. *An actual ferromagnetic body is composed of a great many such regions*, called "domains," *each domain being magnetized to saturation* (i. e., electron spins parallel) *in some direction*. When the material is said to be unmagnetized, the domains are oriented equally in all directions so that the magnetization of the specimen as a whole is zero.

Experimental evidence of the existence of these domains is supplied by the so-called "Barkhausen effect" (figure 5). If a small portion of a magnetization curve such as is shown in figure 5 could be magnified a billion times, it would be seen to be made up of steps, each a sudden change in magnetization as the field is increased with no further change until the field reaches a certain higher value. No known apparatus can give such direct magnification, but these sudden jumps can be detected by winding a coil around the specimen and connecting its ends to an amplifier at the output of which is a pair of telephone receivers. When the field is increased slowly, a series of clicks, or "noise," is heard in the receivers; a more quantitative method shows that the average click corresponds to the reversal of magnetization in a region the size[26] of a cube 0.001 inch on an edge, containing 10^{15} atoms. Under favorable conditions

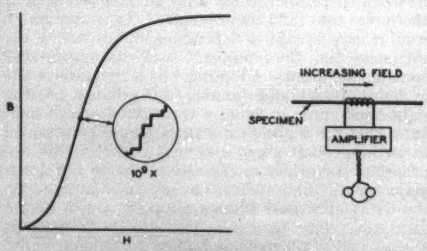


Fig. 5. Sudden changes in magnetization cause the Barkhausen effect

this "Barkhausen noise" can be heard without an amplifier, with the receivers connected directly to the coil.

It has been pointed out that the forces of exchange are opposed by the disordering effect of temperature agitation. As a result, the saturation value of magnetization decreases continually as the temperature is increased, until at the Curie point the ferromagnetism disappears. Data for saturation at various temperatures are shown in figure 6, plotted in such units that the saturation is unity at the absolute zero of temperature, and the Curie point is unity on the temperature axis. On such a plot it is found that the data for iron, cobalt, and nickel fall close together. The lower curve is the theoretical one calculated 30 years ago on the assumption that the elementary

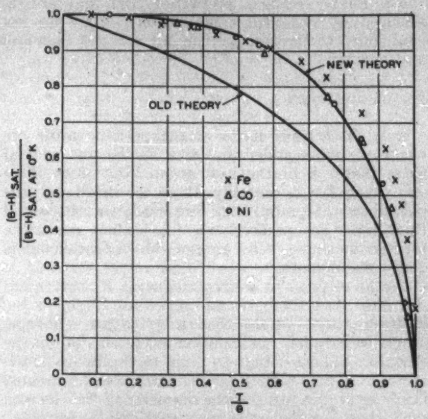


Fig. 6. Dependence on temperature of the saturation magnetization of iron, cobalt, and nickel

magnets, when they are disturbed by temperature agitation, can assume any orientation. If it be assumed, on the contrary, that the spinning electrons responsible for ferromagnetism can assume only 2 orientations with respect to the other electrons in the atom, the upper curve is the result. This is of interest because the spectroscopists and atomic structure experts came independently, each group from its own data, to the conclusion that each electron in an atom can assume only a limited number of orientations with respect to the rest of the atom.

Effect of Crystal Structure

There is another kind of force that must be postulated in order to explain the properties of a single crystal. Because of the spinning electrons which it contains, and also because of their orbital motions, each atom may be regarded as a small magnet. These magnets will influence each other in a purely magnetic way,[27] just as a group of bar magnets will; and in a crystal it may be readily appreciated that because of these magnetic forces between atoms arranged in a regular fashion, some directions of magnetization are more stable than others. In iron the most stable direction is observed to be that of the cube edge, one of the cubic axes of the crystal. In nickel it is the cube diagonal (figure 7).

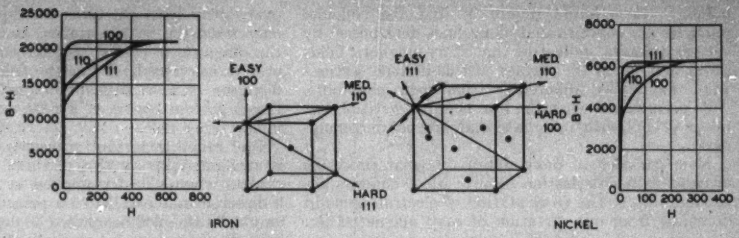


Fig. 7. Magnetic properties and crystal structures of single crystals of iron and nickel (Beck, Honda and Kaya, Webster)

Ordinarily a piece of iron is composed of crystal grains each one of which is too small to be detected by the naked eye. In recent years, however, means have been found to control the grain size of all the common metals, and single grains (i. e., single crystals) have been prepared which are so large that experiments may be performed and data collected on just one such crystal.

The structure of a single crystal of iron may be represented by a cube with an atom at each corner and one in the center, the whole crystal made up of such cubes packed together face to face. It is found experimentally that in the direction of an edge of this cube (called by the crystallographers a [100] direction) the magnetization curve labeled 100 in figure 7 is obtained.[25] In the 2 other principal directions, the direction of a face diagonal and that of a cube diagonal, the other magnetization curves shown are obtained. The difference in the initial parts of the magnetization curves is negligible, the effects being large only above half saturation.

The structure of nickel may be represented also by an assemblage of cubes, but the atoms are arranged in a different manner, being at the corners of the cubes and the centers of the cube faces (figure 7). The magnetization curves for nickel corresponding to the same 3 principal directions are shown also in figure 7, and it may be seen that the curves are reversed in order from those of iron. In iron the [100] direction is said to be the direction of easy magnetization and the [111] the direction of most difficult magnetization, whereas the reverse is true of nickel. It might be said that the electrostatic exchange forces

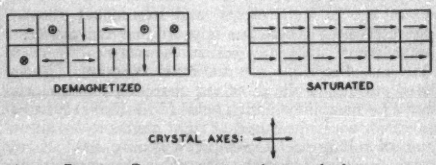


Fig. 8. Domains in a single crystal of iron

align the spins parallel to each other and that the crystal forces determine the particular crystal direction along which they shall be aligned. The forces of exchange are so powerful that they are able to align the spins of a group of atoms, a situation that in the absence of such exchange forces could be accomplished at room temperature only by an applied field of 10,000,000 oersteds. On the other hand, the crystal forces are so feeble that it takes only 1,000 oersteds to redirect the spins of an entire group of atoms from any direction to any other direction. The ratio between these 2 equivalent fields is thus 10^7 divided by 10^3, or 10^4.

As a result of the forces of exchange and the magnetic crystal forces, in a single crystal of iron, for example, the situation is as represented in figure 8. Even when the crystal is apparently unmagnetized,

Fig. 9. Powder-patterns for iron (McKeehan and Ellmore): (left) field outward; (middle) demagnetized; (right) field inward

or demagnetized, there are small regions, called domains, that are magnetized to saturation in one of the 6 equivalent directions of the crystal axes. Actually, the domains vary considerably in size and shape, but are represented conveniently as squares. Each of the 6 directions is equally stable and equally probable when no field is applied. The initial effect of applying a magnetic field is to change the direction of magnetization from one stable position to another, thus increasing the resultant magnetization in the direction of the field. These changes take place suddenly, and they are the cause of the Barkhausen effect; each sudden change in orientation of a domain accounts for one step in the magnified magnetization curve shown in figure 5, or for one click heard in the telephone receiver when listening to the Barkhausen effect.

There is even more direct evidence of the existence of domains in a piece of iron. The iron is placed under a microscope with a magnification of 500, and is covered with a colloidal suspension of iron

oxide.[29] It is found (figure 9) that the colloidal particles are concentrated along lines determined by the crystal axes, indicating that stray magnetic fields go in and out of the surface just as if some sections were magnetized differently from their neighbors. This occurs even when the iron is unmagnetized, but never occurs with materials that are not ferromagnetic.

Now consider in more detail by what processes changes in magnetization occur. Most changes are attributable to the reorientation of electron spins in domains, from one direction of easy magnetization

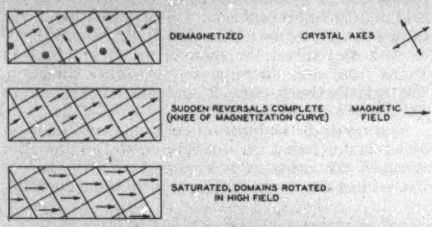


Fig. 10. As the magnetic field strength increases, domains first change direction suddenly, then rotate smoothly

to another (figure 10). These are the changes that take place over the large central portion of the magnetization curve. In general, however, it is obvious that this process is complete before the material is saturated. When all the domains are magnetized parallel to that direction of easy magnetization which is nearest to the direction of the applied field, the only way in which the magnetization can be increased further is by rotating the electron spins in each domain out of the stable position toward the field direction. Such a process is described loosely as the "rotation of the domain." This is the process that occurs in high fields, of the order of 10 to 100 oersteds; as may be seen in figure 7, its beginning corresponds to the place where the curves suddenly bend

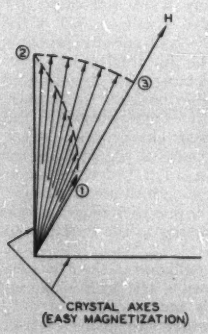


Fig. 11. Vectors represent B-H in iron, increasing in magnitude as the magnetic field (H) increases

First B-H is parallel to H (1); then as B-H increases it deviates in direction from H (2); and finally in high fields is again parallel to H (3)

over, away from the almost vertical section. It is only when the field is applied to a single crystal in the direction of easiest magnetization that this last process is avoided. When the field is applied in the direction of most difficult magnetization, the rotational process begins at a field-strength lower than in any other case.

One other important property of single crystals is accounted for by this picture. This property is evident when a field is applied to a single crystal in a direction not parallel to a principal axis. For example, let the field be applied 30 degrees from a cubic axis of an iron crystal, as indicated in figure 11 by the longest arrow. As this field is increased from zero, the magnetization will correspond in magnitude and direction to the other arrows shown. First it is parallel to the field, but as the field increases it deviates toward a direction of easy magnetization until finally it is saturated in that direction. As the field is increased further, the magnetization approaches again the direction of the field and finally is saturated in this direction. Theory agrees with experiment in that it predicts[30] the direction and amount of the deviation of B-H from H for any given value of B-H.

The 2 ways of changing magnetization that have been described for single crystals, namely sudden changes to new directions of easy magnetization, and continuous rotation of domains, apply equally well to *ordinary polycrystalline* material, the properties of the latter being those of the former averaged for all orientations. One result of this averaging, of course, is that the specimen is now isotropic and B is parallel to H.

These last remarks must be qualified, for the magnetic materials used by engineers are not always isotropic, that is, the crystal axes are not always distributed equally in all directions. It has been known for many years that when a metal sheet is rolled, the crystals composing it tend to be oriented in special ways with respect to the direction of rolling and to the rolling plane. Even after the sheet has been annealed and recrystallized, these special orientations exist, in some metals all the way up to the melting point. Since the magnetic properties depend on the crystal direction in a single crystal, it follows that sheets composed of crystals having special orientations will not have the same magnetic properties in all directions. This was observed some years ago in iron, nickel, and iron-nickel alloys.[31] More recently, there has appeared on the market a silcon-iron[32] alloy for which the permeabilities in different directions are markedly different. Measured parallel to the direction of rolling this material has a permeability in high fields (B = 15,000 gausses) of 4,000, while measured at right angles to the direction of rolling the permeability is only 400. X ray analysis shows[33] that the crystals in this material are aligned so that most of them have a cubic axis lying

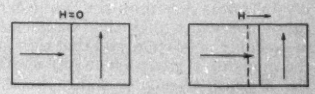


Fig. 12. Magnetization in very low fields progresses by slight displacement of domain boundaries (Becker)

within a few degrees of the direction of rolling. Thus the direction of rolling coincides with the direction of easy magnetization.

In considering the properties of single crystals, the properties in very low fields have not been mentioned, chiefly because relevant data for single crystals are very difficult to obtain. The process that occurs in this region in single crystals and polycrystals must be different from either of the 2 so far considered, because in ordinary polycrystalline material no discontinuities in magnetization are found, i. e., no Barkhausen effect occurs, and also it is known that the fields are not strong enough to rotate the domains to any significant extent against the crystal forces, out of a direction of easy magnetization.

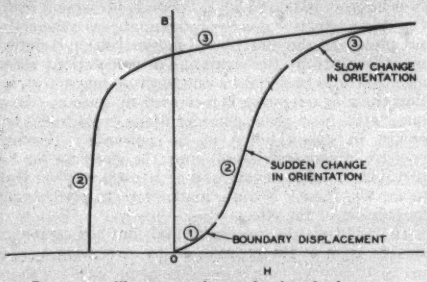


Fig. 13. Illustrating the 3 kinds of change in magnetization

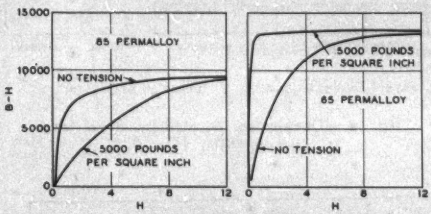


Fig. 14. Effect of tension on magnetization (Buckley and McKeehan)

Knowing as we do the relation between magnetic force and angular displacement in high fields, it is calculated that if this same mechanism applied to changes in magnetization in very low fields the highest value of initial permeability in iron would be about 20 instead of many thousands. In the past the process occurring in low fields has been the cause of much speculation, but recently a satisfactory explanation seems to have been found.[5] The changes that take place here are visualized as displacements of the boundaries of domains (figure 12); the transition region of a few atom diameters (calculated from the forces of exchange to be about 30 atom-diameters[7]) moves so as to enlarge a domain magnetized in the direction of the field at the expense of a domain pointing in a less favorable direction. Such a movement can progress

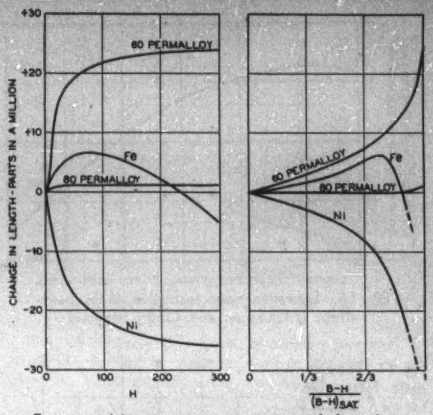


Fig. 15. Magnetostriction in iron, nickel, and 2 iron-nickel alloys ("permalloys")

for a distance that is short compared with the linear dimensions of a domain, and is limited by the small strains present in any actual material.

Thus in the magnetization of an ordinary well-annealed ferromagnetic material there are 3 processes occurring, corresponding to the 3 well known sections of the magnetization curve (figure 13): growth of one domain at the expense of a neighboring one in the initial portion of the curve, sudden changes of direction of domains (with resulting large energy losses) in the middle portion, and continuous or smooth rotation of the domains in the upper portion. The latter 2 processes occur during the traversal of a large hysteresis loop with tips at high flux densities; the first process is important only in low fields after demagnetization.

Effect of Strain

This picture of the changes in magnetization has been made for materials that are free from any considerable strain. As a matter of fact, strain can affect magnetization in an important way, and under certain circumstances a tensile stress of 5,000 pounds per square inch may change the flux density B as much as 10,000 gausses[8,4]—almost from zero magnetization to saturation (figure 14). This effect is illustrated well by data for 65 and 85 permalloy (iron-nickel alloys containing, respectively, 65 and 85 per cent nickel). For 65 permalloy the effect of tension is to increase the magnetization in all fields; for 85 permalloy the effect is the opposite; and in each case the effect of compression is opposite to that of tension. For ordinary iron the effect of tension is to increase the magnetization in small fields, but to decrease it in high fields.

The effect of strain on magnetization has its counterpart in an effect of magnetization on the length of a piece of ferromagnetic material. When a rod of iron is magnetized its length increases by a

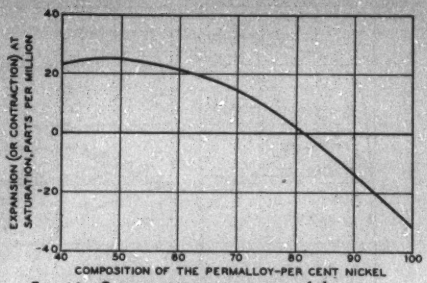


Fig. 16. Saturation magnetostriction of the permalloys (McKeehan and Cioffi, Schulze)

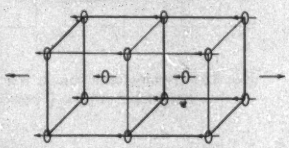


Fig. 17. The magnetic forces between atoms cause a slight elongation in iron (magnetostriction)

small amount. This is but one example of a large class of effects exhibited by all ferromagnetic bodies and known collectively as "magnetostriction." Figure 15 shows the data for change in length of rods of nickel, iron, and 2 alloys, plotted against the field H on the one hand and against relative B-H on the other. When saturation of magnetization is reached, the limiting value of magnetostriction, called "saturation magnetostriction," also is attained. Its values for some iron-nickel alloys are shown in figure 16. Note here that the change in length is an extension in the alloys containing less than 81 per cent nickel, a contraction otherwise. There is a close relation between magnetostriction and the effect of strain on magnetization, it being a general rule that when the magnetostriction is positive (increase in length with magnetization) the effect of tension is to increase magnetization, and vice versa (figures 14, 15, and 16).

The next question to be considered is: How much can theory say of magnetostriction and the effect of strain on magnetic properties? Figure 17 shows how the atoms are arranged in an iron crystal; each atom here is supposed to have a definite magnetic moment as a result of the spin and orbital motion of the electrons. This supposition makes it possible to calculate the magnitude of the mutual magnetic forces which are opposed by the elastic forces holding the crystal together. For iron, the calculations[5] indicate that equilibrium is reached when there has been a slight increase in length in the direction of magnetization and a decrease in length at right angles to this direction such that the volume remains practically unchanged. This calculated magnetostriction is in agreement with experiment as to sign and order of magnitude. With nickel the agreement is not so satisfactory. But in each case the theory is clear in predicting the proper qualitative relationship between magnetostriction and change in magnetization caused by strain.

Thus magnetostriction and the magnetic effects of strain are reciprocal properties, and result from the same kind of magnetic forces between atoms as those that account for the variation in magnetic properties in different directions in a crystal; and just as the crystal structure determines a direction of easy magnetization in a strain-free crystal, so the strain controls the direction of each magnetization when the strain is sufficiently great. Figure 18 shows how the domains are magnetized parallel to the crystal axes in unstrained iron, and how a sufficiently large tension will orient the magnetization parallel to the direction of tension in iron and at right angles to the direction of tension in nickel. When the stress is as large as 10,000 to 30,000 pounds per square inch, the strain effect begins to predominate over the crystal effect and the direction of magnetization is determined mainly by the strain. The calculations show also that in a material having positive magnetostriction the magnetization is increased by tension. In a qualitative way these considerations explain the increase in permeability of 65 permalloy (having positive magnetostriction) and the decrease in 85 permalloy (with negative magnetostriction). But so far the theory is quite inadequate to predict the magnitude of the effect.

In addition to unidirectional or homogeneous strains, such as those produced by stretching a wire

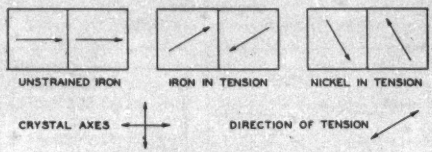


Fig. 18. Domains are oriented by crystal forces and by strain, H = 0

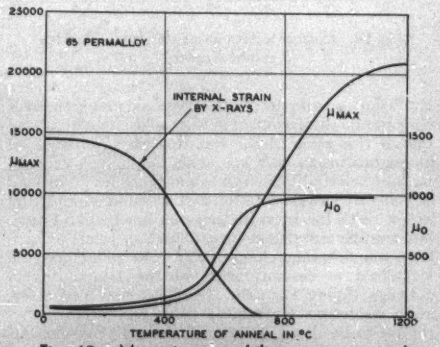


Fig. 19. Magnetic permeability rises as internal strain is diminished by annealing (Dillinger and Heworth)

in the direction of its length, random (heterogeneous) strains often are found which vary in magnitude, sign, and direction from point to point throughout a material. Such strains are produced by cold working, phase transformations, and the like. In such materials the directions of magnetization in the domains determined by the local strains, are more stable the larger the strain. So it can be appreciated that it is harder to change the magnetization of a material that is more severely hard worked. These internal strains are the same ones that contribute to the hardness of a metal—hence the parallelism between magnetic hardness and mechanical hardness, which is so well known.

This relation between internal strain and permeability is illustrated by the data[35] shown in figure 19. The permeabilities of a series of specimens of 70 permalloy tape, originally cold rolled, increase as the annealing temperature is raised. X ray data (the width of the reflected X ray beam) on these same specimens indicate the magnitude of the internal strains existing, and show that they become progressively less as the annealing temperature is increased, the most rapid change taking place in each case between 400 and 600 degrees centigrade, in which region the microscope shows recrystallization has occurred.

Following out this same idea, it may be surmised that to make good material for a permanent magnet something with very intense internal strains is required. The direct determination by X rays of internal strain in a good permanent magnet, confirms this view (figure 20). Here the width of the reflected X ray beams are a direct measure of the internal strains. For comparison with the permanent magnet material are shown curves for other materials with less internal strain. The magnet material in this case was an iron-nickel-aluminum alloy that was precipitation-hardened, a method used more and more extensively during the last 3 or 4 years for such materials. This method is often applicable when the alloy[36] in the stable condition consists of 2 phases at room temperature (figure 21), but when at a higher temperature the one phase dissolves completely in the other to form a solid solution. In making the material, it is quenched rapidly from a high temperature and then reheated to 700 degrees centigrade, at which point the second phase precipitates slowly in very finely divided form. When the optimum amount has precipitated, the cooling is continued to room temperature, no more changes occurring. Each submicroscopic precipitated particle is a center of strain, and it is the presence of these unusually large internal strains that is responsible for the good quality of the permanent magnet.

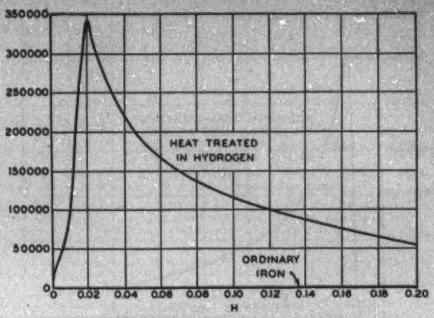


Fig. 22. Permeability curves of ordinary iron and of iron purified by heat treatment in hydrogen at 1,500 degrees centigrade (Cioffi)

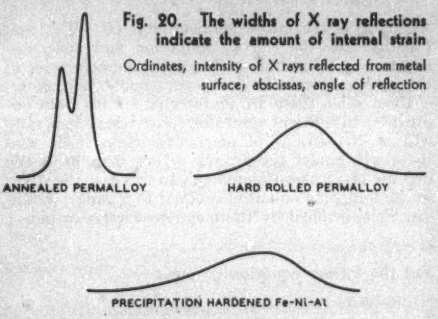


Fig. 20. The widths of X ray reflections indicate the amount of internal strain

Ordinates, intensity of X rays reflected from metal surface; abscissas, angle of reflection

Fig. 21. Precipitation hardening of an alloy for a permanent magnet, such as an alloy of iron, nickel, and aluminum

Going now to the other extreme, where ease of magnetization is required, it is known, of course, that thorough annealing and a homogeneous structure are beneficial. Still there are at least 2 sorts of strains that annealing will not relieve. One is that attributable to the nonmetallic chemical impurities that do not fit into the regular arrangement of atoms in a pure metal or alloy. It has been found recently that by heat treating iron in hydrogen at about 1,500 degrees centigrade the nonmetallic impurities are largely removed, and that what are called "chemical strains" are much reduced. As a result it is found (figure 22) that the maximum permeability increases from 10,000 to 340,000,[12] and a large reduction in mechanical hardness occurs simultaneously.

After the chemical strains and the strains resulting from cold working have been removed, there is still another kind of residual strain—that attributable to magnetostriction. These are ordinarily random in

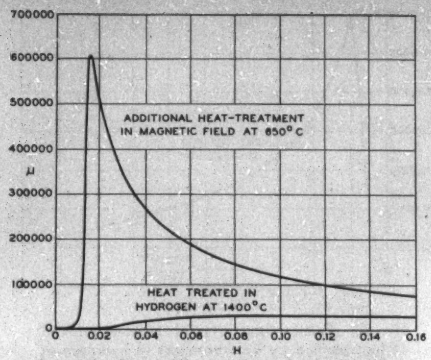


Fig. 23. Permeability curves of 65 permalloy after heat treatment in hydrogen and additional heat treatment in a magnetic field (Dillinger and Bozorth)

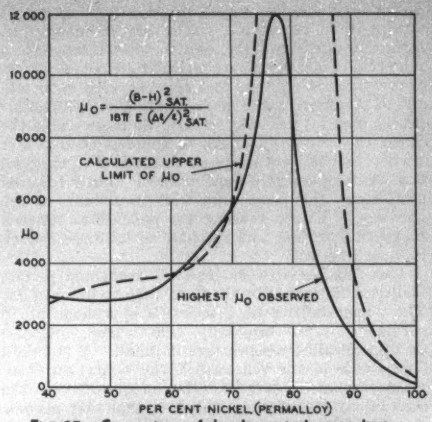


Fig. 25. Comparison of the theoretical upper limit of initial permeability (Kersten) with the highest initial permeabilities observed for iron-nickel alloys (Arnold and Elmen, Schulze)

direction because they are associated with randomly oriented domains, but by a suitable trick they all can be oriented so as to favor magnetization in a single desired direction at the expense of ease of magnetization at right angles. This trick is heat treatment in the presence of a magnetic field. Without going into a more detailed explanation, the experimental results obtained[15] about 2 years ago will be given.

When an annealed specimen of 65 permalloy is heated for a few minutes at 650 degrees centigrade while it is subjected to a magnetic field of 10 oersteds, the maximum permeability is increased from about 20,000 to over 600,000 as shown in figure 23. This material holds the records for the highest maximum permeability, the lowest coercive force, and the lowest hysteresis loss at high flux densities. It may be compared with the most permeable material known in 1,900, iron with a maximum permeability of less than 3,000.

So far only the effects of stress on the orientation of domains in medium and high fields have been considered. But stress has an effect on the initial permeability also. It already has been said that in very weak fields a change in magnetization is attributed to a movement of the boundaries between

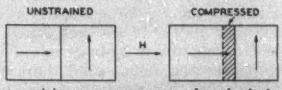


Fig. 24. Magnetostriction in the shaded region acts as a barrier to further change in magnetization

domains, the domains oriented nearly parallel to the field growing at the expense of adjacent domains oriented in less favorable directions. Such a growth obviously may be hindered by strain. A relation has been derived[37] connecting the initial permeability with the internal stress and other magnetic quantities:

$$\mu_0 = \frac{0.018(B-H)^2_{\text{sat.}}}{(\Delta l/l)_{\text{sat.}}\ \sigma_i}$$

where μ_0 is the initial permeability, $(B-H)_{\text{sat.}}$ and $(\Delta l/l)_{\text{sat.}}$ are the (ferric) induction and magnetostriction at saturation, and σ_i is the average value of the internal stress in dynes per square centimeter.

Even when there are no internal strains from impurities, insufficient annealing, etc., there generally will be the strains of magnetostriction itself, and these will hinder the growth of one domain at the expense of another (figure 24). In this case the stress in the foregoing equation is equal to Young's modulus, E, multiplied by the magnetostrictive strain,

$$\sigma_i = E(\Delta l/l)_{\text{sat.}}$$

and the former equation becomes

$$\mu_0 = \frac{0.018(B-H)^2_{\text{sat.}}}{(\Delta l/l)^2_{\text{sat.}}\ E}$$

This equation really gives a theoretical upper limit for μ_0. These theoretical limits and the highest observed values for iron-nickel alloys are shown in figure 25. This indicates why the composition of the permalloy having the highest initial permeability is very nearly the same as that for which the magnetostriction is zero.

The effects of strain now will be summarized briefly. The origin of the effects lies in the *magnetic* action between neighboring atoms. The magnetic action is balanced by the elastic (electrostatic) forces between atoms. The balance of these forces results in a change in shape of the magnetic body when it is magnetized (magnetostriction), and also a change in magnetization resulting from strain

(strain-sensitivity). Magnetization may be either aided or hindered by a homogeneous (unidirectional) strain, the effect depending on the magnetostriction in a way that can be estimated qualitatively but not quantitatively. But material in which local strains are directed at random is more difficult to magnetize because the strains prevent a change in magnetization; and the more intense such strains are, the harder the material is to magnetize or demagnetize. The effect of local strains upon the initial permeability can be calculated with fair success, but other magnetic quantities, such as maximum permeability, can as yet be estimated in a qualitative way only.

Summary

In concluding the author wishes to go back from here to summarize what is known about the origin of the forces responsible for the various magnetic properties and about the sizes of the various units. This information is summarized in table II.

Table II—Summary of Data Regarding Origin of Forces Responsible for Various Magnetic Properties

Unit Concerned	Property	Origin of Property	Size of Magnetic Unit
Electron	Magnetic moment	Electron spin	One unit of spin per electron
Paramagnetic atom	Magnetic moment	Uncompensated spins and orbital motions of electrons	4, 3, and 2 uncompensated spins per atom in Iron, Cobalt and Nickel, respectively
Domain	Ferromagnetism Change in properties at Curie point	"Exchange" between electrons in neighboring atoms	Volume of domain is about (0.001 inch)[3]
Single crystal or region of homogeneous strain	Crystal anisotropy Magnetostriction Strain sensitivity	Magnetic forces between atoms	10^8 domains per cubic centimeter
Polycrystal	Orientation - average of single crystals and strain units	Sum of effects of single crystals and strains	Size of specimen

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Most of the material used in this article can be found in more technical form in the following books and summarizing articles. For some topics reference must be made to the original works, as indicated in the text.

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Pilot Wire Relay Protection

Recent developments in relay protective schemes, using metallic pilot channels for isolating a transmission line during fault conditions, reduce considerably the magnitude of the currents which must be handled. Schemes recently developed have many other advantages over the older pilot wire schemes, being more economical to install and operate, and having excellent reliability. In addition to the advantages inherent in all pilot schemes, such as high speed tripping and absolute selectivity, the latest schemes provide indication of the condition of the pilot wire circuit at all times.

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THE idea of pilot wire protection of electric power lines and equipment has appealed to relay engineers for the last 25 years, because of the simplicity and direct action of this type of protection. Although simple and direct in theory, its practical application has until recently usually been involved and expensive, and relay engineers have generally considered it to be limited in usefulness—suitable only under special conditions. This situation is unfortunate, because pilot wire schemes of general utility and reasonable economy are now available.

The 1926 edition of the "Relay Handbook" lists advantages and disadvantages of pilot wire protection; the advantages listed are:

1. Immunity to faults outside of protected zone.
2. Independent of load currents.
3. Practically instantaneous.
4. Requires no co-ordination with other protected zones.
5. Applicable to short or long lines.
6. Provides both phase and ground protection.
7. Short circuit calculations not essential.
8. Simple construction of relays used.
9. Potential connections not required.

The disadvantages listed in the "Relay Handbook" are:

1. Cost of pilot wire channel.
2. Cost of special current transformers.
3. Necessity of uniform characteristics of current transformers.
4. Lack of supervision of pilot wire circuit continuity.
5. Induction in pilot wire circuit.

For many years prior to 1926 there had been very little change in the theory or art of pilot wire protection. In the light of changes since that time, it is interesting to note that the above advantages still apply without substantial change, but that many of the above disadvantages have since been largely removed, due to the rather recent idea of using the pilot wire channel as a remote *control* circuit, instead of a remote *metering* circuit. Attenuation thereby becomes a negligible factor in the transmission of signals.

New Principles

In the first pilot wire systems, secondary currents from the current transformers were circulated over the pilot wires. This placed heavy burden on the current transformers, required pilot wires that were short and had low impedance, and necessitated 3 pilot conductors for 3 phase systems (if both phase and ground protection were desired).

The first major development in 20 years in pilot protection occurred in March 1927 with the trial installation of a carrier current channel for pilot protection of a transmission line on the American Gas and Electric system in Ohio. This system has been described in detail by A. S. Fitzgerald.[1] The carrier channel was used to compare the instantaneous directions of fault current at the 2 ends of the protected power circuit. The idea of comparing the direction of power or reactive kilovolt-amperes instead of the instantaneous direction of current was suggested at that time, but rejected because it required potential connections.

The first installations of pilot wire protection using d-c single-channel metallic pilot-wire circuits to compare the directions of fault current at the 2 ends of a transmission line were apparently made in 1931 and 1932 by several companies. Installations were made by the Oklahoma Gas and Electric Company, Duquesne Light Company, Los Angeles Gas and Electric Corporation, Philadelphia Electric Company, and The Tennessee Electric Power Company. The first general discussion of the theory and application of this new system of pilot wire protection was presented by J. H. Neher.[2] These systems of pilot wire protection were fundamentally different from anything developed during the previous 20 years, although they resembled somewhat the carrier pilot scheme in principle.

A paper recommended for publication by the A.I.E.E. committee on protective devices, and tentatively scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 28-31, 1936. Manuscript submitted June 26, 1935; released for publication Oct. 14, 1935.

The authors wish to acknowledge the assistance of W. E. Dent, Jr., and H. E. House of the Tennessee Electric Power Company.

1. For all numbered references see list at end of paper.

Development Work

The very satisfactory results obtained from distance relays on the Tennessee Electric Power Company system in the last 4 years were largely instrumental in removing objections to the use of potential connections. The use in distance relays of potential amplification of low voltages during fault conditions, together with the fact that the starting units of distance relays made ideal initiating units for pilot wire protection, were 2 influential items in renewing interest in pilot wire schemes.

The increased use of pilot wire protection on the Tennessee Electric Power Company system since 1931 has been due to improvements in the reliability of the pilot channel and of the pilot relay equipment, resulting from intensive development work on the generally recognized limitations of pilot wire protection.

The commercial telephone circuit, while most generally available for pilot wire service, is so completely standardized that its adaptation to pilot wire requirements presents several important engineering problems which are discussed in this paper. Power company owned telephone circuits have certain definite limitations as pilot wire channels, largely due to their more severe exposure and the general use of insulating transformers. While the power company owned telephone circuit can be handled more flexibly for protective purposes, this is more than compensated for by the technical difficulties involved. However, there seems to be a field for this type of pilot wire service where exposed telephone lines are already available without additional cost.

Power company requirements for communication are very exacting. The general recognition of this fact in the last few years by the communication companies and their study of power company protective practices has resulted in improving reliability. It seems likely that development work on pilot wire circuits may be of general advantage to the telephone as well as to the power industry, particularly in the field of protection.

Circuit Continuity

Consideration of telephone circuits as pilot channels involved conceptions of circuit continuity fundamentally different from anything used previously in communication practice. In the usual telephone circuit, an open circuit, short circuit, or ground lasting for several seconds is of small consequence, unless the circuit is busy. In many early pilot wire schemes, continuous integrity of the circuit was fundamental. Momentary short circuits of the pilot wires (or ground in the case of normally grounded battery supply) would cause incorrect tripping of oil circuit breakers.

The telephone companies were anxious to provide adequate telephone circuits for pilot wire service and made available all the recent improvements in protection designed for toll and program supply circuits. As these improvements did not seem adequate for the severe requirements of pilot wire service, it was decided to analyze the conventional requirements of pilot channels, and also to attack the problem from another side by working with the Bell Telephone System in making an analysis of telephone circuit interruptions, including their relative frequency, influence, and controllability. This analysis involved actual field operating experience, as well as general office studies.

Interruptions from electrical causes occupied the major share of attention at first, but it was soon found that the use of lead covered cable for pilot wire conductors greatly reduced interruptions from lightning, foreign contact, and induction, that rise of ground potential could be dealt with by sufficient

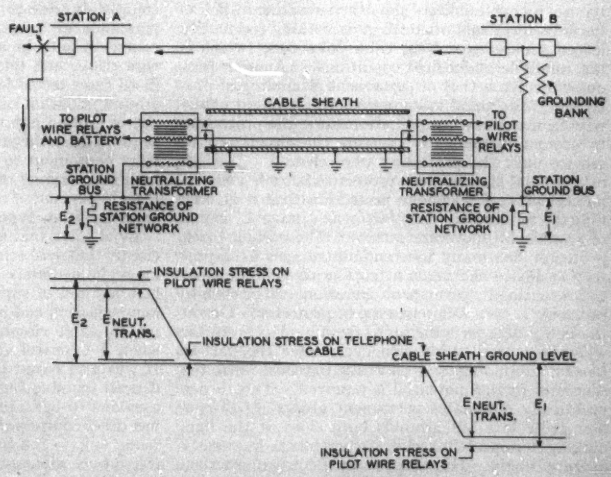

Fig. 1. Schematic diagram of recently developed pilot wire relay protective scheme using metallic channel and neutralizing transformer

See figure 6 for complete circuit showing relays and telephone protective equipment

insulation or by neutralizing transformers, and that battery failure was of such rare occurrence that the usual back-up protection could be relied upon to cover such a contingency. While progress was being made in the elimination of electrical interference affecting pilot wire protection, it was apparent that the interruptions subject to administrative control were of probably greater importance and involved greater difficulties in their reduction or elimination; for example, interruptions occurring in connection with routine maintenance and construction activities, such as testing, trouble shooting, and cable splicing.

The communication companies have made considerable progress in eliminating interference with

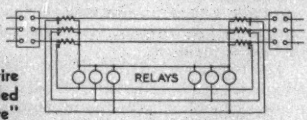

Fig. 2. Simplified schematic diagram of the earliest pilot wire scheme, often called "a-c pilot wire"

This scheme uses pilot wire conductors to connect the current transformer secondary in a differential relay scheme

leased circuits at cable terminals, central offices, and other junction points, by establishing distinctive markings, insulated binding post covers, etc., and by requiring authority to work on such leased circuits. Many power companies have had the same problems in connection with the maintenance of their own power circuits, but the general use of clearance orders under the dispatchers control has greatly reduced interference with service. The telephone industry has adopted in many places similar measures for the supervision of maintenance and construction on circuits where continuity is highly essential. However, some power companies still experience considerable trouble on leased circuits due to interference by cable splicers and others working at points between terminals where there is nothing to identify leased circuits except the cable color code (which is not infallible under field conditions). Another serious difficulty is that of permanent grounding of protectors. Electrical interruptions which might otherwise be momentary would often cause the protectors to ground permanently, putting the circuit out of service until the protectors were cleared. The use of fuses and carbon block protectors is such a fundamental part of telephone protection that it is very difficult to eliminate this factor as a possible source of trouble in pilot wire service. The carbon block protector has many inherent advantages as a protective device and much attention has been devoted to preventing its permanent operation, rather than to replacing it by a different type of protector. One of the newer devices is the unit type a-c relay protector which operates within one cycle after the carbon blocks, grounding and shorting the line until the source of foreign potential is removed. This device practically eliminates permanent grounding of carbon protectors but grounds both sides of the line, making it inoperative, while carbon blocks frequently operate singly. However, most electrical interference, except lightning, exists for 0.5 second or more and might occur during a few cycles when pilot wire tripping is taking place, so that it is highly desirable to prevent interference from reaching the telephone circuit, rather than to protect the circuit from permanent trouble due to the interference.

Neutralizing Transformers

In February 1935 the Southern Bell Telephone and Telegraph Company, Bell Telephone Laboratories, and The Tennessee Electric Power Company made the first tests on a neutralizing transformer ever used for pilot wire circuits. The neutralizing transformer consists of a primary winding and 2 (or more) secondary windings on the same magnetic core. As shown in figure 1, the primary winding is connected between the station ground bus and the cable sheath so as to have impressed across it the voltage which would otherwise cause circuit failure. By transformer action this voltage appears in the secondary windings, which are connected in series with the communication wires, in such a direction as to oppose the disturbing voltage. The use of such an arrangement makes it possible to obtain a reliable path of relatively low transmission loss and d-c resistance into the power station for relay tripping, telemetering, dialing, etc. The neutralization is practically complete, in contrast to the limited reduction provided by "series resistance" or "series reactance" protection. The neutralizing transformer eliminates the operation of carbon block protectors, and the protectors are therefore provided only as back-up protection.

Circuit Supervision

Figure 1 illustrates the operation of the neutralizing transformers during ground faults. It is impossible to neutralize the rise of ground potential completely, due to transformer ratio errors, and capacitance of cable and other leakages. This, of course, results in an insulation stress on the pilot wire relays and telephone cable, but this stress has in all cases tested less than one per cent of the total ground potential rise. In a station with 4,000 volts rise of ground potential the neutralizing transformer would reduce the stress on telephone equipment and relay equipment to less than 40 volts, which is well within the rating of all insulation involved and less than 10 per cent of the voltage required to operate the most sensitive type of carbon block protector.

Even after taking every precaution to provide a circuit that will seldom fail, it is highly essential to know immediately when failure does occur. The first method of supervision was by the use of neon lamps at each end of the circuit. The charging current of cable circuits has been found to be a factor when d-c control voltages are applied to the cable. It was also found that neon tubes would cause undesired tripping by flashing over internally on voltages due to lightning and induction that did not affect other equipment. The vacuum contact relay was found to have the same weakness, and in certain cases it had to be replaced by a relay with a wide air gap be-

tween contacts. Another method of supervision tried was the usual ground detector scheme using ungrounded battery, and grounding the midpoint of 2 indicating voltmeters, or high resistance relays, to indicate any unbalance. This scheme failed to detect the simultaneous grounding of both sides of the circuit, but was a great improvement over grounding the supply battery, which caused tripping if the circuit was grounded by testing, maintenance activities, or protector operation.

Polar Relays

Recently much improvement has been made in the way of making pilot wire circuits self supervisory. This, of course, means continuous closed circuit operation. The most satisfactory method is to use direct current of one polarity for supervision and the other polarity for tripping. On such installations there are provided 2 relays with copper oxide rectifiers in series with their coils at one end of the circuit, using one for tripping and the other for supervision. Battery voltage is supplied at the other end of the circuit and reversed whenever the directional fault detector at that end operates. This not only takes care of the usual pilot wire scheme involving directional comparison, but also provides for transferred tripping which seemed to have considerable utility, but appeared to involve almost impossible requirements as to continuity of the pilot wire circuit. The rectifier polarized supervisory relay at the end opposite from the battery supply supervises the circuit against open circuits, double grounds, crosses, and battery failures. At some stations it is possible to bring this alarm to the attention of an operator or dispatcher directly, or over another supervisory circuit. Where this is not possible the circuit may be supervised by an undercurrent and an overcurrent relay at the battery end of the line.

The use of the plan described hereinbefore almost entirely eliminates difficulties with temporary failure of the pilot wire circuit, unless such failure should occur coincident with the fault on the protected section of the power system. If protector operation can be eliminated it is believed that there are very few other hazards to the continuity of the pilot wire circuit that will be of a permanent nature. Furthermore, with continuous supervision on the circuit it is generally possible to detect these hazards and clear them up before power trouble occurs. It will be seen from the above that adequate supervision of the circuit under all likely conditions of failure is of extreme importance. The circuit may fail by being opened, short circuited, grounded, or grounded and short circuited.

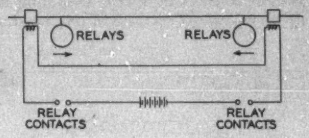

Fig. 4. Simplified schematic diagram of one of the first d-c pilot wire schemes

Three phase transmission line and relays shown by one line diagram. Pilot wire circuit shown with all conductors. Pilot wire circuit is a d-c telegraph system. Instantaneous directional fault detecting relays used at end for "directional comparison" method. Pilot wire circuit is normally open and no supervision is obtained

With these recent improvements in pilot wire tripping and supervision and the use of neutralizing transformers, experience indicates that reliability of a leased pilot wire circuit is adequate, with a reasonable amount of attention by the communication companies in the matter of designating these circuits and of educating their personnel as to the proper precautions in working on such circuits. Even with the most conscientious effort on the part of communication companies, it was difficult to maintain an adequate degree of continuity on the type of circuit first used for transferred tripping[2] and on some types of circuits used for tripping by directional comparison. The new types of circuits just described have the great advantage that any interference with the circuit is immediately reported to the operator or dispatcher, who can communicate with the telephone company, thus permitting the cause to be investigated and steps to be taken to render its repetition unlikely. This is a great improvement over former methods where the first notice any one had of the pilot wire circuit being in trouble was its failure to operate properly when power trouble occurred, and there was no way of knowing how many hours or days the pilot wire circuit had been in trouble.

Figures 2 to 5 indicate schematically some of the improvements in circuit design that have been developed for metallic pilot wire protection within the last few years. These circuits are intended to illustrate the elementary principles of circuit supervision discussed in this paper.

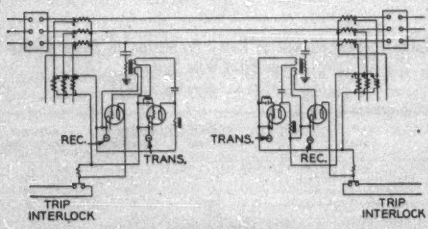

Fig. 3. Simplified schematic diagram of the earliest carrier channel pilot scheme

Current transformers in the 3 phases are of different ratios resulting in sufficient residual current under any fault condition to bias the transmitting tube and send out carrier frequency on the positive half cycles of residual current. The polarity of the residual currents at 2 ends of the line is such that the receiving and transmitting elements at either end co-operate to lock open the trip circuits in case of through faults and to close the trip circuits in case of faults in the protected section

Operating Experience

The Tennessee Electric Power Company made its first installation of metallic pilot wire protection on a

transmission tie line in Nashville in October 1932, using leased telephone cable for the pilot channel. Experience gained with the Nashville pilot wire installation was instrumental in developing the features necessary for the reliable operation of such equipment and was a deciding factor in rebuilding the distribution system in South Chattanooga. The system consists of 4 new switching substations and involves 5 short sections of overhead single circuit 11

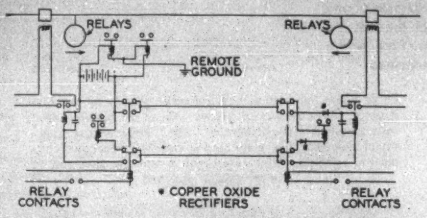

Fig. 5. Simplified schematic diagram of latest pilot wire scheme developed by the Tennessee Electric Power Company

Pilot wire circuit is normally closed but fully supervised. All supervision is obtained by relays giving an audible local alarm for attended stations. In case of nonattended stations the supervisory alarm is transmitted over other alarm circuits (or unaffected links of pilot wire in case of a tandem feed loop with all sections protected by pilot wire). By the use of copper oxide rectifiers the tripping and supervisory currents are caused to be of opposite polarity so that interference with the pilot wire circuit during normal conditions operates only the supervisory relays and not the tripping relays. With this scheme battery supply is provided in one of the stations, eliminating the disadvantages of grounded battery supply from a central office. Insulation between the station and the telephone line is maintained by the use of vacuum contact relays and other relays having high insulation between coils and contacts, as shown here, or by neutralizing transformers as shown in figure 1

kv tie lines with heavy industrial loads distributed along them. The leased circuits for the pilot wire protection of this area are all in aerial cable. Vacuum contact relays and other highly insulated relays are used throughout. One centrally located substation was selected as the heart of the pilot wire system. The pilot wire circuits have one terminal at this central substation and station storage battery voltage is supplied to all circuits through a neutralizing transformer at this station.

A new system of polarized closed circuit supervision was developed for the pilot wire equipment in the South Chattanooga area. This system gives immediate warning of failures of the leased circuits or of the battery supply. This same supervisory system is also used to transmit to the central substation of the group an alarm indication whenever any circuit breaker has opened or in case of power failure. All 4 substations are nonattended and the alarm signals received at the central substation are transmitted to the office of the system load dispatcher over a single pair of wires which are leased for that purpose. A typical pilot wire circuit is shown in figure 6.

This particular circuit has been in use on 3 pilot wire installations in South Chattanooga for 16 months. The chief difference between this and previous circuits is that ungrounded battery voltage has been used so that one permanent ground on any portion of the circuit cannot cause false operation or failure to operate unless a subsequent ground on some other portion of the circuit occurs. Continuous supervision against open circuits has been combined with supervision of oil circuit breakers at the 3 outlying stations. The code alarm sender at Alton Park substation transmits indications from all stations in the area to the dispatching office, but of course it does not distinguish between an open circuit on the pilot wire equipment and a feeder circuit in permanent trouble at one of the outlying stations. Operating experience has shown very little difficulty in determining whether an alarm signal indicates power trouble or pilot wire circuit trouble.

Instantaneous pilot wire protection is available at all times even if the circuit breaker at one end of the line section fails to reclose after an interruption. For testing a line after an interruption the scheme illustrated here utilizes an auxiliary switch on the oil circuit breaker to pick up the pilot wire auxiliary relay whenever the oil circuit breaker is open. It may be seen that the line may be tested from either end or both ends at once, the only requirement being that the pilot wire auxiliary relays and pilot wire tripping relays must have time to reset between the opening of the finger *b* on the oil circuit breaker and the closing of the finger *a*. Since some of the circuit breakers in the South Chattanooga area are quite rapid in operation a safeguard was added in the form of a small auxiliary relay with its coils in parallel with the closing solenoid of the oil circuit breaker and its normally closed contacts in series with the breaker auxiliary switch and the pilot wire auxiliary relay.

No difficulties have been experienced with the South Chattanooga scheme and no close adjustments have been found necessary.

The performance record of the South Chattanooga pilot wire scheme (see table I) may be analyzed according to the functions which are considered essential in a modern pilot wire installation. Of course, the primary function is to serve as a relay protective scheme. A relay protective scheme is no stronger

Table I—Performance of Relay Protection in South Chattanooga Pilot Wire System

May 1, 1934 to September 1, 1935

Section	Correct Operations	Incorrect* Operations	Adjacent Operations
St. Elmo—Alton Park	11	1**	90
Rossville—Alton Park	21	1**	48
Long St.—Alton Park	5	0	30
Total	37	2	168
	95% correct		

* All unnecessary operations—no failures to operate have occurred.
** Considered incorrect but this is questionable on account of lack of information.

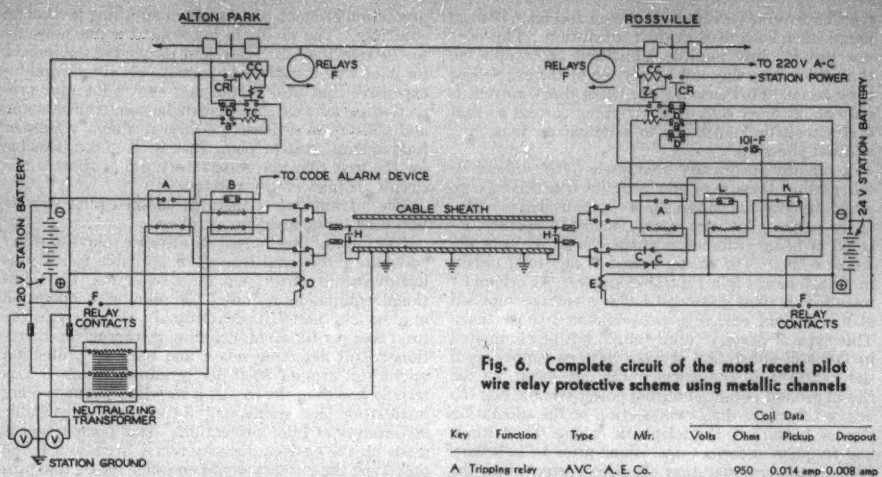

Fig. 6. Complete circuit of the most recent pilot wire relay protective scheme using metallic channels

Key	Function	Type	Mfr.	Coil Data: Volts	Ohms	Pickup	Dropout
A	Tripping relay	AVC	A. E. Co.		950	0.014 amp	0.008 amp
B	Undercurrent alarm	AVC	A. E. Co.		1,000	0.014 amp	0.008 amp
C	Rectifier	Rectox	W. E. & M. Co.		200*	Forward	Direction
C	Rectifier	Rectox	W. E. & M. Co.		40,000**	Back	Direction
D	P. W. auxiliary relay		W-Leonard	120	4,000	80 volts	20 volts
E	P. W. auxiliary relay		W-Leonard	24	800	18 volts	4 volts
F	Directional fault detectors	Special	G. E.				
CR	Closing relay						
CC	Closing solenoid or motor of OCB						
TC	Trip coil of OCB						
H	Protective carbons	26–30	W. E. Co.				
K	Vibrating reed relay	AVR	A. E. Co.	24			
L	Slow release alarm relay	ASR	A. E. Co.	24			
V	Ground voltmeters	Min.	W. E. & M. Co.	150	150,000		
Z	Auxiliary lockout relay		G. E.				

* at 0.050 amp ** at 130 volts impressed

than its weakest link, which general experience in the past has shown to be the continuity of the pilot wire circuit, referring particularly to the continuity of the pair of wires connecting the stations. The South Chattanooga scheme involves a third function of great importance—giving the load dispatcher an immediate report of relay operations.

It is interesting to note that there have been no burn-downs of the tie lines since the pilot wire equipment was installed. On 88 per cent of the cases of trouble, service was restored on the instantaneous test. This record is not considered unusually high but it is considerably higher than the average "instantaneous performance" of this company, which is about 75 per cent.

The pilot wire equipment has been in almost continuous service except for routine maintenance since its installation. During the 16 months period there were 7 interruptions in the 3 leased circuits. All of these cases of trouble were detected at once by the circuit supervisory relays, reported by the code sender, and corrected, and most of them were cleared up in a few minutes with none extending for more than an hour. In every case the difficulty was corrected before the pilot wire equipment was called upon to operate.

As first designed the code sender reporting alarms from the pilot wire area did not distinguish between heavy voltage surges and successful instantaneous reclosures, because any heavy voltage surge would operate the initiating relays. Subsequently a time delay was added to the alarm sending relay on instantaneous reclosing feeders and tie lines at the pilot wire stations. This eliminated 90 per cent of the instantaneous alarm indications due to surges. Since the nonattended stations are not inspected immediately following successful instantaneous, 15 second, or 2 minute reclosures, the primary function of the alarm scheme is to report correctly all *permanent* failures of the power circuits, so that distribution maintenance men can be sent out promptly to the proper station. Between May 1, 1934 and Sept. 1, 1935, the code sender reported 122 permanent alarms, of which 120 were correct, and 2 were questionable.

The performance of the South Chattanooga pilot wire scheme has been close to 100 per cent correct. The authors consider this performance exceptionally satisfactory for a relay scheme involving newly developed equipment and methods.

The foregoing record of the South Chattanooga pilot wire system can be contrasted with the record of the South Nashville–West Nashville pilot wire installation. There have been several cases of trouble in the Nashville pilot wire which required it to be left out of service for hours at a time. The chief difference between this installation and the Chattanooga pilot wire system is that in Nashville battery supply is obtained at the middle of the loop at the telephone company exchange and accordingly has its midpoint solidly grounded and uses very light fuses and heat coils for protection. This precludes the possibility of

rectifier reverse current supervision and instead neon lamps have been used at each substation. This does not provide any audible indication of trouble, so that difficulties may not be noticed at the exact time they occur. Furthermore, the supervisory current is only about 5 per cent of the tripping current so that high circuit resistance due to loose connections, etc., will not show up.

Reference has already been made to the difficulties inherent in the use of pilot wire for transferred tripping—because the tripping relay is connected continuously to the pilot wire circuit, ready to operate, instead of being switched into the circuit by fault detector relays. The Carter Street–Long Street circuit in Chattanooga is a typical example. As originally installed, it used grounded battery voltage supplied at a telephone exchange between the 2 substations. This type of battery supply could not be eliminated in favor of substation storage battery supply until the neutralizing transformer was developed, as the rise of ground potential during power trouble was too heavy to permit direct connection of the substation storage battery to the telephone cable. This circuit had frequent incorrect operations prior to February 1935, but every operation has been correct since the installation of the neutralizing transformer and ungrounded battery in February 1935.

Until August 1933, all of the development work was concerned with pilot wire channels using leased lead covered cable in city areas. At that time there was finished an experimental installation of pilot wire protection using a power company owned exposed or "hot" telephone line of open wire construction adjacent to transmission right-of-way. It was quickly found that a carefully designed filter was necessary to prevent operation of the d-c relays on induced 60 cycle current in case of faults beyond the protected section. High voltage condensers and reactors were secured at small cost and the filter was tested successfully in the laboratory under transient and steady station conditions. Installation of the filter was not completed until after the close of the 1934 lightning season, but in 1935, false operations continued to occur, due to insufficient contact spacing on the battery supply relays, and inadequate grounding of the protective tubes on the line side of the telephone insulating transformers.

Another installation using an exposed telephone line was completed early in 1935. This is between Nashville and Murfreesboro and uses transferred tripping to open the 110 kv bus breaker at Murfreesboro in case the 110 kv breaker opens at South Nashville. This installation shows promise of very satisfactory operation.

Both exposed telephone lines have insulating transformers at all stations, and the pilot wire equipment is connected on the line side of the insulating transformers. No supervision is provided on these telephone lines except their almost continuous use for dispatching and commercial traffic.

General Utility

The availability of adequate channels for pilot wire protection opens the way toward greatly improved protection at much less cost than anything heretofore available. The saving in investment is due not only to the fact that the relay and protective equipment for pilot wire installations is relatively simple and inexpensive, but also to the fact that pilot wire protection permits savings in distribution, transmission, and substation expense, because it allows a simpler fundamental system plan, that is, it makes feasible for the first time the satisfactory use of short single circuit tie lines of any voltage.

The advantages of metallic channel pilot protection may be summed up as follows:

Low Capital Investment. If distance relays or other adequate directional relays are available to serve as instantaneous directional fault detectors, the additional equipment required for pilot wire operation may be less than $75 per terminal. On new jobs the total cost per terminal including instantaneous directional fault detecting relays and back-up protection might run around $600 per terminal, which is materially less than the cost of a standard distance relay installation that would still not give the remarkable advantages of pilot protection. This comparison is made on the basis of distance relays because it is the only type the authors would consider for tie line protection if pilot protection was not available, and because the starting units of distance relays are considered by them to be the best type of fault detector unit for pilot protection. Furthermore, in many cases there is a substantial saving in transmission or distribution cost, because short single circuit tie lines can be used—and relayed selectively.

Reasonably Low Pilot Channel Cost. Thirty dollars per route mile per year is a typical rental figure for metallic circuits in the base rate areas of cities. This covers everything including maintenance, an item sometimes underestimated in studying cost of carrier current or privately owned telephone circuits. In fact, the maintenance alone of privately owned single circuit open wire telephone lines may easily exceed $20 per mile per year. Leased routes between cities have been quoted at $48 per mile per year for a full metallic circuit. This is less than the carrying charges of a single circuit telephone line. The rates for the distances involved in protecting tie lines in or around city areas seem to be low enough to attract some business of this kind, especially in connection with new tie lines. Lower leased rates would undoubtedly extend the field of pilot wire systems to the point where it would be standard protection for city tie lines, especially with those companies which have used protection of this kind sufficiently to have confidence in it. The leased rates between cities seem to be an obstacle to the general use of pilot wire protection for such service, judging from the very limited amount of such protection in use today. Some progress toward more favorable rates has been made recently by the communication companies, such as the use of air line mileages, lower rates for single wire circuits with ground return, and a differential in favor of ground return channel circuits using low frequency as compared with rates for circuits suitable for voice frequency. In some localities telephone companies are already quoting more attractive rates for pilot wire service, low frequency

ground return channels in some cases being as low as $18 per air line mile per year, and there is a general tendency to encourage development of pilot wire schemes that will not require high cost facilities.

Low Maintenance Cost. Maintenance of the pilot channel has been discussed in the preceding paragraph. Maintenance of the terminal equipment is also cheap as the relays are simple and more or less standard. No elaborate calculations are necessary in planning the scheme or in making the settings, and installation and testing involve no unusual difficulties.

High Speed. Tripping speeds of 1 to 3 cycles can be obtained with metallic pilot wire protection. This compares with 10 to 40 cycles with other methods on those portions of a tie line where sequential clearing is necessary. To any relay time must be added the circuit breaker time of 15 to 25 cycles with the older breakers, 8 to 12 cycles with more recent breakers, and 3 cycles or less with breakers now under development. This remarkable reduction in breaker time makes reduction in relay time all the more desirable and permits real advantages to be taken of the high speed inherent in pilot protection.

Absolute Selectivity. Being a differential scheme there is no question of selectivity if proper equipment has been chosen and structural defects do not develop. Furthermore, pilot protection does not depend upon constant characteristics of instrument transformers, properly calculated settings or constant generating conditions, but is inherently selective regardless of these conditions.

Independence of Other Zones of Protection. The zone protected by metallic wire is completely independent of all other protected areas.

Metallic Pilot Wire Protection Can Be Used on Tie Lines With Tapped Loads. The only precaution is that the load should not be large enough to operate the initiating relays. No special equipment at the tap connection is necessary.

Excellent Reliability. The first metallic pilot wire schemes were deficient in this respect but development work to date has resulted in great improvement in reliability. This is due to several factors, such as more suitable relay equipment, co-operation on the part of the communication companies in improving circuit reliability, circuit design for immunity from momentary circuit failures (unless coincident with power trouble), and circuit design for continuous supervision.

References

1. A Carrier Current Pilot System of Transmission Line Protection, A. S. Fitzgerald. A.I.E.E. Trans., v. 47, Jan. 1928, p. 22–8.

2. The Use of Communication Facilities in Transmission Line Relaying, J. H. Neher. A.I.E.E. Trans., v. 52, June 1933, p. 595–602.

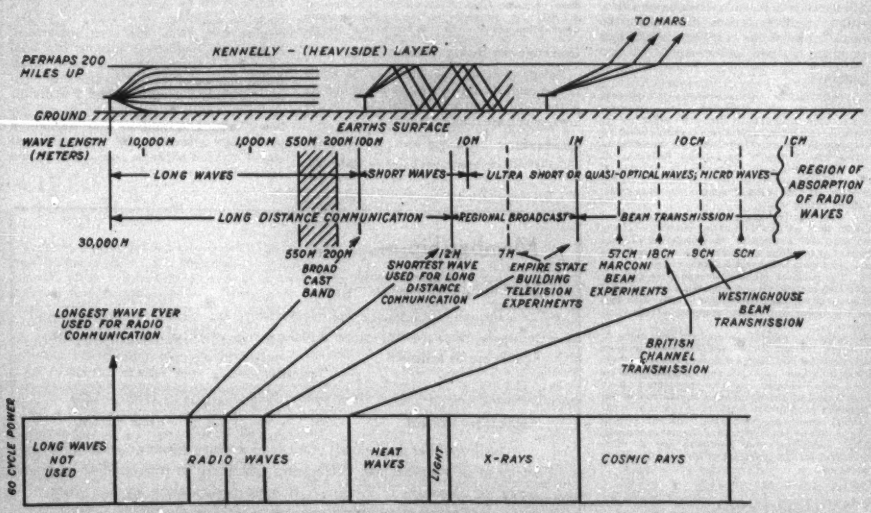

Diagram showing how the various wave lengths are used in radio communication, and their relation to radiation of other wave lengths. The "Westinghouse beam transmission" on a wave length of 9 centimeters, indicated at the right of the diagram, refers to a demonstration that formed part of that company's exhibit at the "Century of Progress" exposition in Chicago, Ill., during 1933–34. The "British channel transmission" on 18 centimeters refers to the commercial radiotelephone circuit between Lympne, England, and St. Inglevert, France (see "Production and Utilization of Micro-Rays," November 1933 issue of ELECTRICAL ENGINEERING, pages 739–40)

News
Of Institute and Related Activities

Nomination of A.I.E.E. Officers for 1936 Election; Members Invited to Submit Suggestions by Dec. 15

FOR THE nomination of national officers to be voted upon in the spring of 1936, the A.I.E.E. national nominating committee will meet during the winter convention, January 28–31, 1936. To guide this committee in performing its constituted task, suggestions from the membership are, of course, highly desirable. To be available for the consideration of the committee, all such suggestions must be received by the secretary of the committee at Institute headquarters, New York, N. Y., not later than December 15, 1935.

As reported on page 892 of the August 1935 issue of ELECTRICAL ENGINEERING, the sections of the constitution prescribing the election procedure were amended by vote of the membership. Corresponding amendments to the by-laws were adopted by the board of directors on October 22, 1935. In accordance with the provisions in the constitution and by-laws, as amended, quoted herewith, actions relative to the organization of the national nominating committee are now under way.

Constitution

28. There shall be constituted each year a national nominating committee consisting of one representative of each geographical district, elected by its executive committee, and other members chosen by and from the board of directors not exceeding in number the number of geographical districts; all to be selected when and as provided in the by-laws. The national secretary of the Institute shall be the secretary of the national nominating committee, without voting power.

29. The executive committee of each geographical district shall act as a nominating committee of the candidate for election as vice president of that district, or for filling a vacancy in such office for an unexpired term, whenever a vacancy occurs.

30. The national nominating committee shall receive such suggestions and proposals as any member or group of members may desire to offer, such suggestions being sent to the secretary of the committee.

The national nominating committee shall name on or before January 31 of each year, one or more candidates for president, national treasurer, and the proper number of directors, and shall include in its ticket such candidates for vice presidents as have been named by the nominating committees of the respective geographical districts, if received by the national nominating committee when and as provided in the by-laws; otherwise the national nominating committee shall nominate one or more candidates for vice president(s) from the district(s) concerned.

By-Laws

SEC. 22. During September of each year, the secretary of the national nominating committee shall notify the chairman of the executive committee of each geographical district that by December 15 of that year the executive committee of each district must select a member of that district to serve as a member of the national nominating committee and shall, by December 15, notify the secretary of the national nominating committee of the name of the member selected.

During September of each year, the secretary of the national nominating committee shall notify the chairman of the executive committee of each geographical district in which there is or will be during the year a vacancy in the office of vice president, that by December 15 of that year a nomination for a vice president from that district, made by the district executive committee, must be in the hands of the secretary of the national nominating committee.

Between October 1 and December 15 of each year, the board of directors shall choose 5 of its members to serve on the national nominating committee and shall notify the secretary of that committee of the names so selected, and shall also notify the 5 members selected.

The secretary of the national nominating committee shall give the 15 members so selected not less than 10 days' notice of the first meeting of the committee, which shall be held not later than January 31. At this meeting, the committee shall elect a chairman and shall proceed to make up a ticket of nominees for the offices to be filled at the next election. All suggestions to be considered by the national nominating committee must be received by the secretary of the committee by December 15. The nominations as made by the national nominating committee shall be published in the March issue of ELECTRICAL ENGINEERING (Journal of A.I.E.E.), or otherwise mailed to the Institute membership not later than the first week in March.

INDEPENDENT NOMINATIONS

Independent nominations may be made in accordance with provisions in Section 31 of the constitution and Section 23 of the by-laws, which are quoted below:

Constitution

31. Independent nominations may be made by a petition of twenty-five (25) or more members sent to the national secretary when and as provided in the by-laws; such petitions for the nomination of vice presidents shall be signed only by members within the district concerned.

By-Laws

SEC. 23. Petitions proposing the names of candidates as independent nominations for the various offices to be filled at the ensuing election, in accordance with Article VI, Section 31 (constitution), must be received by the secretary of the national nominating committee not later than March 25th of each year, to be placed before that committee for the inclusion in the ballot of such candidates as are eligible.

On the ballot prepared by the national nominating committee in accordance with Article VI of the constitution and sent by the national secretary to all qualified voters during the first week in April of each year, the names of the candidates shall be grouped alphabetically under the name of the office for which each is a candidate.

(*Signed*) H. H. HENLINE,
National Secretary

November 1, 1935.

Annual Meeting of A.S.M.E. in December. The technical program of the annual meeting of The American Society of Mechanical Engineers to be held in the Engineering Societies Building, New York, N. Y., December 2–6, 1935, has been announced. A total of 35 different sessions has been scheduled. Among these sessions, those which may be of interest to electrical engineers include 3 power sessions, 2 hydraulic sessions, 2 railroad sessions, an oil and gas power session, 2 radiant heat sessions, 3 psychology sessions, and 2 cost sessions, at one of which a paper on power distribution costs will be presented.

Membership—

Mr. Institute Member:

Though applications for membership are being received substantially, we are not quite equaling our work of last year. The figures are as follows:

	September		May to October	
	1934	1935	1934	1935
Applications received	55	50	232	230

Will you therefore do all you can to submit desirable names to the chairman of your Section membership committee as requested in our letter of October 1, 1935. It is your participation in this work that maintains the membership.

Ernest Fisher

Chairman National Membership Committee

Lehigh Valley Section Sponsors Joint Meeting

Approximately 550 persons attended a highly successful engineers' dinner meeting held September 28, 1935, at the Hotel Mallow-Sterling, Wilkes-Barre, Pa., under joint sponsorship of the Lehigh Valley Section of the A.I.E.E., the local sections of The American Society of Mechanical Engineers and American Institute of Mining and Metallurgical Engineers, the Wilkes-Barre Chamber of Commerce, and the Engineers' Club of the Lehigh Valley. The meeting marked the culmination of an all-day program which earlier in the day included inspection trips to anthracite coal mines and other points of interest in and near Wilkes-Barre.

After dinner, the attendants listened to 3 interesting addresses. In the first, F. H. Wagner, vice president and general manager, Lehigh Valley Coal Company, Wilkes-Barre, Pa., outlined briefly some of the high points in the history of mining engineering in the anthracite region. He said that although the mining engineer might have been regarded as a necessary evil in the early days, he was considered indispensable today. In the second address, James H. Pierce, president, James H. Pierce and Company, Scranton, Pa., pointed out the various factors responsible for the steady decline in anthracite tonnage since 1926, and outlined measures being taken to increase the consumption of anthracite. In the third address, N. G. Reinicker (M'18) vice president and general manager, Pennsylvania Power and Light Company, Allentown, Pa., discussed some of the problems with which the electric utility is confronted in serving the anthracite industry and some of the measures taken to preserve continuity of service. W. H. Lesser (M'24) was chairman of the committee on arrangements.

A.I.E.E. 1936 Winter Convention

Committees are making arrangements for the program of the A.I.E.E. 1936 winter convention, which will be held in the Engineering Societies' Building, 33 West 39th St., New York, N. Y., January 28–31, 1936. Similarly to the plan of the past 2 years the convention will convene on a Tuesday with technical sessions both mornings and afternoons of the first 3 days while Friday, the fourth day, will be devoted entirely to inspection trips. The evenings will be given over to social functions—the smoker, the Edison medal presentation, and the dinner-dance. Details as soon as they become available will be announced in ELECTRICAL ENGINEERING.

A technical program, which will advance the theory and practice of electrical engineering in many specialized fields, is being developed. Two well-rounded symposiums, one on modernization of distribution systems, the other on magnetic materials and structures, should provide unusual interest for many engineers. The former symposium is a normal outgrowth of the trend of the times. The latter symposium, while mainly from the communication point of view, nevertheless should be of value to many others as the magnetic properties of the materials are important in electrical designs. In addition to the symposiums a number of other papers will be presented at sessions on subjects as follows: instruments and measurements, electrical machinery (2 sessions), automatic stations, power transmission and distribution, communication, electrochemistry and electrometallurgy, transportation, electrophysics, and protective devices.

Some of the papers on the program already have been published while others appear in this issue and still others will appear in subsequent issues up to the time of the convention. For scheduling, see the footnote on the first page of each published paper.

WINTER CONVENTION COMMITTEE

The personnel of the general committee making the arrangements is as follows: C. R. Beardsley, *chairman;* T. F. Barton, C. O. Bickelhaupt, A. F. Dixon, E. E. Dorting, C. R. Jones, W. R. Smith, George Sutherland, and R. H. Tapscott. The following have been appointed as chairmen of subcommittees: C. S. Purnell, *dinner-dance;* S. A. Smith, Jr., *inspection trips,* and George Sutherland, *smoker.*

Russia Joins Illumination Commission. The U.S.S.R. has been admitted to membership in the International Commission on Illumination according to an announcement by G. H. Stickney (A'04, F'24) president of the United States National Committee of the I.C.I. With the addition of Spain, which was admitted to membership during the convention in Germany last July, there are now 17 countries affiliated with the commission.

Wilson Dam Substation, Being Erected in Alabama

Photo courtesy Delta-Star Electric Company

A VIEW of the 44,000-volt steel-tower substation which is now nearing completion in Alabama at Wilson Dam. This substation is a T.V.A. project. The 3-pole and 6-pole disconnecting switches are shown on the right-hand tower and on the center bay structure. Note also the ground wires for lightning protection strung on the tops of the 4 towers outside the substation fence.

E.C.P.D. Holds Annual Meeting

Charles F. Scott (A'92, F'25, HM'29, past-president and member for life) professor of electrical engineering emeritus, Yale University, New Haven, Conn., and chairman of the board appointed by Governor Cross to administer the recently enacted engineers' registration law in the State of Connecticut, was elected chairman of the Engineers' Council for Professional Development at the third annual meeting of that body held in New York, N. Y., on October 8, 1935. Professor Scott succeeds C. F. Hirshfeld (A'05) chief of research of the Detroit (Mich.) Edison Company, who has served as chairman of the E.C.P.D. since its formation.

The Engineers' Council for Professional Development is a conference of engineering bodies organized to enhance the professional status of the engineer through the cooperative support of the national organizations directly representing the professional, technical, educational, and legislative phases of the engineer's life. The participating bodies are: American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, The American Society of Mechanical Engineers, American Institute of Electrical Engineers, Society for the Promotion of Engineering Education, American Institute of Chemical Engineers, and National Council of State Boards of Engineering Examiners.

George T. Seabury, secretary of the American Society of Civil Engineers, was re-elected secretary of the E.C.P.D. New members of the executive committee also elected were C. F. Hirshfeld, representing The American Society of Mechanical Engineers, Harrison P. Eddy, of Boston, Mass., past-president of the American Society of Civil Engineers, representing that society, and L. W. W. Morrow (A'13, F'25, and

director) editor of *Electrical World*, New York, N. Y., representing the American Institute of Electrical Engineers. Other members of the executive committee who continue in office and the societies they represent are: F. M. Becket, of New York, past-president, American Institute of Mining and Metallurgical Engineers; H. C. Parmelee, of New York, American Institute of Chemical Engineers; R. I. Rees, of New York, Society for the Promotion of Engineering Education; and D. B. Steinman, of New York, National Council of State Boards of Engineering Examiners.

After the meeting adjourned the annual dinner, at which the chairman, C. F. Hirshfeld presided, was held at the Engineers' Club, and was attended by about 30 representatives of the participating bodies and guests of the E.C.P.D. A résumé of the work of the 4 principal committees and of the actions of the annual meeting was reported by Dr. Hirshfeld. Professor Scott spoke on the significance of the activities of E.C.P.D. in carrying forward its program in a spirit of understanding and co-operation.

At the annual meeting reports of the committees were presented and approved. These reports will be made public when printed. The 4 committees under whose guidance the principal activities are conducted have been set up to cover the 4 phases of the engineer's training. These are: committee on student selection and guidance, charged with the pre-collegiate phases; committee on engineering schools, whose interests at present are directed toward carrying out a program of accrediting engineering curricula; committee on professional training, which gives its attention to the problem of the young engineer and recent graduate; and committee on professional recognition, whose concern is with procedures by which the individual becomes a recognized member of the engineering profession.

Because of misunderstandings of the purposes and objectives of the committee on professional recognition which had arisen since the 1934 annual meeting, the council of E.C.P.D. adopted a resolution in which it regretted and disclaimed any statement that had been made in its behalf that might have been construed as unfriendly toward the engineers' registration movement, and any intention to set up a certifying agency in conflict with the legal registration of engineers by state boards or to parallel or supplant the National Bureau of Engineering Registration.

At the request of the committee on professional recognition its "program of certification," adopted by the E.C.P.D. in October, 1934, was referred back to the committee for further study and clarification.

Future AIEE Meetings

Winter Convention,
New York, N. Y., Jan. 28–31, 1936

North Eastern District Meeting,
New Haven, Conn., May 1936

Summer Convention,
Huntington Hotel, Pasadena, Calif., June 22–26, 1936

Middle Eastern District Meeting,
Pittsburgh, Pa., part of week of Oct. 12, 1936. Transferred from Akron.

Recent Views of Columbia River Projects

Something of the tremendous magnitude of the Government's Grand Coulee power and irrigation project and Bonneville power and navigation project may be gleaned by study of the several illustrations on the facing page. These snapshots were taken early in September 1935 upon the occasion of the visit of President E. B. Meyer and party to these projects, and indicate the status of progress as of that time.

The Grand Coulee project is on the upper Columbia River in the state of Washington, about 100 miles west of Spokane, and as at present scheduled, according to the latest information available from the U.S. Bureau of Reclamation, embraces in this initial phase the excavation for and the construction of the foundation for the proposed 500 foot dam and related structures. According to reports, an estimated $60,000,000 will be required to carry this initial phase of the project to completion during the next 2 years. The final project contemplates a 150 mile reservoir providing some 5,200,000 acre-feet of usable irrigation water, together with provisions for a power plant expected to be capable of generating some 1,890,000 kva.

The $32,500,000 Bonneville project on the Columbia River boundary line between the states of Washington and Oregon some 40 miles east of Portland and 145 miles from the sea, is expected to open the Columbia River to navigation by flooding the Cascade Rapids, and also to create power development possibilities amounting to some 600,000 horsepower. Work on the project was launched in November 1933, and is scheduled to be completed some time in 1937.

(1, across the top) Cofferdam and foundation excavation at Bonneville. Size of project and equipment used may be indicated by noting the men spotted in the white circles.

(2) Downstream view of the Bonneville power house structure as it appears from the construction road through the construction railroad trestle.

(3) Looking down into the west abutment excavation for the Grand Coulee Dam from a point some 1,200 feet above it at the top of the slide that has imposed construction difficulties. (At this point the river flows north.) Mason City, contractors' camp, may be seen across the river in the upper background, the north end of the cofferdam extends into the picture from the right and slightly above center, and the main excavation down approximately to bedrock may be seen toward the right inside of the cofferdam.

(4–5) These 2 together, give something of a panoramic view of the Grand Coulee project from the upper west bank. The river flows to the north (left). Contractors' camp may be noted again at the left. The cofferdam appears through the upper center, with the main excavation in the foreground toward the left, where magnitudes again may be compared by noting the 5 yard shovel in the lower extreme foreground toward the left of (5). Also, the famous conveyor system may be traced from the main excavation leading toward the spoil dump more than a mile away toward the right, together with its feeder line extending across the river to the excavation for the east bank abutment.

(6) Conveyor system extending from main excavation more than a mile over the hill to Rattlesnake Canyon spoil dump. This belt conveyor system comprised of successive sections each dumping on to the following one, involves a total of some 4,000 horsepower in electric motive drives, together with associated controls and automatic safety features; it operates at 620 feet per minute, and has a rated capacity of 2,500 cubic yards per hour (1.2 tons per second).

(7) Conveyor distributor head discharging excavated material at the rate of more than one ton per second after it has been raised 350 feet or more from the excavation.

(8) Composite panoramic view indicating the general character of the terrain adjacent to the Grand Coulee project and indicating something of the extent to which speculative towns and town sites have sprung up. Mason City, the contractors' camp, may be noted again at the extreme right in the background; cement storage plant may be noted slightly to the left, also spoil dump in Rattlesnake Canyon may be seen over the hill separating the lower foreground at the right from the central background. This is the view of the project that greets the eye as the visitor comes over the crest of the hill on the highway.

Another Light-Weight Stainless-Steel Train. The "Mark Twain" a 4-car light-weight stainless-steel train has been added to the fleet of streamlined Diesel electric trains of the Burlington Railroad. It will run between St. Louis, Mo., and Burlington, Iowa. The new train is similar in structure and appearance to the 3 "Zephyrs" now in operation on the Burlington. Like its predecessors, the "Mark Twain" is powered by a 600-horsepower Diesel electric engine which operates on common fuel oil. The train, supplied with fuel, water, and sand, weighs 287,245 pounds, and has seats for 92 passengers. It contains a kitchen, dinette, baggage car, and railway post office. The train was built by the Edward G. Budd Manufacturing Company, Philadelphia, Pa. The stainless steel body structure was fabricated by means of the "shot weld" process used in the building of railroad trains, elevated cars, airplanes, and truck bodies.

Draftsmen Organize. The American Society of Draftsmen, with national headquarters at Room 911, 424 South Broadway, Los Angeles, Calif., has recently been organized to take an active interest in the welfare of the large number of men who are in the drafting phase of engineering.

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Thomas Alva Edison Foundation Organized

Owen D. Young will serve as national chairman of the country-wide movement to honor Thomas Alva Edison by the establishment of a program to keep alive the ideals of the "wizard of Menlo Park," it was recently announced by William S. Barstow (A'94, M'99, F'12, and Life Member), president of The Thomas Alva Edison Foundation. National vice-chairman will be George B. Cortelyou.

The Edison Center for the Advancement of Youth in Science will comprise the physical setting from which a wide educational program will be developed with emphasis on the encouragement of youth in the pursuit of scientific knowledge, to be an ever-living memorial in keeping with Edison's life-long services to mankind, and particularly to youth.

The basic memorial will include facilities for the permanent care of Edison's personal library, which is probably one of the most valuable scientific libraries in existence, his records and papers, and originals or replicas of each of the more than 1,000 inventions which he developed. The plans also include provision for a final resting place for the great inventor. Menlo Park, the scene of Edison's early activities, will be marked by a simple and impressive shaft, as a part of the general memorial program.

Officers of The Thomas Alva Edison Foundation are: William S. Barstow (A'94, M'99, F'12 and Life Member) president; W. H. Meadowcraft, honorary vice president; L. W. W. Morrow (A'13, F'25, and director) and F. A. Scheffler (A'93, F'12, and member for life) vice presidents; and W. S. Mallory, secretary and treasurer. These, with Dr. A. E. Kennelley (A'88, M'99, F'13, HM'33, Life Member and past-president), H. H. Barnes, Jr. (A'00, F'13, and past vice president), W. J. Orchard, Dr. C. F. Scott (A'92, M'93, F'25, HM'29, member for life, and past-president), Dr. C. H. Sharp (A'03, F'12, and member for life), W. H. Taylor, P. B. Millar (A'03, M'13) and Arthur Walsh, comprise the board of directors.

Chemical Industries Exposition. What is reported to be "the greatest industrial pageant of chemical achievement since the depression" is the reward in store for those planning to attend the 15th Exposition of Chemical Industries, which will be held in Grand Central Palace, New York, N. Y., December 2–7, 1935. The exposition this year is divided into the following classifications: chemicals and chemical products; plastics, molded products, and lacquers; laboratory equipment and supplies; general equipment; instruments of precision; containers; brewing equipment; materials handling equipment; raw materials; natural resources; and educational exhibits.

Columbia University Scholarship Awarded

The special tuition scholarship at Columbia University, New York, N. Y., which is placed at the disposal of the A.I.E.E. each year has been awarded for 1935–36 to Joseph Leo Dalton (A'35) of Glenside, Pa. Mr. Dalton received the degree of bachelor of science in electrical engineering from Pennsylvania State College in 1934, and is now a candidate for the degree of master of science in electrical engineering.

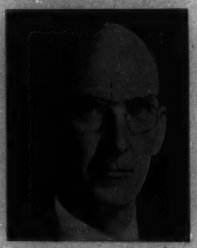
This scholarship was originally founded by a group of Columbia alumni. Each year a committee of alumni, members of the A.I.E.E., considers the applications of graduate students for this scholarship. This year the committee, H. C. Carpenter, Francis Blossom, and Prof. W. I. Slichter, chose the recipient as the best from a group of 8 applicants. Availability of this scholarship was announced in ELECTRICAL ENGINEERING for February 1935, page 248.

Recent Progress in Welding Research

At the request of the committee on research of the Institute, the technical committee on welding has made available to the members of the Institute a report entitled "Recent Progress in Welding Research." It was prepared collectively by the fundamental research committee, a committee of the American Welding Society of which H. M. Hobart (A'94, F'12, past vice president, and member for life) is chairman. The availability of this report is, therefore, due to the informal collaboration between several committees and societies.

The report, notwithstanding its length (containing over 20,000 words plus a bibliography of 283 references) is considered to be preliminary to a final report which it is anticipated will be a more critical review of the recent literature on research in the welding fields. As much more work is necessary before this final revised report can be completed, a limited supply of mimeographed copies of the report in its present form has been prepared and copies may be had without charge by members of the A.I.E.E. and the A.W.S. (as long as the supply lasts) on application to either H. H. Henline, national secretary of the A.I.E.E. or William Spraragen, secretary of the A.W.S., both at 33 West 39th Street, New York, N. Y.

In Memoriam



J. ALLEN JOHNSON

THE death of J. Allen Johnson, on October 4, 1935, removed from the American Institute of Electrical Engineers its forty-seventh president and one of its most loyal and active members.

After his graduation from the Worcester Polytechnic Institute, in 1905, with the degree of bachelor of science in electrical engineering, Mr. Johnson embarked upon his life-work in the generation, transmission, and distribution of electric power. He quickly rose to positions of considerable responsibility, and in 1929 was appointed chief electrical engineer of the Buffalo, Niagara and Eastern Power Corporation. He contributed several important technical papers to the Institute publications.

Mr. Johnson joined the Institute in 1907, and was transferred to the grade of Fellow in 1927. He was the first chairman of the Worcester Polytechnic Institute Branch, in 1905, and was organizer and first chairman of the Niagara Frontier Section, 1925–26. He served as a member of many Institute committees and as chairman of several, as director 1928–32, vice president 1932–34, and as president 1934–35. Throughout these activities he was loyal at all times to the highest ideals of the Institute.

His ability as an engineer, his keen perception of the human values involved, his high ideals, and the breadth and thoroughness of his thought upon all matters affecting his field of work won him not only an outstanding reputation in his chosen profession, but also the respect and admiration of all who knew him.

RESOLVED: That the board of directors of the American Institute of Electrical Engineers hereby expresses, upon behalf of the membership, its deepest regret at the death of Mr. Johnson, and its sincere appreciation of his many important contributions to the development of Institute activities, and be it further

RESOLVED: That these resolutions be entered in the minutes and transmitted to members of his family.

—A.I.E.E. Board of Directors, October 22, 1935

The report deals with *recent* researches on welding subjects and the references rarely relate to any publication of earlier date than 1933. The policy followed in preparing this compilation was to utilize the experience of specialists in each branch of welding and to include in the bibliography only those articles and papers which were considered by the specialists to be the most notable and valuable contributions to the literature of the subject.

Notwithstanding the recognized incompleteness of the report in its present form, it is believed that any approach to an equivalent is not yet available in any language and that, therefore, until the revision is completed, it will be of much value to welding specialists and others interested in the technical phases of welding and its applications.

Engineering Foundation

Election Held by Engineering Foundation

The 21st annual meeting of The Engineering Foundation was held in the Engineering Societies Building, New York, N. Y., on Thursday, October 10, 1935. The meeting opened as the final meeting of the 1935 board and was followed immediately by the first meeting of the 1935–36 board. Since, during the past year, the annual meeting of the board of The Engineering Foundation was advanced from January to October, the 1935 board held office only from January to September. The 1935–36 board holds office until the annual meeting in October 1936.

The Engineering Foundation is a department of United Engineering Trustees, Inc., organized in 1904, and now joint agency of the 4 national societies representing the civil, mining and metallurgical, mechanical, and electrical engineers. The Engineering Foundation, founded by Ambrose Swasey (HM'28) in 1918, is entrusted with the expenditure of the income from endowments and other funds, its present preferred activity being engineering research.

The feature of the annual meeting of October 10, 1935, was the election of officers. H. P. Charlesworth (M'22, F'28, and past-president) assistant chief engineer, American Telephone and Telegraph Company, New York, N. Y., was re-elected chairman. Mr. Charlesworth is a representative of the A.I.E.E. on the board. D. Robert Yarnall, a representative of The American Society of Mechanical Engineers, and a member of the firm of Yarnall-Waring Company, Philadelphia, Pa., was re-elected vice chairman. The executive committee, the members of which were elected or re-elected, is composed of these 2 members, together with the following 3 persons: A. L. Queneau, *trustee*, metallurgist, United States Steel Corporation, New York, N. Y., and a representative of the American Institute of Mining and Metallurgical Engineers; Edwards R. Fish, *member-at-large*, chief engineer, boiler division, Hartford Steam Boiler Inspection and Insurance Company, Hartford, Conn., and a representative of The American Society of Mechanical Engineers; and O. E. Hovey, *trustee*, consulting engineer, American Bridge Company, New York, N. Y. (Mr. Queneau succeeds J. V. N. Dorr, as a member of the executive committee.) Doctor A. D. Flinn was re-elected director and secretary.

These officers and the executive committee of The Engineering Foundation are elected by The Engineering Foundation board from among its own members. The Engineering Foundation board is itself elected by the board of trustees of United Engineering Trustees, Inc. Members of The Engineering Foundation board who were elected at the meeting of United Engineering Trustees, Inc., on June 27, 1935, and who serve for terms of 4 years expiring at the annual meeting in 1939, or upon expiration of terms as trustees, are as follows:

H. P. Charlesworth, trustee, to succeed himself
George E. Beggs, nominated by A.S.C.E. to succeed himself
Albert E. White, nominated by A.S.M.E. to succeed himself
F. Malcolm Farmer, nominated by A.I.E.E. to succeed C. E. Skinner
John V. N. Dorr, member-at-large, to succeed himself
Edwards R. Fish, member-at-large, to succeed himself.
G. L. Knight (A'11, F'17), *ex officio*, president, U.E.T., Inc.

The complete membership of The Engineering Foundation board, consisting of the above mentioned newly elected members, and the members holding over from previous elections, is as follows:

Name		Term Expires
Four Trustees of U.E.T., Inc.		
Otis E. Hovey	A.S.C.E.	1937
A. L. Queneau	A.I.M.E.	1938
D. Robert Yarnall	A.S.M.E.	1936
H. P. Charlesworth	A.I.E.E.	1939
Eight Members Nominated by Founder Societies		
George E. Beggs	A.S.C.E.	1939
Langdon Pearse	A.S.C.E.	1938
George D. Barron	A.I.M.E.	1936
Everette DeGolyer	A.I.M.E.	1938
Albert E. White	A.S.M.E.	1939
W. H. Fulweiler	A.S.M.E.	1936
F. M. Farmer	A.I.E.E.	1939
W. I. Slichter	A.I.E.E.	1936
Three Members-at-Large		
Frederick M. Becket		1938
John V. N. Dorr		1939
Edwards R. Fish		1939
Ex-Officio, President, U.E.T., Inc.		
G. L. Knight (A'11, F'17)		

At this annual meeting, members of the research procedure committee were appointed as follows:

D. Robert Yarnall, *chairman*, representing The Engineering Foundation

F. M. Farmer (A'02, F'13, and director) second member representing The Engineering Foundation, Thaddeus Merriman, representing the A.S.C.E.

F. F. Colcord, representing the A.I.M.E.

W. H. Fulweiler, representing the A.S.M.E.

L. W. Chubb (A'09, F'21) representing the A.I.E.E.

No changes were suggested in the membership of the other committees, except for the appointment of C. L. Eksergian, chief engineer, Budd Wheel Company, to the welding research committee. H. P. Charlesworth was re-elected representative on National Research Council.

Among other business transacted at the annual meeting was the adoption of the condensed annual report of The Engineering Foundation for the period January 1 to September 30, 1935, for transmittal to United Engineering Trustees, Inc., for the annual meeting of said corporation which was held October 24, 1935. Further details will be given in succeeding issues of ELECTRICAL ENGINEERING.

American Engineering Council

Federal Relief Projects

Excerpts from the current "news letter" of the American Engineering Council follow:

The approval of projects under the federal works relief program has been speeded up in recent weeks to make work available against the winter peak in operations. The jurisdiction of federal agencies over portions of the program has been clarified and funds have been shifted, especially to the Works Progress Administration, whose position is strengthened as a means of providing quick jobs.

Discontinuance of the division of applications and information, and clarification of functions of the advisory committee on allotments, seem to place broad discretionary power under the state administrators and directors as to the carrying out of approved projects and the advancement of projects not yet approved.

The Works Progress Administration, the largest spending and employing agency of the program, has been given a high degree of flexibility through the approval of approximately twice as many projects as there is money to finance. In other words, each State has a pool of projects from which to draw in placing the jobless in work suited to their individual skills, with latitude as to the selection of projects at the time and place most needed. The expectation is that W.P.A. will handle work aggregating more than $1,000,000,000.

Of primary importance is the entrace of the Corps of Engineers of the U.S. Army into the W.P.A. program. Lt. Col. F. C. Harrington has been appointed chief engineer of W.P.A. Officers of the corps have been appointed consulting field engineers in 11 areas of the United States. The consulting field engineers soon will visit their areas to secure full information as to the works program in each state, with "particular regard to those obstacles or difficulties which are hampering the speedy development of the program."

The Public Works Administration is going

forward with a new program involving between 3,000 and 4,000 projects in which federal grants from new money and loans from the P.W.A. revolving fund amount to about $500,000,000. With the addition of funds which the project sponsors have secured by private borrowings, the program amounts to about $750,000,000 of new construction. In addition, numerous projects are in various stages of construction under the old P.W.A. program.

Indefinite continuation of the Civilian Conservation Corps is contemplated in plans which call for a tapering off of enrollment from a peak of about 600,000 to 300,000 next July. Of approximately 750,000 young men who finish their formal education each year, some 600,000 are employable. On the basis discussed, the corps could offer half of these a year of out-of-door work at some time in their young manhood. The age limit for enrollment, originally 18 to 25, has been widened from 17 to 28. W.P.A. also plans to employ young men and women from 16 to 25, especially those from large relief families, to supplement the primary earnings of heads of families carried under the work program.

Other A.E.C. Items

"The Engineer's Duty as a Citizen," a pamphlet prepared as an outline for a discussion course at the Newark College of Engineering, is now in its third edition. The author, Roy V. Wright, editor of the *Railway Age* and other trade publications, has made revisions during the summer. New material added includes an account of the political experiences of Joshua D'Esposito, builder of Chicago's $100,000,000 Union Station, who ran for office on a reform ticket. The work of Col. William J. Wilgus, railroad engineer and executive, who came out of retirement to direct work relief in New York City, also is described. The pamphlet seeks to outline, with specific examples, some of the ways in which engineers can discharge their civic responsibilities, as individuals or by group action. Copies are obtainable at 25 cents each from the book store of the Newark College of Engineering, 367 High Street, Newark, N. J.

American Engineering Council at the present time, through its member organizations, represents 38 engineering bodies composed of 7 national societies and 31 state and local engineering organizations. New members of Council, since the new membership plan of nominal dues to State and local societies went into effect in January 1935, include the following:

State Societies: Arkansas Engineers' Club, Little Rock; Engineering Societies of New England, Boston; Florida Engineering Society, Gainesville; Louisiana Engineering Society, New Orleans; Maryland Association of Engineers; Michigan Engineering Society, Detroit; and South Carolina Society of Engineers, Columbia.

Local Societies: Associated Engineers of Spokane, Wash.; Cleveland Engineering Society, Ohio; Engineers' Club of Baltimore, Md.; Engineers' Club of Columbus, Ohio; Engineers' Club of Philadelphia, Pa.; Engineers' Club of St. Louis, Mo.; Engineers Society of Western Pennsylvania, Pittsburgh, Pa.; and Providence Engineering Society, R. I.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or to reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

The Status of Television in Europe

To the Editor:

Further developments have recently taken place regarding the operation of television in England and the following comments are given as a supplement to the recent article by A. W. Cruse under the above title (ELECTRICAL ENGINEERING, Sept. 1935, pages 966–9).

The article mentions the public service operating on a low definition, offered by the British Broadcasting Corporation. This service was stopped on September 11, 1935, after very short notice, so that no public service is now operating at all.

Regarding the proposed experimental television service from Alexandra Palace the B.B.C. was authorized on August 12 to complete the arrangements for the provision of transmitting apparatus on the lines given in the above-mentioned article. March 1936 has been given as the date of inception for this service, but actually work on the contract is at present held up.

The opinions of the membership of The Television Society are worth quoting on the technical aspect of the scheme. In answer to a recent questionnaire the majority of replies stated that "interlaced scanning gave no advantages that were not offset by greater disadvantages. "Further, it was agreed that 240 lines were quite sufficient for a public service.

Very truly yours,

G. V. HARRAP (A'34)
58 Wellington Road,
Dunston, Gateshead, England

Overcompounded D-C Generators in Parallel Without an Equalizer

To the Editor:

"Letters to the Editor" on the subject of "Overcompounded D-C Generators in Parallel Without an Equalizer" have appeared in ELECTRICAL ENGINEERING intermittently for the past 2 or 3 years. No unanimity of opinion is shown.

The question to be discussed may be fully stated as follows. If 2 overcompounded generators, driven by prime movers with drooping speed-load characteristics, are in momentarily stable parallel operation without an equalizer connection and the speed of one generator changes, which generator assumes a greater share of the load? I have investigated this question by carefully controlled experimental tests. Two points of the experimental procedure are very important. First, the temporary stable condition, without equalizer, may be produced in only one way: by putting the machines in parallel with an equalizer connection, adjusting the circuit constants until the current through the equalizer is zero, and then opening a switch in the equalizer. This switching was performed by 1 blade of a 2 pole switch, the second blade of which enforced a speed change on 1 of the prime movers (see *S*, figure 1). Secondly, it is essential that the speed of each generator be known accurately at every instant so that we will not confuse cause and effect; the first change in

Fig. 1. Connection diagram

G_1—Rated 5 kw, 125 volts, 40 amperes, 1450 rpm
G_2—Rated 4 kw, 125 volts, 32 amperes, 1350 rpm

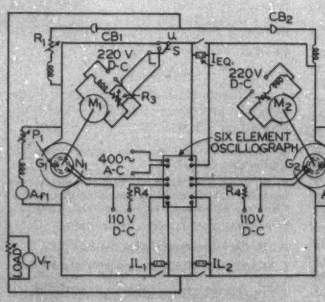
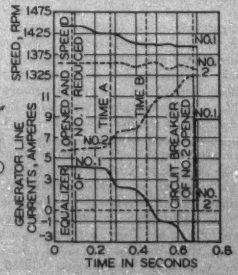


Fig. 2. Typical results of tests



speed is to be the *cause* and *not the result* of a change of load. The speed recording devices used (a 400 cycle wave and a shaft contact) gave an accurate value of speed for each single revolution of each generator.

The oscillograms taken by this method show the opening of the equalizer and the subsequent changes in speed and line current of each generator. Figure 2 shows typical results. Note that, as a *result* of lowered speed, generator 1 *drops* its load and finally shifts to motor operation. In over 100 tests, with various load divisions and with speed either increased or decreased, the results were entirely consistent; increased speed causes the generator to take more load and *vice versa*.

It is possible (*e. g.*, at time *A* or *B* of figure 2) to determine the rate of change of current in each generator circuit and to substitute these values with measured resistance and inductance in the Kirchhoff's loop equation involved. The checks are as close as could be expected and the experimental results thus check the theory.

The purpose of this study was to settle the controversy mentioned in the first paragraph. The following conclusions were reached.

1. The presentation of Prof. Harold Pender in his book "Direct Current Machinery" is contrary to both fact and theory. It should not be expected to be correct because it is the result of applying a steady state analysis to a transient condition.

2. The oscillograms given by Professor J. C. Brainerd (ELECTRICAL ENGINEERING, volume 51, Oct. 1932, page 745) in support of Professor Pender's view, are valueless because they fail to show when the transient condition began, and because the boundary condition of a change in relative speed of the generators was not enforced. Thus, his oscillograms show the incontrovertible fact that if a prime mover has a drooping speed characteristic, the generator has a drooping speed characteristic. The change of speed is the result and not the cause of the change of load.

3. Prof. O. W. Walter (ELECTRICAL ENGINEERING, volume 53, Nov. 1934, pages 1553–4) points out the correct theory.

4. The work of E. H. Nelson and Sidney Rock (ELECTRICAL ENGINEERING, volume 54, March 1935, pages 347–8) points out certain obvious results obtained by starting the transient condition while current is flowing in the equalizer connection and checks the oscillograms of Professor Brainerd with the definite admission that the speed change is the result and not the cause of the change in load division.

5. The letter of J. O. Reid (ELECTRICAL ENGINEERING, volume 54, March 1935, pages 348–9) gives a nicely worded, correct analysis of the problem, particularly in the statement, "If the transfer (of load) is the result of a momentary speed variation, this variation will be in the opposite direction from that resulting from the load transfer." In other words, the only dissenting opinions on this problem are due to a failure to differentiate between cause and effect. This failure causes improper experimental control and produces erroneous experimental results.

Very truly yours,

RICHARD R WHIPPLE (A'30)
Asst. Prof. of Elec. Engg.,
State Univ. of Iowa, Iowa City

Personal Items

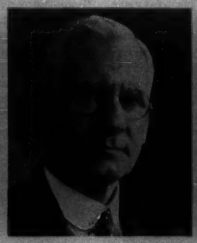
J. L. WILSON (A'25) assistant chief surveyor, American Bureau of Shipping, New York, N. Y., is chairman of the Institute's committee on applications to marine work, for the year 1935–36. Mr. Wilson was born May 29, 1894, at Elizabeth, N. J. After graduating from Webb Institute of Naval Architecture in 1914, he undertook postgraduate work in mechanical engineering at the Polytechnic Institute, New York. Previous to graduation he did work in connection with shipbuilding. After graduation, he became assistant editor of *Marine Engineering*. In 1915 he became a designer of submarines for the Lake Torpedo Boat Company, later undertaking aviation research in the U.S. Navy Department, Washington, D. C. He entered the scientific section of the New York Navy Yard in 1916, and during 1916–17 was chief engineer of the Talbot Boiler and Engine Corporation. He entered the employ of the American Bureau of Shipping in 1917, being at that time surveyor at Philadelphia, Pa. In 1920 he was transferred to the technical staff at New York, N. Y., and in 1926 was appointed to his present position as assistant chief surveyor. Mr. Wilson has for a number of years supervised all the electrical engineering work of the bureau, including the construction, installation, and maintenance of electrical apparatus on vessels of the Merchant Marine under the cognizance of the American Bureau of Shipping. The work also has involved modification of electrical standards for marine work. He has been active on a number of sectional committees relating to electrical installations on shipboard, and has been a member of the Institute's committee on applications to marine work since 1925.

C. F. SCOTT (A'92, F'25, HM'29, past-president and member for life) professor of electrical engineering emeritus, Yale University, New Haven, Conn., was elected chairman of the Engineers' Council for Professional Development at the third annual meeting of that body, held in New York, N. Y., October 8, 1935. Dr. Scott has been active on the E.C.P.D. since its inception, having been a member of its executive committee, as well as A.I.E.E. representative in the E.C.P.D. Dr. Scott, who rose to prominence in the Westinghouse Electric and Manufacturing Company during his term of service with that company from 1888 to 1911, and who since the latter year has been professor of electrical engineering at Yale University, has also had a long term of service with the Institute. He has served on many of its committees and other groups, contributed several technical papers to it, and served as its president 1902–03. He was instrumental in securing funds for the Engineering Societies Building in New York, N. Y., and was chairman of the building committee. A biographical sketch outlining Doctor Scott's career was given in the May 1934 (50th anniversary issue of ELECTRICAL ENGINEERING, page 795.

A. L. POWELL (A'13, F'26) supervising engineer, Atlantic division, Incandescent Lamp Department of the General Electric Company, New York, N. Y., is chairman for 1935–36 of the Institute's committee on production and application of light. Mr. Powell was born in Brooklyn, N. Y., April 6, 1889. Graduating from the school of electrical engineering of Columbia University in 1910, he entered the employ of the Edison Lamp Works, Harrison, N. J., that same year. After a year on the test course, he entered the commercial engineering department in 1911, later that year entering the lighting service department where he remained as first assistant to the illuminating engineer until 1924. During this period he was engaged in the design of lighting installations and equipment, tests, and experimental and research work. He also gave many lectures on lighting throughout the country, and was a frequent contributor of technical articles. During 1924–25 he was special representative in Europe, of the International General Electric Company, teaching and working with local lighting industries. He was a delegate of the U.S. Committee of the International Commission on Illumination at Geneva, 1924, and a member of the U.S. Commission to the Paris Exposition, 1925. In 1925, he became manager of the engineering department of the Edison Lamp Works at Harrison, N. J., and in 1932, was transferred to his present position. In the latter year, Mr. Powell made another trip to Europe to investigate lighting conditions, and in 1935 was a member of the United States delegation to the

J. L. WILSON

C. F. SCOTT



A. L. POWELL

meeting of the International Commission on Illumination held in Germany. Mr. Powell has served the Institute as a member of its board of examiners since 1929, and a member of the committee on production and application of light since 1933. He was president of the Illuminating Engineering Society, 1934–35, is now vice president of the Montclair (N. J.) Society of Engineers, is a member of the Architectural League, New York (N. Y.) Electrical Association, and Sigma Xi, and has served on many committees dealing with lighting.

F. H. HOLLISTER

C. T. SINCLAIR

T. F. BARTON

F. H. Hollister (A'08, M'30) chief electrical engineer, Sargent and Lundy, Inc., Chicago, Ill., is chairman of the Institute's committee on power generation for the year 1935–36. Mr. Hollister was born at Cambridge, N. Y., Oct. 5, 1882. After attending Northwestern University, he transferred to the University of Michigan, where he graduated in 1906 with the degree of bachelor of science in electrical engineering. Following graduation he entered the test department of the General Electric Company at Schenectady, N. Y., and spent 2 years each in the test, construction, and lighting engineering departments of the company. In 1912, he was transferred to the district engineer's office of the General Electric Company at Atlanta, Ga., where he remained for 4 years. In 1916, Mr. Hollister entered the employ of Sargent and Lundy, Inc., consulting engineers, Chicago, to specialize particularly in steam-electric power production design and associated engineering problems. In 1930, he was made chief electrical engineer and a director of Sargent and Lundy, Inc., having charge and supervision of the electrical department. Mr. Hollister has served the Institute as a member of the executive committee of the Chicago Section, and has been a member of the national committee on power generation since 1929.

T. F. Barton (A'12, M'18, F'30) district engineer, New York, (N. Y.) district, General Electric Company, is chairman of the Institute's committee on legislation affecting the engineering profession, for the year 1935–36. Mr. Barton was born at Orangeburg, S. C., December 25, 1885. He graduated from Clemson Agricultural College with the degree of bachelor of science in 1906, and a few years later received the degree of electrical engineer from that institution. Upon graduation in 1906, he entered the test department of the General Electric Company at Schenectady, N. Y., and has been employed by the General Electric Company continuously since that time. He was at first in the direct current engineering department at Schenectady, and in 1911 was transferred to the engineering department of the company's New York district. In 1917 he returned to Schenectady where he entered the central station engineering department, being section head in charge of application work in connection with power generating, transmission, and distribution systems. In 1927 he became engineer of the New York district, in charge of engineering for the state of New York, northern New Jersey, and western Connecticut. Mr. Barton has been particularly active in the Institute's New York Section, having been chairman of this Section 1932–33, and a member of its executive committee 1933–34. He also has served on 5 of the Institute's committees, the first being the membership committee 1917–18, at present is a member of 3 committees.

C. T. Sinclair (A'19, M'29) electrical engineer, Byllesby Engineering and Management Corporation, Pittsburgh, Pa., is chairman of the Institute's committee on power transmission and distribution for the year 1935–36. Mr. Sinclair was born in Towson, Maryland, December 16, 1894, and graduated from Lehigh University, 1917, with the degree of electrical engineer. Following brief employment with the Western Union Telegraph Company after graduation, he enlisted in the Field Artillery and was later commissioned in the corps of engineers of the U.S. Army. In 1919 he entered the employ of the Pennsylvania Water and Power Company at Holtwood, Pa., in their test department, and later in their operating department in Baltimore. In 1922 he went to New York, N. Y., with the United Electric Light and Power Company in charge of their planning division. He became assistant superintendent and later the superintendent of the transmission and distribution department of that company, in charge of the engineering, construction, and operation of the transmission and distribution system, including the pioneer low voltage a-c network system in New York City. In 1925 he went to Pittsburgh with the Philadelphia Company as assistant electrical engineer, responsible for the design of the transmission and distribution system. He later became electrical engineer for the Byllesby Engineering and Management Corporation in the same type of work. Mr. Sinclair has written numerous articles for the technical press and presented a number of papers before the Institute, largely on distribution subjects. He has been active in the Institute for a number of years, having been chairman of the subcommittee on distribution and vice-chairman of the committee on power transmission and distribution. He was a member of the executive committee of the Pittsburgh Section, chairman of several of its committees, and chairman of the Section in 1930–31. He has served as chairman of the underground systems committee of the National Electric Light Association and of the underground section of the transmission and distribution committee, Edison Electric Institute. He is a member of the sectional committee on wires and cables, American Standards Association, and is chairman or member of various committees of that association. He was editor-in-chief of the "Underground Systems Reference Book," issued in 1931 by the National Electric Light Association.

H. S. Warren (A'03, F'13) director of protection development, Bell Telephone Laboratories, Inc., New York, N. Y., is chairman of the Institute's committee on safety codes for 1935–36. He was born in Oldtown, Maine, and studied electrical engineering at Stanford University, graduating in 1898 with the degree of bachelor of arts. Immediately after, he entered the employ of the Standard Electric Company of California, making a study for a projected 50,000 volt transmission line from Amador County to San Francisco. His next work was with the California State Board of Harbor Commissioners, and in 1898, he took a position with the Nevada County Electric Power Company, Nevada City, Calif. In 1899, he began work with the American Bell Telephone Company (subsequently the American Telephone and Telegraph Company), in Boston, Mass., in connection with the commercial realization of the loaded-line principle, to which art he made many contributions. He also was in charge of divisions responsible for development work on equipment and on transmission and protection. More recently, Mr. Warren's work has been connected with problems of inductive co-ordination and protection. He has had an active part in all major inductive co-ordination problems of the Bell Telephone System involving electrified railways since his early work in connection with the single-phase electrification of the New Haven Railroad. The department of which he is now head is in charge of development work for the Bell System on this and other phases of inductive co-ordination. In 1912, he was instrumental in starting the pioneer investigations of the Joint Committee on Inductive Interference in California. He has been an active participant in the work of the Joint Subcommittee on Development and Research of the Edison Electric Institute and the Bell Telephone System, beginning with the formation of the subcommittee in 1923. He is at present Bell System chairman of the subcommittee. For many years he has had

charge in the Bell System of development work on electrolysis and on structural coordination. Mr. Warren acquired his present position in 1934, when the Bell Telephone Laboratories and the department of development and research of the American Telephone and Telegraph Company were consolidated. He has served the Institute as a member of its committee on safety codes since 1915, and on other committees.

T. D. Yensen (A'09, M'23) engineer in charge of the magnetic division of the research department of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been awarded the Henry Marion Howe medal by the American Society for Metals for a paper of which he was a co-author, on properties of iron, adjudged the best paper published in the *Transactions* of the society during 1934. Doctor Yensen is a native of Norway, and is a graduate of the University of Illinois, where he received the degrees of bachelor and master of electrical engineering and electrical engineer. In 1927 he received the degree of doctor of philosophy in physics at California Institute of Technology. A discovery credited to Doctor Yensen is "hypernik," a magnetic alloy of high permeability.

A. J. Althouse (A'11, M'29) assistant general manager, Metropolitan Edison Company, Reading, Pa., has been elected president of the Pennsylvania Electric Association. Mr. Althouse has been employed in various positions in Pennsylvania electric companies since 1906, having been employed at Bethel, Birdsboro, and Hamburg before becoming general superintendent of the Metropolitan Edison Company at Reading in 1925. In 1929 he was made assistant general manager. Mr. Althouse has been a member of the Pennsylvania Electric Association for 25 years, and recently served as a vice president. He is a past-chairman of the Lehigh Valley Section of the Institute.

F. B. Jewett (A'03, F'12, and past-president) vice president, American Telephone and Telegraph Company, New York, N. Y., has accepted the chairmanship of a committee on warning signals to lessen hazards of collisions at sea, formed by the Science Advisory Board. Doctor Jewett is at present serving the Institute as chairman of the Iwadare foundation committee, as a representative on the Hoover medal board of award, and as a member of the committees on the Lamme medal and on the code of principles of professional conduct, of which he is a former chairman.

H. S. WARREN

M. D. Engle (A'21, M'26) who has been assistant superintendent of the station engineering department of the Edison Electric Illuminating Company of Boston, Mass., has been appointed superintendent. Mr. Engle, a graduate of the University of Michigan, came to the company in 1925 as assistant superintendent, having previously been assistant to the electrical engineer of the Consolidated Gas, Electric Light and Power Company, Baltimore, Md., and assistant to the chief mechanical engineer with McClellan and Junkersfeld, consulting engineers at New York, N. Y.

James Burke (A'93, F'13, and member for life) whose retirement from the Burke Electric Company, Erie, Pa., was announced in Electrical Engineering for August 1935, page 913, has been elected president of the International Electrotechnical Commission. He has been a member of the United States National Committee of the commission for many years. He served on the committee as a representative of the National Electrical Manufacturers' Association from 1914 to 1930, and as a representative of the Institute from 1930 to 1932.

G. A. Riley (A'28, M'29) who since 1924 has been assistant superintendent of electric distribution of the Los Angeles Gas and Electric Corporation, Los Angeles, Calif., has been appointed superintendent. Mr. Riley graduated from the University of Illinois in 1904, and entered the employ of the company the following year. He became general foreman in the electric distribution department in 1919, holding this position until his appointment as assistant superintendent.

H. E. Dexter (A'14, M'17) general commercial manager, Central Hudson Gas and Electric Corporation, Poughkeepsie, N. Y., has been elected to the board of directors of the company. Mr. Dexter has been with the company since 1927, and has been responsible for the administration of the commercial and sales policies of the company, which have included a progressive plan of co-operation with appliance dealers.

H. C. Dean (A'12, F'30) vice president of the New York and Queens Electric Light and Power Company, Flushing, N. Y., has been elected a director of the company, and also a member of its executive committee. Mr. Dean has been a member of the Institute's board of examiners since 1933 and of the committee on legislation affecting the engineering profession since 1934, and was a member of the power transmission and distribution committee 1929–32.

C. W. Koiner (A'04, F'12) city manager of Pasadena, Calif., has been appointed a consulting engineer for the new power division of the Public Works Administration. He has had considerable experience in the management of electric plants, and is a former district manager of the Southern California Edison Company. Mr. Koiner, a past-president of the International City Managers Association, has been city manager of Pasadena since 1933, having previously served in this office from 1921 to 1925.

W. N. Clark (A'05) president, Southern Colorado Power Company, Pueblo, has been presented with a diamond studded medal chain by the Rocky Mountain Electrical Association. The award, established a year ago, is presented "for the most outstanding result or material contribution toward the advancement of the electrical industry by an individual or company in the Rocky Mountain region."

Harry Reid (A'22, F'31) president of Harry Reid and Company, Inc., New York, N. Y., is now with the Associated Gas and Electric Company, being engaged in operating management of that company, taking with him the staff of the company of which he has been head.

Roy Wilkins (A'16, F'29) former vice president in charge of manufacturing, Pacific Electric Manufacturing Corporation, San Francisco, Calif., is now with K. P. F. Electric Company, San Francisco. He served as a member of the Institute's committee on instruments and measurements 1923–24 and 1925–27.

F. T. Hicks (A'26) patent attorney for the Kelvinator Corporation who has been at Cleveland, Ohio, now has opened an office at Detroit, Mich., and is specializing in prosecutions before the United States Patent Office, of which he is a former member of the examining staff.

Gothard Sargl (A'17) former superintendent of construction for Stone and Webster Engineering Corporation, Boston, Mass., has engaged in a general contracting business at Beaumont, Tex. He was recently engaged on the construction of plants at Beaumont and Baton Rouge, La.

M. F. Brall (A'32) former assistant to chief engineer, Michigan Gas and Electric Company and Michigan Public Service Company, Holland, is now with the Timken Roller Bearing Company at Canton, Ohio.

R. D. Miller (M'32) former chief engineer in the Oregon area for The Pacific Telephone and Telegraph Company at Portland, Ore., has been made assistant vice president and is now at San Francisco, Calif.

E. L. Gaines (A'22, M'30) former traffic superintendent of the Home Telephone and Telegraph Company, Fort Wayne, Ind., has become sales engineer for the American Automatic Electric Sales Company, Chicago, Ill.

WHITWORTH FERGUSON (A'25, M'34) former vice president and electrical engineer of the Robertson Electric Construction Company, Buffalo, N. Y., is now associated with the Ferguson Electric Construction Company, Buffalo.

E. E. ALTHOUSE (A'28, M'34) who has been division distribution superintendent of the Central Hudson Gas and Electric Corporation at Poughkeepsie, N. Y., is now division operating superintendent at Kingston.

E. L. HOLMGREN (A'19) former transformer engineer with Westinghouse Electric and Manufacturing Company, Sharon, Pa., is now with the Kuhlman Electric Company, Bay City, Mich., as transformer design engineer.

E. J. VERRIER (A'28) formerly steam plant superintendent, Anglo-Newfoundland Development Company, Grand Falls, N. F., is now building superintendent and chief engineer at the Montreal General Hospital, Montreal, Can

E. B. WHITMAN (M'34) formerly with the West Penn Electric Company, Pittsburgh, Pa., recently engaged in consulting engineering with the firm of Whitman, Requardt and Smith, Baltimore, Md.

M. C. WINETSKY (A'25) recently with Empreza Forca e Luz de Ribeirao Preto, Campinas, Brazil, S. A., is now an engineering assistant with the Public Service Electric and Gas Company, Elizabeth, N. J.

CARL WHITMORE (A'18) former general manager of installation with the Western Electric Company, Inc., New York, N. Y., is now at Albany, N. Y., with the New York Telephone Company.

W. K. GRAVES (A'33) former relay inspector with the Potomac Electric Power Company, Washington, D. C., is now with the Cerro de Pasco Copper Corporation at La Oroya, Peru, S. A.

W. J. KENLINE (A'35) formerly employed by The Southern Sierras Power Company, El Centro, Calif., is now with the San Diego (Calif.) Consolidated Gas and Electric Company.

F. E. SWIFT (A'16, M'30) who has been with The McKinnon Industries, Ltd., St. Catherines, Ont., Can., is now with the Howell Electric Motors Company, Howell, Mich.

P. L. MORTON (A'33) recently employed by Ford, Bacon and Davis, Inc., at Seattle, Wash., is now employed in the meter department of the Puget Sound Power and Light Company, Seattle.

C. T. LINDSTROM (A'26) formerly with the Blaw-Knox Company, Pittsburgh, Pa., is now development engineer with American Cyanamid and Chemical Company, Bridgeville, Pa.

L. A. WHITSIT (M'19) former hydraulic engineer with United Engineers and Constructors, Inc., Philadelphia, Pa., is now principal engineer in the U.S. Engineers Office at Eastport, Me.

R. C. KEMP (A'31) former engineer in charge of electrical sales with Reginald Aitken, Kingston, Jamaica, W. I., has engaged in private practice as an electrical engineer.

H. R. NELSON (A'32) who has been employed by the Wisconsin Gas and Electric Company at Kenosha is now employed by the Waukesha Motor Company, Waukesha, Wis.

C. S. LUMLEY (A'23, M'29) former chief executive engineer of Longwood Towers Company, Brookline, Mass., is now with Smith, Hinchman and Grylls, Inc., Detroit, Mich.

S. O. COWAN (A'31) former manager of the Columbia Blue Print Company, Columbia, S. C., is now an assistant electrical engineer with Underwriters Laboratories, Inc., Chicago, Ill.

V. R. BACON (A'19) engineer formerly with United Engineers and Constructors, Inc., Philadelphia, Pa., is now with the American Gas and Electric Company, New York, N. Y.

C. N. RICE, JR. (A'28) former valuation engineer with Byllesby Engineering and Management Corporation, Chicago, Ill., is now with the Northern States Power Company at Eau Claire, Wis.

G. A. MILLS (M'18) former field executive of the Middle West Utilities Company, Chicago, Ill., is now at Lawrence, Kan., as executive vice president of The Kansas Electric Power Company.

G. W. BAKER (A'33) who has been an assistant in the department of electrical engineering at Columbia University, New York, N. Y., is now an engineer with Tung-Sol Radio Tubes, Inc., Newark, N. J.

H. A. CAMPBELL (A'35) who has been a technician with the Consolidated Aircraft Corporation at Buffalo, N. Y., is now in the engineering department of the corporation at San Diego, Calif.

P. A. ROBERT (A'35) former serviceman at New York, N. Y., for International Business Machines Corporation, is now in the Company's educational department at Endicott, N. Y.

E. E. STEINERT (A'30) formerly with the General Electric Company at Schenectady, N. Y., is now an electrical engineer in the bureau of engineering of the U.S. Navy Department at Washington, D. C.

A. E. TORRANCE (A'34) formerly in the electricity department of the city of Port Elizabeth, South Africa, is now in the engineering department of Johnson and Phillips at Johannesburg.

J. C. MCCLUNG (A'28) former foreman in the underground distribution department of the Los Angeles Gas and Electric Corporation, Los Angeles, Calif., has been made overhead electrical engineer.

R. U. BERRY (A'29) air conditioning department, General Electric Company, Bloomfield, N. J., has been placed in charge of special applications in the recent consolidation of all divisions of the department.

A. W. ROBERTSON (A'27) chairman of the board, Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa., has been elected president of the Electrical Manufacturers Club.

D. G. EVANS (A'20) electrical engineer, Wisconsin Gas and Electric Company, Racine, has been appointed assistant manager. He has been with the company since 1919.

K. J. GRANBOIS (A'31) formerly with the Pennsylvania Water and Power Company at Holtwood, is now test engineer for the Safe Harbor Water Power Corporation at Safe Harbor, Pa.

F. M. RYAN (A'19, M'26) Bell Telephone Laboratories, Inc., New York, N. Y., has been asked to serve on a radio technical committee for aeronautics recently organized by the U.S. Department of Commerce.

J. A. ROSEBOROUGH (A'34) recently with Continental Can Company of California, Oakland, has become chief engineer of radio station KRE, Berkeley, Calif.

W. D. WEIDLEIN (A'31, M'32) consulting engineer formerly with Black and Veatch, Kansas City, Mo., is now with Wm. D. Weidlein and Company at Kansas City.

L. F. PRIES (A'33) formerly with the Colonial Radio Corporation, Buffalo, N. Y., is now with the Wurlitzer Grand Piano Company, De Kalb, Ill.

F. S. HIMEBROOK (A'32) recently with the Master Electric Company, Dayton, Ohio, has accepted a position with The Hoover Company, North Canton, Ohio.

R. J. WEESNER (A'35) formerly with the Taylor-Winfield Corporation, Warren, Ohio, is now employed by the American Sheet and Tin Plate Company at Gary, Ind.

P. W. KUHLMAN (A'33) is now in the communication department of the Air Corps Technical School, Chanute Field, Rantoul, Ill.

C. A. SCHNEIDER (A'04, M'13) engineer with Ford, Bacon and Davis, Inc., has been transferred from Seattle, Wash., to New York, N. Y.

R. M. HULL (A'26, M'32) division distribution engineer, Pennsylvania Power and Light Company, has been transferred from Allentown to Harrisburg.

T. M. Hauer (A'22) engineer formerly with the Empire Management Company, Philadelphia, Pa., is now with the Central Ohio Light and Power Company at Findlay.

J. E. Millikan (A'34) is now employed in the sales department of the Ideal Electric and Manufacturing Company, Mansfield, Ohio.

L. H. Ruhlen (A'34) electrician formerly with Libbey-Owens Ford Glass Company, Toledo, Ohio, is now with the Interlake Iron Company, Toledo.

Richard Smith (A'35) former meterman at Wewoka for the Oklahoma Gas and Electric Company is now in the commercial department at Shawnee.

C. K. Beyette (A'34) former student engineer with the Texas Electric Service Company at Eastland is now district operator at Wichita Falls.

E. A. Skonberg (A'30) formerly with the Ekholm Corporation, Boston, Mass., is now with the Mengel Body Company, Louisville, Ky.

J. W. Davis (A'33) division plant engineer of the Southern Bell Telephone and Telegraph Company who has been at Atlanta, Ga., is now at Jackson, Miss.

G. M. Babcock (A'26) former assistant foreman for the Los Angeles Gas and Electric Corporation, Los Angeles, Calif., has been made electrical protection engineer.

C. E. Parks, Jr. (A'34) has been transferred from substation operation to relay maintenance in the Public Service Company of Indiana, Greenwood.

W. P. Bear (M'22) is now a sales engineer in the general sales department of the Pacific Gas and Electric Company, San Francisco, Calif.

K. M. Klein (A'35) formerly an inspector, Oregon State Highway Commission, Waldport, is now resident bridge engineer at Salem.

H. A. Tankersley (A'30) former student engineer with the Texas Power and Light Company at Hillsboro is now district dispatcher at Temple.

P. B. Taylor (A'25, M'34) who has been at Washington, D. C., is now in the aircraft radio laboratory at Wright Field, Dayton, Ohio.

E. A. Moyle (A'26) recently with S. W. Scales Electric Company, Greenville, Tex., is again with the Texas Power and Light Company, Dallas.

E. O. Lunn (A'32) recently with Bradian Mines, Ltd., Bralorne, B. C., Can., is now an engineer with Peterson and Cowan Elevator Company, Ltd., Vancouver.

V. G. Dodds (A'26) Aluminum Company of America, recently was transferred from Albany, N. Y., to San Francisco, Calif.

P. C. Clark (A'23) recently became field engineer for A. T. Jergins Trust, oil producers at Bakersfield, Calif.

R. C. Thorn (A'34) of Tutbury, England, is now at Columbo, Ceylon, India, with the Columbo Commercial Company.

Kurt Schornfeld (A'31) is now an engineer with the Kurman Electric Company, New York, N. Y.

L. J. Mulbach (A'28) is now employed as machine designer by E. W. Bliss Manufacturing Company, Salem, Ohio.

M. W. Smedburg (A'33) is now employed by the Rural Electrification Administration at Washington, D. C.

R. J. McGonegle (A'34) is now connected with the Michigan Electric Power Company at Lapier.

W. G. Eschmann (A'26) is now employed as aeronautical engineer by Glenn L. Martin Company, Middle River, Md.

E. A. Freedman (A'34) is now in the construction department of the Consolidated Gas Company, New York, N. Y.

Thomas Howells, Jr. (A'31) is now an electrician with the Stanton Operating Company, Pittston, Pa.

C. R. Isbminger (A'30) is now an engineer in the rectifier section of the Union Switch and Signal Company, Swissvale, Pa.

E. E. Piepho (A'27) is now an electrical engineer with the Detroit Edison Company, Detroit, Mich.

Harry Wilkie (A'30) is now an assistant radio engineer with the Signal Corps at Fort Sam Houston, San Antonio, Tex.

W. H. Treadway (A'34) is now assistant electrical engineer with the Illinois Commerce Commission, Springfield.

E. B. Etchells (A'33) is now employed by General Motors Research, Detroit, Mich., as project engineer.

C. E. Houston (A'32) is now in the geophysics department of the Humble Oil Company at Houston, Tex.

F. J. Safford (A'35) is now enrolled in the training course of the Harnischfeger Corporation at Milwaukee, Wis.

H. H. Hayes (A'33) has been appointed a junior engineer for the Works Progress Administration at Pierre, S. D.

F. W. Suhr (A'32) is now employed by the Wisconsin Hydro-Electric Company at Amery.

Obituary

Joseph Allen Johnson (A'07, F'27, and junior past-president) chief electrical engineer, Buffalo, Niagara and Eastern Power Corporation, Buffalo, N. Y., died October 4, 1935. Mr. Johnson was born at Northboro, Mass., June 21, 1882. Following graduation from the Worcester Polytechnic Institute in 1905, he was employed by the Ontario Power Company at Niagara Falls, and was appointed electrical engineer in 1912; when this company was purchased by the Hydro-Electric Power Commission of Ontario in 1917, Mr. Johnson became assistant engineer. In 1918 he was appointed electrical engineer of the Cliff Electrical Distributing Company, Niagara Falls, N. Y., which in a consolidation later that same year with the Hydraulic Power Company and the old Niagara Falls Power Company into The Niagara Falls Power Company, became electrical engineer of the enlarged company. In this capacity he was responsible for many important features of the electrical design of the Niagara development during the period of their rapid growth from 1918 to 1924. In 1929, he was appointed chief electrical engineer of the Buffalo, Niagara and Eastern Power Corporation, which position he held until the time of his death. Perhaps the most important of the many developments in the art of power generation and transmission in which Mr. Johnson took a prominent part was that of the system of generator voltage control by individual regulators, which he originated and pioneered in the plant of the Ontario Power Company about 1910, and which he described in a technical paper shortly thereafter. His contributions to the art of generator testing by means of the retardation method are also well known. Mr. Johnson had contributed to the Institute several important papers. In 1933 he received the A.I.E.E. national prize for best paper in engineering practice, and in 1934, with his co-author, again received this prize. Mr. Johnson began his term of service with the Institute when he became first chairman of the Student Branch at Worcester Polytechnic Institute in 1905. He was also organizer and first chairman of the Niagara Frontier Section, serving as chairman 1925–26. Mr. Johnson had served the Institute on a large number of its committees. He had been a director of the Institute 1928–32, vice president 1932–34, and president 1934–35. He had served as Institute representative on other organizations, including among these American Engineering Council. He also was active on the technical committees of the Edison Electric Institute, and was a member of the American Association for the Advancement of Science and of the Electrical Standards Committee of the American Standards Association. One of the last honors which Mr. Johnson received was the honorary degree of doctor of engineering which was conferred upon him by Worcester Polytechnic Institute, June 14, 1935. In his absence, caused by illness, the diploma and doctor's hood were received for him by his son, a member of the graduating class. The citation for Mr. Johnson's degree was, in part: "A leader in the development and applica-

tion of electrical energy from Niagara Falls, he has for years directed power production at that grand center. From a humble private in the army of electrical engineers . . . he has risen to high command, to be an authority in his chosen field . . . ." Resolutions adopted by the Institute's board of directors at its meeting on October 22, 1935, commemorating Mr. Johnson's career, are given on page 1274 of this issue.

SAMUEL REYNOLDS PRITCHARD (M'13) professor of electrical engineering at Virginia Polytechnic Institute, Blacksburg, died September 30, 1935. Doctor Pritchard was born at Bascombville, S. C., October 30, 1863, and received the degrees of bachelor of arts and master of arts from South Carolina University in 1885 and 1889, respectively. He served for a time as instructor at the university and at Wofford College, Spartanburg, S. C., and in 1893 became head of the department of electrical engineering at Virginia Polytechnic Institute, serving as dean of the college of engineering for the past 10 years. Doctor Pritchard was also a member of the American Association for the Advancement of Science and of the Society for the Promotion of Engineering Education.

SAMUEL DUNLAP COLLETT (A'96, and member for life) retired, Brooklyn, N. Y., died recently. He was born at Newport, Ind., October 25, 1868, and received the degree of bachelor of science in mechanical and electrical engineering at Rose Polytechnic Institute in 1890. The following year he received a bachelor of science degree in civil engineering, and in 1894 the degree of master of science. In 1891 he became connected with Thomson-Houston Electric Company, being assigned to several branch offices, and in 1897 became eastern manager for the Elevator Supply and Repair Company, New York, N. Y. Later he was with the Elevator Supplies Company, Inc., at Hoboken, N. J.

LOUIS G. CARPENTER (M'28) consulting engineer, Denver, Colo., died September 12, 1935. He was born at Orion, Mich., March 28, 1861, and was graduated from the University of Michigan in 1879, later taking graduate studies there and at The Johns Hopkins University. In 1888 he became professor of physics and engineering at Colorado State Agricultural College, later becoming professor of engineering and director of the experiment station. In 1911 he engaged in a consulting practice, principally in matters relating to hydraulics. He served as state engineer for Colorado during 1903–05, and undertook considerable work in foreign countries in his consulting practice.

CLARENCE FREDERICK NORBERG (A'28), head of the service department of The Washington Water Power Company, Spokane, died August 31, 1935, as the result of injuries received in an automobile accident. He was born at Kenora, Ont., Can., June 14, 1903, and graduated from the University of Washington in 1926 with the degree of bachelor of science in electrical engineering. Following graduation he was employed in the engineering department of The Washington Water Power Company, and in 1931 joined the service department, of which he became head in 1934.

JAMES CLARK, JR. (A'10, M'28) president, James Clark, Jr., Electric Company, Louisville, Ky., died October 9, 1935. He was born August 29, 1869, and was graduated from the electrical engineering course at Massachusetts Institute of Technology in 1890. Two years later he engaged in business as a manufacturer of electrically driven tools, motors, and generators. He served as a member of the Institute's committee on general power applications during the period 1930–34, and was a member of a number of other organizations.

SHANKER SADASHIV TATREY (A'32) electrical engineer, Belgaum Electricity Company, Ltd., Belgaum, Bombay, India, died August 9, 1935. He was born at Navasari, Bombay, June 30, 1890, and was graduated from the Victoria Jubilee Technical Institute, Bombay, in 1917. He had since been employed by a number of electrical companies in India, designing and constructing several distribution systems.

Membership

Recommended for Transfer

The board of examiners, at its meetings held September 25 and October 26, 1935, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Sleeman, Hector, chief engr., Rangoon Elec. Tramway & Supply Co. Ltd., Rahgoon, Burma, India.
Tate, Thomas R., director, National Pwr. Survey, Federal Pwr. Comm., Washington, D. C.
Williams, Allison R., rate specialist, Elec. Rate Survey, Federal Pwr. Comm., Washington, D. C.

3 to Grade of Fellow

To Grade of Member

Amsden, Burton R., Elec. Rate Survey, Federal Pwr. Comm., Washington, D. C.
Atlas, Louis, asst. engr., Brooklyn Edison Co., Brooklyn, N. Y.
Bailey, J. F., div. mgr., Fla. Pwr. Corp., Ocala.
Davis, R. L., cons. engr., Grand Rapid, Mich.
deKay, R. D., member of technical staff, Bell Tel. Labs., Inc., New York, N. Y.
Eastom, Frank A., assoc. prof. of E.E., Univ. of Colo., Boulder.
Faucett, M. A., associate in E.E., Univ. of Ill., Urbana.
Fletemeyer, Louis H., Jr., power engr., R & H Chemicals Dept., E. I. du Pont de Nemours & Co. Inc., Niagara Falls, N. Y.
Goldner, Henry A., equipment maintenance engg., Amer. Tel. & Tel. Co., New York, N. Y.
Gordon, Walter S., Jr., gen. foreman catenary constr., Pennsylvania R.R. Co., Baltimore, Md.
Hanners, William H., outside plant facilities engr., Amer. Tel. & Tel. Co., New York, N. Y.
Harrell, Frederick E., asst. chief engr., Reliance Elec. & Engg. Co., Cleveland, O.
Heafer, Harold F., div. plant engr., Southwestern Bell Tel. Co., Houston, Tex.
Herring, Edgar J. C., director and gen. mgr., Jost's Engg. Co. Ltd., Bombay, India.
Ienger, N. N., E.E., Tata Hydro Electric Companies, Bombay House, Fort Bombay, India.
Jenkins, Paul R., div. equipment engr., Amer. Tel. & Tel. Co., Denver, Colo.
Kirkwood, Arthur C., assoc. engr., Burns & McDonnell Engg. Co., Kansas City, Mo.
Lewis, F. A., asst. editor, A.I.E.E., New York.
Lindvall, F. C., asst. prof. of E.E., Calif. Inst. of Tech., Pasadena.
Malan, Stephanus A., E.E., Electricity Supply Commission, Johannesburg, So. Africa.
Meador, Barclay F., asst. to chief engr., Elec. Assignments, Great Lakes Pipe Line Co., Kansas City, Mo.
McKinley, John L., gen. engr., Public Service Co., of Colo., Denver.
Moody, Dwight L., dial toll switching engr., Bell Tel. Labs., Inc., New York, N. Y.
Page, Harold F., div. transmission engr., Amer. Tel. & Tel. Co., Chicago, Ill.
Palmer, H. B., assoc. prof. of E.E., Univ. of Colo., Boulder.
Peirce, W. T., chief E.E., Am. Steel & Wire Co., Worcester, Mass.
Rights, H. T., E.E., in charge of oscillograph design, Westinghouse Elec. & Mfg. Co., Newark, N. J.
Riley, James R., tel. engr., N. Y. Telephone Co., New York.
Schnure, Fred O., elec. supt., Bethlehem Steel Co., Sparrows Point, Md.
Schurch, E. C., E.E., U.S. Bureau of Reclamation, Denver, Colo.
Torok, Julius J., E.E., Corning Glass Works, Corning, N. Y.
Wiewall, Miguel J., instructor in E.E. and physics, Univ. of Porto Rico, Mayaguez, P. R.
Wilcox, Bertram W., statistical dept., Buffalo, Niagara & Eastern Pwr. Corp., Buffalo, N. Y.
Wilson, Richard I., engr., Habirshaw Wire & Cable Co., New York, N. Y.
Wyman, M. B., mgr., engg. dept., Westinghouse Elec. & Mfg. Co., St. Louis, Mo.
Young, H. P., head, elec. pwr. & machy. section, The Polytechnic, London, Eng.

36 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before Nov. 30, 1935, or Jan. 31, 1936, if the applicant resides outside of the United States or Canada.

Baker, R. M., Westinghouse E. & M. Co., E. Pittsburgh, Pa.
Barnes, D. M., Associated Telephone Co. Ltd., Long Beach, Calif.
Birge, K. R., 302 City Hall Bldg., Pasadena, Calif.
Brown, D. L., Portland Gen. Elec. Co., Ore.
Burns, A. E., Pacific Tel. & Tel. Co., San Francisco, Calif.
Burrell, R. W., N. Y. & Queens Elec. Lt. & Pwr. Co., Flushing, N. Y.
Carpenter, A. G., Jr. (Member), Federal Power Comm., Washington, D. C.
Challgren, C. F., National Sugar Refining Co., Long Island City, N. Y.
Crawford, C. H., Gen. Elec. Co., Schenectady, N. Y.
DeNagy, B. (Member), Gibbs & Hill, New York, N. Y.
Eastin, M. R., Harmon Elec. Shops, Harmon-on-Hudson, N. Y.
Engel, E. D., Univ. of Wash., Seattle.
Evans, F. E. (Member), 8577—98th St., Woodhaven, L. I., N. Y.
Evans, J. L., Metropolitan Edison Co., Reading, Pa.
Finlaw, J., Phila. Elec. Co., Pa.
Friedman, A., Elec. Generator & Motor Co., Cleveland, Ohio.
Geddes, G., Buffalo Gen. Elec. Co., N. Y.
Gettinger, R. F. (Member), Westinghouse Elec. & Mfg. Co., St. Louis, Mo.
Gibbons, J. P., Goodman Mfg. Co., Chicago, Ill.
Gidlund, H. F., Pub. Serv. Co. of Colo., Denver.
Giesecke, H. W., 306 W. 109th St., New York, N. Y.
Gleichman, R. C., Federal Pwr. Comm., Washington, D. C.
Grane, M. M., 194 West 4th St., New York, N. Y.
Guseck, F., Canadian Lt. & Pwr. Co., Montreal, Que., Can.
Haefner, S. J., Union Col., Schenectady, N. Y.
Hamlin, E. W., Univ. of Kan., Lawrence.
Hammerstrom, A. P., Westinghouse Elec. & Mfg. Co., St. Louis, Mo.

Harvey, A. J., Jr., 2627 Idlewood Rd., Cleveland, Ohio.
Hierath, D. C., Gen. Elec. Co., New York, N. Y.
Johnson, C. H. (Member), Idaho Maryland Mines Co., Grass Valley, Calif.
Keever, L. M., N. C. State Col., Raleigh.
Kipp, E. B., Westinghouse Elec. & Mfg. Co., Los Angeles, Calif.
Koerner, C. T., Mackay Radio & Telegraph Co., New York, N. Y.
Kuenzler, E. A., Bell Tel. Lab., Inc., New York, N. Y.
Lord, H. W., General Elec. Co., Schenectady, N. Y.
Martin, J. R., Case Sch. of Applied Sci., Cleveland, O.
Martinez de la Terre, A. M., Cayey Hydro Elec. Plant, Cayey, Puerto Rico.
McMurray, W. K., St. Joseph Ry., Lt., Ht. & Pwr. Co., Mo.
Meadows, C. W., Brooklyn Edison Co., Inc., Brooklyn, N. Y.
Meyer, L. W., Federal Pwr. Comm., Washington, D. C.
Miller, A. A., Buffalo Gen. Elec. Co., N. Y.
Montgomery, E. G. (Member), Am. Tel. & Tel. Co., New York, N. Y.
Montgomery, L. McD., Okla. Gas & Elec. Co., Shawnee.
Mosman, C. R. (Member), Am. Tel. & Tel. Co., Chicago, Ill.
Neiman, W. E., N. Y. C. Pwr. Survey, New York, N. Y.
Ozment, K. J., Camp Twanoh, Belfair, Wash.
Paul, R. D. (Gibbs & Hill), New York, N. Y.
Peterson, C. H., N. Y. Tel. Co., New York, N. Y.
Peterson, R. M. (Member), Am. Tel. & Tel. Co., New York, N. Y.
Prentice, B. R., Gen. Elec. Co., Schenectady, N. Y.
Quarles, L. R., Univ. of Va., University.
Raps, F. J. (Member), Buffalo Gen. Elec. Co., N. Y.
Rees, M. M., Union Oil Co., Oleum, Calif.
Rinke, A., Brooklyn Edison Co., Inc., Brooklyn, N. Y.
Ritchie, D. R., 1518 Addison St., Berkeley, Calif.
Roddy, F. T., Minnesota Utilities Co., Minneapolis.
Roll, E. P., Jr. (Member), Federal Power Comm., Washington, D. C.
Schindler, R. W., 4106 Spokane Ave., Cleveland, Ohio.
Schmidt, H. R., 345 Adelphi St., Brooklyn, N. Y.
Scott, J. P., Union Elec. Lt. & Pwr. Co., St. Louis, Mo.
Sills, A. L., Federal Pwr. Comm., Washington, D. C.
Simmons, L. C., Harmon Electric Shops, Harmon, N. Y.
Sinclair, J. H., 400-2 Public Bldg., Regina, Sask., Can.
Smith, R. W., Robbins & Myers Inc., Springfield, Ohio.
Stockwell, G. A., Los Angeles Bureau of Pwr. & Lt., Calif.
Taugher, F. P., Westinghouse Elec. & Mfg. Co., St. Louis, Mo.
Thompson, C. St. C., Western Union Telegraph Co., New York, N. Y.
Toltesey, P. J., Brooklyn Edison Co., Inc., Brooklyn, N. Y.
Trekell, H. B., General Elec. Co., W. Lynn, Mass.
Wilder, G. L., Locke Insulator Corp., Salt Lake City, Utah.

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Foreign

Milner, R. C., Macintosh Cable Co. Ltd., Derby, England.
Minchin, C. W. H., Mawdsley's Ltd., Dursley, Gloucester, Eng.
Mukerjee, G. C. (Member), Hindu Univ., Benares, India.

3 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as it now appears on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Bruce, Otto, 214 White St., Waverly, Mass.
Chiofalo, J., 203 Graham Ave., Brooklyn, N. Y.
Crite, Mitchel, 32 E. 126th St., New York, N. Y.
Ghosh, K. C., c/o Compagnia Generale Di Elettricita, 34 Via Borgognone, Milan, Italy.
Golikoff, A., Main P. O. Gen. Del., Moscow, U. S. S. R.
Kimball, Gordon S., 154 Elmer Ave., Schenectady, N. Y.
Nelson, Charles J., 1515 N. Lotus Ave., Chicago, Ill.
Roselle, P. M., 2018 Chestnut St., Harrisburg, Pa.
Soskin, Samuel B., 1141 S. Central Park, Chicago, Ill.
Spiegel, William F., 7 Stegman Court, Jersey City, N. J.
Vance, Paul E., c/o Marietta Mfg. Co., Point Pleasant, W. Va.
Whittemore, Geo. W., 151 Ridgewood Ave., Glenwood, N. J.

12 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

BOSCH KRAFTFAHRTECHNISCHES TASCHENBUCH. 4ed. of "Technischen Tabellen." Stuttgart, Robert Bosch A.G.; Berlin, VDI-Verlag, 1935. 6x4 in. lea., 2.50 rm. A pocketbook containing a well-chosen collection of data for the automotive engineer. Includes physical, electrical, chemical, and mechanical data, information about fuels, lubricants, internal-combustion engines, electrical equipment for automobiles and aircraft, and general data on racing records, etc.

FUNDAMENTALS of INDUSTRIAL MARKETING. By R. F. Elder. N. Y. and Lond., McGraw-Hill Book Co., 1935. 317 p., illus., 9x6 in., cloth, $3.00. An attempt to present comprehensively the problems connected with the marketing of goods used in manufacture or trade.

ELEMENTS of ELECTRICAL ENGINEERING, a Textbook of Principles and Practice. By A. L. Cook. 3 ed. N. Y., John Wiley & Sons, 1935. 603 p., illus., 9x6 in., lea., $4.00. A textbook dealing with the fundamentals and their application in practice, intended for an introductory course for engineering students.

FANS. By T. Baumeister. N. Y. and Lond., McGraw-Hill Book Co., 1935. 241 p., illus., 9x6 in., cloth, $3.50. A book to assist the fan user in the selection of the best equipment for any given service conditions. Chapters are devoted to design and testing, and to the flow of fluids.

GENERATING STATIONS, Economic Elements of Electrical Design. By A. H. Lovell. 2 ed. N. Y. and Lond., McGraw-Hill Book Co., 1935. 438 p., illus., 9x6 in., $4.50. Describes the application of economic principles to the problems of the design of generating stations and transmission systems. The selection of apparatus, the proportioning of details of the assembly, the balancing of initial and subsequent costs, and related topics are considered. The new edition has been revised in the light of recent developments.

HEATING and AIR CONDITIONING. By J. R. Allen and J. H. Walker. 4 ed. N. Y. and Lond., McGraw-Hill Book Co., 1935. 444 p., illus., 9x6 in., cloth, $4.00. A comprehensive account of fundamental principles and working methods, intended as a text for students.

INTRODUCTION to QUANTUM MECHANICS. By L. Pauling and E. B. Wilson. N. Y. and Lond., McGraw-Hill Book Co., 1935. 468 p., illus., 9x6 in., cloth, $5.00. A textbook of practical quantum mechanics for chemists, experimental physicists, and beginning students of theoretical physics.

Die KRITISCHEN DREHZAHLEN WICHTIGER ROTORFORMEN. By K. Karas. Vienna, Julius Springer, 1935. 154 p., illus., 10x7 in., paper, 18 rm. Derivation of methods and formulas to calculate the critical speeds of rotors with more exactness than is obtainable by the usual graphical methods.

MECHANICAL and ELECTRICAL EQUIPMENT for BUILDINGS. By C. M. Gay and C. D. Fawcett. N. Y., John Wiley & Sons; Lond., Chapman & Hall, 1935. 429 p., illus., 9x6 in., $5.00. The essentials of building equipment, embracing statements of the fundamental theories involved and their broad applications, but not covering the engineering design.

NEON SIGNS, Manufacture, Installation, Maintenance. By S. C. Miller and D. G. Fink. N. Y. and Lond., McGraw-Hill Book Co., 1935. 288 p., illus., 9x6 in., cloth, $3.00. A practical description of the manufacture, installation, and maintenance of these signs.

NOISE, a Comprehensive Survey From Every Point of View. By N. W. McLachlan, with a foreword by Sir Henry Fowler. Lond., Oxford Univ. Press, 1935. 148 p., illus., 7x5 in., cloth, $2.25. An introduction to the subject for both lay and technical readers interested in the prevention of noise.

PLANE and SPHERICAL TRIGONOMETRY. By L. M. Kells, W. F. Kern, and J. R. Bland. N. Y. and Lond., McGraw-Hill Book Co., 1935. 269 p., illus., 9x6 in., cloth, $2.50. A textbook to present the subject simply and comprehensively.

PRINCIPLES of EXPERIMENTAL and THEORETICAL ELECTROCHEMISTRY. By M. Dole. N. Y. and Lond., McGraw-Hill Book Co., 1935. 549 p., illus., 8x6 in., cloth, $5.00. A book intended for graduate students with a grounding in physical chemistry.

DIESEL LOCOMOTIVES & RAILCARS. By B. Reed. Lond., Locomotive Pub. Co., 1935. 190 p., illus., 9x6 in., cloth, 6s. A review of the present situation in the development of Diesel rolling stock in America and Europe, including data on costs, efficiencies, etc.

MEASUREMENTS in RADIO ENGINEERING. By F. E. Terman. N. Y. and Lond., McGraw-Hill Book Co., 1935. 400 p., illus., 9x6 in., cloth, $4.00. A comprehensive engineering discussion of the measuring problems commonly encountered by radio engineers, intended to serve the practicing engineer and the student.

PHOTO-ELECTRIC and SELENIUM CELLS, Their Operation, Construction and Uses. By T. J. Fielding. Lond., Chapman & Hall, 1935. 140 p., illus., 8x5 in., cloth, 6s. An elementary presentation of the subject intended for beginners and amateur experimenters interested in the construction and uses of light sensitive cells.

POWER OPERATOR'S GUIDE (1001 Practical Helps), a Compilation of Ideas, Methods, and Tools for Saving Time, Labor, and Money in the Power Plant and Along the Line of Power Services. Compiled and edited by E. J. Tangerman. N. Y. and Lond., McGraw-Hill Book Co., 1935. 548 p., illus., 9x6 in., cloth, $4.00. A compilation of practical hints upon the operation and maintenance of power plant machinery, chosen from *Power*.

PRACTICAL RADIO COMMUNICATION, Principles, Systems, Equipment, Operation, including Short-Wave and Ultra-short-wave Radio. By A. R. Nilson and J. L. Hornung. N. Y. and Lond., McGraw-Hill Book Co., 1935. 754 p., illus., 9x6 in., lea., $5.00. A textbook designed for those preparing for licenses as radio operators.

PUBLIC UTILITY QUESTION. By H. G. Hendricks. Pub. by author at 5629 Kansas Ave., Washington, D. C.; on sale Amer. News Co., 131 Varick St., New York, 1935. 148 p., tables, 8x5 in., cloth, $2.00. Discussion by a former member of the staff of the house committee on interstate and foreign commerce of the part played by the holding company in the public utility industry.

REPORTS on PROGRESS in PHYSICS. Lond., The Physical Society; printed at the University Press, Cambridge, 1934. 371 p., illus., 10x7 in., cloth, 12s6d. Detailed accounts of recent advances in physics up to the end of 1933, prepared by specialists in the various fields.

STORY of RADIO. By O. E. Dunlap, Jr. N. Y., Dial Press, 1935. 326 p., illus., 9x6 in., cloth, $2.75. A popular history of the development of radio, from the work of Maxwell and Hertz to television.

Engineering Societies Library

29 West 39th Street, New York, N. Y.

MAINTAINED as a public reference library of engineering and the allied sciences, this library is a cooperative activity of the national societies of civil, electrical, mechanical, and mining engineers.

Resources of the library are available also to those unable to visit it in person. Lists of references, copies or translation of articles, and similar assistance may be obtained upon written application, subject only to charges sufficient to cover the cost of the work required.

A collection of modern technical books is available to any member residing in North America at a rental rate of five cents per day per volume, plus transportation charges.

Many other services are obtainable and an inquiry to the director of the library will bring information concerning them.

Industrial Notes

Increased Sales for General Electric.—Orders received by the General Electric Co., for the third quarter of 1935 amounted to $54,400,819, compared with $40,458,901 for the third quarter of 1934, an increase of 34%. Orders received for the nine months amounted to $158,943,765, compared with $132,613,543 for the first nine months of last year, an increase of 20%.

High-Output Photronic Cell.—A photoelectric cell of the "dry-plate" type which provides an increased current output has been developed by the Weston Instrument Corp., Newark, N. J. Known as the type 2 photronic cell, it is intended primarily for use at levels of illumination so low that the regular photronic cell will not provide sufficient output for the purposes intended. Current output of the new cell is about 3 times that of the regular photronic cell for the same illumination.

New High Voltage Switch.—The Delta-Star Electric Co., Chicago, Ill., announces its "FMR-239" motor or manually operated, balanced-blade disconnecting switch for inverted mounting. There are three stacks of insulators per pole, two of which rotate, one raising and lowering the blade, the other rotating a contact which engages the forked end of the main blade. In operation, the contact entirely releases before the blade is removed, thus reducing cantilever stresses to a minimum. The new switch is available in voltages from 115 to 287 kilovolts, and in capacities up to 1,200 amperes.

New Portable Test Units.—The Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa., announces a new line of compact lightweight portable volt-ohmmeters and test units, suitable for general testing, laboratory and radio work. The volt-ohmmeter is particularly useful for exploration and trouble shooting in complex circuits such as radios, public speech amplifiers, signal systems, control systems and other applications where a detailed knowledge of circuit conditions and values must be obtained. Several types are available including simple ohmmeters, volt-ohmmeters, d-c test units and the more elaborate multi-scale a-c and d-c test units. The instruments weigh approximately 2 pounds, have a 2.4 inch scale length, an accuracy within 2% for d-c volts and milliamperes and within 5% for alternating current.

Tin Consumption Increases.—According to the October issue of the Bulletin of the International Tin Research and Development Council published by The Hague statistical office, the world's apparent consumption of tin during the first eight months of the current year totaled 90,910 tons, showing an increase of 11,692 tons, or 14.8%, compared with the corresponding period of 1934. The total production of tin in the first eight months of 1935 is given as 84,929 tons, an increase of 14,306 tons over the corresponding figure for 1934. In the year ended August 1935 the consumption of tin in the United States of America increased by 11.9% to 54,160 tons. Tin consumption in Russia continues to expand, a new record of 6,345 tons having been reached for the year ended August 1935. Consumption in Italy has also reached a record of 5,362 tons for the year ended August, representing an increase of 34.4% over the figure for the previous year. France and Belgium show decreases of 16.7% and 25.0%, respectively.

Big Furnaces for Ford.—Thirteen big bell-type electric furnaces, larger than any of this type heretofore constructed, will soon be installed by the General Electric Co., in the Rouge plant of the Ford Motor Co., where, in conjunction with twelve other bell-type furnaces built by another manufacturer, they will be used to anneal steel strip for the Ford V-8. Each is of sufficient capacity to bright-anneal, in one charge, two 16,000-pound coils of steel strip 48 inches wide, 52 inches outside diameter and 30 inches inside diameter. A number of the furnaces had already been shipped to the Ford plant by late September, while those still in the course of construction were inspected with interest by Henry Ford on the occasion of his recent visit to the G-E Schenectady Works. The purchase of the large furnaces is based on results of tests made in a G-E furnace of this type which was installed in the Ford plant early this year. The test furnace demonstrated the ability of the bell-type electric furnace to produce steel of superior qualities in a short annealing time and at low cost. The annealing cycle is in the neighborhood of 45 hours—much shorter than with conventional fuel-fired equipment.

Trade Literature

Texrope Drives.—Bulletin 1259, 32 pp. Describes texrope drives for machine tools; profusely illustrated. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Mica Undercutter.—Bulletin, 4 pp. Describes the improved Ideal undercutter, electrically driven, for servicing and undercutting commutator mica. Ideal Commutator Dresser Co., Sycamore, Ill.

Cathode-Ray Oscillograph. Bulletin GEA-1768A, 4 pp. Describes type HC-10 B1 cathode-ray oscillograph, suited for the study of recurring waves from power frequencies to several million cycles per second. General Electric Co., Schenectady, N. Y.

Farm Line Accessories. Bulletin 513-H 28 pp., "O-B Materials for Low-Cost Farm Lines." Describes hardware, insulators and fittings applicable in low-cost distribution line construction. Ohio Brass Co., Mansfield, O.

Arc Welders.—Bulletin HW-4, "Weld It Well." Describes a complete line of arc welders, from 50 to 800-ampere units, as well as welding fixtures and accessories. Condensed specifications and performance data are included. Harnischfeger Corp., Milwaukee, Wis.

Water Heating Load Control.—Bulletin GEA-1669D, 4 pp. Describes type T-11 time switches for controlled water heating, for indoor and outdoor service, and especially designed for the off-peak control of water-heater loads. General Electric Co., Schenectady, N. Y.

Gear Motors.—Bulletin 1870, 4 pp. Describes a new line of gear motors, including helical gear and worm gear units, either direct connected or coupled types, in single, double and triple reductions for horizontal, vertical and right angle drive. Diehl Mfg. Co., Elizabethport, N. J.

Engine-Type Alternators.—Bulletin 1153-A, 24 pp. Describes engine type alternators for use with any kind of reciprocating prime movers; available for standard engine speeds from 100 rpm to 600 rpm in standard ratings from 25 kva to 10,000 kva. Numerous installations are illustrated. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Pumps.—Bulletin 166, 12 pp. Describes class 7-AT and 8-AT air cushion valve vacuum pumps, single-stage and two-stage horizontal bearing type. Bulletin 224, 4 pp., describes class SHD, SMD and SLD double suction, single stage, sleeve bearing centrifugal pumps. Pennsylvania Pump & Compressor Co., Easton, Pa.

Fuse Links.—Bulletin, 16 pp. Describes "Unifit" (universal) fuse links for every service requirement, adaptable to all standard makes of cutouts of new and old designs; available in three types—strain, spring and silver links of spring type with silver fusible element, and in all standard ratings. Line Material Co., So. Milwaukee, Wis.

Circuit Breaker Arc Extinguisher.—Bulletin 45, 4 pp., "Pacific Expulsion Chamber." This device has been developed for use in oil circuit breakers to insure early arc extinction with a minimum of oil carbonization, without oil throw and without stress to the breaker in which it is installed. Pacific Electric Mfg. Co., 5815 Third St., San Francisco, Calif.

Arc Welding.—Bulletin, 42 pp. Describes automatic arc welding by the "electronic tornado" system, for use in industries where products of relatively uniform character are produced in large quantities. The various types of welds suitable for automatic welding are illustrated by line drawings; typical applications are pictured. Lincoln Electric Co., Cleveland, O.

Magnetic Contactors.—Bulletin 1145, 4 pp. Describes a complete line of new "Line-Arc" magnetic contactors, for use on mill, crane machinery controllers, and other d-c applications, up to 800-ampere capacity in which the arc, formed as the circuit is opened, is ruptured harmlessly in a narrow path or line centered between, but not touching the arc shields. The Electric Controller & Mfg. Co., 2700 E. 79th St., Cleveland, O.

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Front Cover

A view of the Pleasant Valley (N. Y.) substation of the New York Power and Light Company where the Niagara-Hudson and New York Edison transmission systems are joined together. Photo by F. A. Lewis (A'31)

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In This Issue—

MAGNETIC MATERIALS are featured in 3 papers in this issue. One summarizes the results of extensive research on magnetic alloys of iron, nickel, and cobalt (*pages 1292–9*); a second discusses different grades of silicon steel and other magnetic materials and their application to communication equipment (*pages 1348–53*); a third outlines recent improvements in communication transformers, which have been made possible largely by improved core materials (*pages 1367–73*). A fourth paper on this same general subject contains a bibliography of 211 items on research in magnetics done during the years 1933–34 (*pages 1354–9*).

LIGHTNING protection of distribution systems is treated in 2 papers in this issue. One paper summarizes the experiences of one large company in rather severe lightning territory where the improvement in protection expected from interconnecting the arrester grounds and the secondary neutrals was not as great as expected (*pages 1400–05*). The other paper reports the results of measurements of lightning currents in arresters on 4 distribution systems in different parts of the United States; a maximum current of 17,000 amperes was recorded (*pages 1395–9*).

ELECTROCHEMICAL and electrometallurgical industries have developed so rapidly in recent years that it has been impossible to disseminate the knowledge which has been gained. Some notes on the engineering development of these industries, particularly in France, have been prepared by a French engineer. Descriptions of new equipment for producing calcium carbide and aluminum electrically are included (*pages 1320–31*).

SALIENT pole synchronous machines are discussed in 2 papers in this issue: one outlines methods of determining load losses and presents the results of calculations made by those methods (*pages 1332–40*); the other presents the results of pulling-into-step solutions made on the new large mechanical integraph at the University of Pennsylvania (*pages 1385–95*).

RECENT research in the field of dielectrics, particularly on materials and methods used at high voltages, was reported in one paper presented at the recent meeting of National Research Council's committee on electrical insulation (*pages 1288–91*). A news report summarizes the principal subjects discussed at this meeting (*page 1416*).

THE danger of self-excitation of a Scherbius machine used in a variable ratio frequency converter for inherently constant power transfer has been studied, and means of preventing self-excitation during normal operation have been indicated (*pages 1359–66*).

NOISE frequency induction on telephone lines resulting from exposure to electric power lines has been subject to considerable investigation by both communication and power system engineers. The results of some recent studies are reported in this issue (*pages 1307–15*).

THE MKS (meter-kilogram-second) system of units was adopted by the International Electrotechnical Commission at its plenary meeting of June 1935. Not since 1881 has a decision of similar international significance been made (*pages 1373–84*).

IN ADDITION to the many technical papers and discussions thereon which were part of the recent meeting of the A.I.E.E.. Great Lakes District at Purdue University, a noteworthy feature was the attention given to students (*pages 1410–12*).

MASS TRANSIT by means of continuously moving electrically operated platforms is said to have some advantages over other means of rapid transit for the congested sections of large cities (*pages 1340–7*).

THE technical program for the annual winter convention of the A.I.E.E. to be held in New York, N. Y., January 28–31, 1936, has been announced (*pages 1408–09*).

A VOLT-TIME curve for solid insulation, presented in this issue, considerably extends the range of information available on this subject (*pages 1300–01*).

METHODS of segregating the losses in single phase induction and capacitor motors are outlined in this issue (*pages 1302–06*).

1936 TRANSACTIONS

Important Notice!

The A.I.E.E. TRANSACTIONS for 1936 will be produced only for those having subscription cards on file at A.I.E.E. headquarters not later than Friday, December 20, 1935. Present production methods require determination, in advance of the printing of the January 1936 issue of ELECTRICAL ENGINEERING of the exact number of TRANSACTIONS volumes to be provided for. For the convenience of members desiring to maintain in this permanent form a file of A.I.E.E. papers and discussions, important additional information and a convenient order blank are provided on page 10 of the advertising section of the November 1935 issue.

Friendship and the Engineer

—*A Message From the President*

IN these trying times of stress and economic instability, engineers, like the rest of the business world, are trying to keep the ships of enterprise off the rocks of economic and financial disaster, and are exerting heroic efforts to keep the flag of hope flying bravely in the storm. Their associates and fellow workers can help bear the burden of worry and responsibility by their sympathy and loyalty, and by simply offering their friendship in the constant courageous battle.

Recently I had occasion to interview a man who is the executive head of a large corporation. In the course of our conversation, he remarked, "Friendship in business means nothing to me; it is only the cold hard facts that count." I feel sorry for such a man. Do you know that after many years of considering only cold hard facts, business finally has awakened to the idea that human interest is the greatest force in industry?

The one thing that counteracts discord is harmony, and we approach this in business along the path of friendship. The man who is on friendly terms with his associates will carry on his business or activity far better than the one who is actuated only by the colder sentiments. We try to believe that we think and act independently, but as a rule we are greatly influenced by our contacts with others, particularly by those of our business associates who are our friends.

And so it is with us in our Institute life. The benefits which an engineer derives from his membership in the Institute come primarily from his taking advantage of the opportunities presented for establishing and extending intimate relations and mutual understandings with others of his profession. The development of a true spirit of helpfulness in the free exchange of ideas contributes immensely to individual advancement. But, beyond this, lies the even greater personal satisfaction of association, good-fellowship, and friendliness.

The season of the year when friendliness and good-fellowship are in greatest evidence is fast approaching. At this time our thoughts are inclined to dwell more on others—members of our families, friends, associates, and those who are in need. We try to foster good feeling and draw upon our many resources to extend a helping hand in replacing sorrow and sadness with joy and cheerfulness.

However, many of us in our every day lives are far too susceptible to the material things which play a part in our efforts—sometimes a large part and sometimes small. While material things constitute the basic element of our business activity and are fundamental to our physical well-being, they really make up the smaller portion of the sum of our contentment.

The greatest joy and satisfaction are derived from the little things in life—those things that, in general, are without cost to us and can be procured without difficulty—our friends, who think and speak kindly of us, interesting books, cheerful words, friendly smiles, or acts of kindness. They usually take us by surprise.

Everyone has heard the familiar legend of the man who searched all over the world for diamonds, and, finding none, returned home in disappointment. Then to his delight, he discovered "acres of diamonds" on his own land which he had neglected to search before starting on his quest.

It is the same with many of us. We are possessed with an insatiable desire for the unattainable. We strive to accomplish some material purpose because of the satisfaction, the feeling of success that accompanies victory. While it is true that patience, perseverance, and aggressiveness are commendable and essential to progress and individual advancement, they often cause us to miss the myriad little things surrounding us that really make living enjoyable and worth-while.

As the holiday season approaches, it brings with it a spirit of happiness and rejoicing. Christmas reminds us of many happy events—forgotten in the daily struggle to keep up with the times—the old homestead, the merry voices, and smiling faces. The most minute and trivial circumstances connected with those joyful meetings crowd upon our minds at each recurrence of the season as if the last had been but yesterday.

Christmas can win us back to the realization of the importance of friendship in our daily lives. Injecting its spirit into our every endeavor will return its blessings a thousandfold.

With this message I extend to all the members of the American Institute of Electrical Engineers my friendly and sincere wish for happiness this Christmas season and the coming year.

Recent Progress in Dielectric Research

Research in the several fields intimately involved in improving the formulation and application of electrical insulating materials is continuing with unrelenting efforts. The following summary of some of the current (1934–35) results indicates something of the scope and significance of this work.

By
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RESEARCH and experimental development have produced several interesting advances during the past year. Direct study of insulating materials has resulted in new combinations for special types of service and in noteworthy new extensions in the high voltage field. In the field of basic research, as usual the effort has been toward better experimental control, more intimate knowledge, and more clearly cut theories in all classes of dielectric materials and phenomena. Liquids have received the greatest attention because of their wide ranges of inherent properties, their susceptibility to control, and the great interest in them from the standpoints of both theory and application as insulators.

Liquids

Research in the field of liquids has covered an especially wide range of study of dipolar properties. Much of this is in the direction of correlation with other knowledge of molecular structure and combination arising in chemical research. Such work is full of ultimate promise of new knowledge bearing upon the insulating properties of materials. Up to the present, however, available results from the standpoint of insulation are limited to such matters as dielectric constant and loss at high frequencies. All such work is in the high frequency range where the dipolar elements of loss, phase difference, and dielectric constant are clearly established. Interesting data of this type for insulating oils are present in papers by Beck,[1] Rieche,[83] and Sommerman,[45] all of which indicate that molecular dipolar behavior at normal temperatures is limited to the high frequency range. Further, it generally is unaffected by increases in low frequency losses, and there may be several different polar elements in the same liquid. In certain cases low frequency losses which seem to have polar characteristics are ascribed to polarized aggregates of much larger than molecular dimensions. Nowhere in all this work is there as yet a possibility of a quantitative check of Debye's theory in the matters of loss and phase difference, owing to the as yet imperfect knowledge of the phenomena of internal friction and dissociation.

Conduction in insulating liquids has been studied theoretically by Sammer[88] who extends to the case of liquids Schumann's theory for crystals. Expressions for d-c and a-c behavior are derived as based upon ionic mobilities, and certain qualitative agreements with the results of experiment are obtained. Schumann,[40] in a theoretical analysis, shows that the motions in liquids of layers of different ionic densities or space charge may result in one or more maxima of current as observed by Whitehead and his coworkers. Further interesting experiments in this direction are reported by Hofmann[20] who, using the "schlieren" method and a movie camera, photographs the motion of the space charge and measures its velocity. He finds ionic mobilities up to 10^{-4} cm/sec/volt/cm, confirming the value announced by Whitehead and Marvin[58] several years ago. The mobilities of the ions in ordinary electrolytic solutions are in this range and it is not yet clear how this high value can be reached in the more viscous insulating liquids. Hofmann,[20] in explanation of various features of his results, invokes the attraction of polar molecules to a free ion and the motion of the resulting larger aggregate. Gillies[14] reports observations on conduction at high field strength, confirming the theory that ionization by collision is the basic factor. The electrical purification of liquids by application of continuous voltage has been studied by Whitehead and Shevki[64] who show the close relationship between short time conduction, dielectric loss, and space charge, during the clean-up and recovery periods.

Several important papers on breakdown in liquids have appeared. Scheu[89] has studied the conditions under which breakdown strength of oils may be regarded as a genuine characteristic of the material under test. At ordinary frequencies he finds necessary the allowance of much longer "rest periods" between breakdowns than those usually stipulated in test specifications. In order to suppress the scattering in breakdown values to the minimum inherent in the nature of the oils, he maintains that the time between breakdowns and also the "rest time" before the first breakdown should be 30 minutes. He recommends that standard specifications be amended to take account of these facts, but it appears doubtful that it will be worth while in routine testing to increase the time required so drastically for the sole purpose of diminishing the scattering of breakdown values. Particularly interesting is the influence of pretreatment voltage impulses reported by this author. He finds that by subjecting the oil to several voltage impulses, the scattering of subsequent breakdown values was much reduced, both with ordinary

Full text of the annual report of the chairman as presented to the 8th annual meeting of the National Research Council's committee on electrical insulation, Pittsfield, Mass., Oct. 17–18, 1935. See also news report, page 1416, this issue.

1. References listed at end of paper.

frequency and with impulse breakdowns, and also that the breakdown strength was increased. He used up to several hundred such impulses before the actual breakdown series. The cumulative effect of a great many such impulses is probably similar to the effect of a direct voltage applied for an extended time, but with impulses lasting only a fraction of a microsecond much higher field strength may be applied without resulting breakdown.

Another interesting and skillful study is that of Strigel[48] on the spread of the observable time intervals of the order 10^{-3} to 10^{-7} second between the application of voltage and the resulting breakdown of small gaps. The time lag of discharge may be divided into 2 parts: the first part is the time during which, for a given impulse voltage and long time dielectric strength of the oil, no breakdown is possible, thus fixing the shortest possible time for the building up of the discharge; the second part, determined statistically, gives the mean spread of the observations of the discharge lag. The minimum building-up time is found to be independent of the electrode materials, but the mean spread of the time lag shows a definite dependence upon the material. An electrode with smaller work function causes a smaller value of the mean spread of the discharge lag. The minimum building-up time is the time necessary for breakdown when all initial conditions are favorable; for example, that at the instant of application of voltage a primary electron is present or just enters the gap from the electrode, and the path of this electron and its resulting avalanche take place in such direction and under such conditions as are most favorable for breakdown, being thus definitely a probability phenomenon. Breakdowns resulting from stresses of less than 10^{-3} second duration are pure ionization phenomena, mechanical and thermal breakdown processes being excluded by reason of the longer time intervals necessary.

Equally important is an extensive review of experiment and various theories of liquid breakdown by F. Koppelman.[21] Of particular interest is his examination of the influence of pressure upon breakdown. He reviews the thermal theory of Günther-Schulze,[16] the gas ionization theories of Nikuradse[30] and of Edler and Zeier,[10] and the electromechanical theory of Gemant[13] in their relations to gas laws and the constants of the liquids, and concludes that no one of them is completely sufficient to explain the facts. He offers, as more satisfactory, a modification of Gemant's idea of a progressively elongated gas bubble. Koppelman assumes that breakdown starts with a minute gas bubble formed on the electrode as a result of any one of several causes, such as a minute discharge from an equally minute surface inequality. The bubble forms, and Koppelman's new proposal is that, in so forming, the surface of the bubble takes the charge from the electrode surface, the bubble itself thereby becoming the electrode. In this way, the bubble elongates and spreads into the liquid, finally forming an electron dart at the leading region of high stress. This picture eliminates the pressure in its effect on gaseous ionization, its influence being limited to its mechanical action as related to the forces of liquid adhesion of electrode, to surface tension, and to other factors bearing upon the actual motion of the head of the bubble.

In my report of last year are comments concerning the opposing theories of breakdown of Edler and Zeier who favor the thermoelectric processes, and of Koppelman who prefers the pure electric or ionization breakdown for pure liquids. Koppelman has presented new evidence in support of his views in a series of studies with a-c flat topped and peaked waves. The results show definite correlation with crest rather than with effective values, thus supporting the theory of pure electric breakdown. These latter results of Koppelman were reported at a conference on insulation research at the Technische Hochschule of Hanover, Prof. H. Schering, director. The published report of this conference contains brief descriptions of other interesting researches, and particularly of recent improvements in methods and equipment for measurements at high voltage.

Further studies of breakdown in commercial oils not completely purified, particularly as related to the influence of pressure, are reported by F. M. Clark.[4] He finds an interesting correlation with the corresponding behavior in gases and suggests a mechanism for breakdown in liquid similar to that in gases.

The chemistry of petroleum insulating oils is reviewed by Dupui[9] with a helpful classification of various types as correlated with chemical stability. From several papers on oxidation, may be mentioned an interesting attempt by Ornstein, Janssen,[31] and Krygsman, to evaluate transformer oils in terms of reaction constants and activation energies. These quantities are found to vary with aging of the oil. With an oil aged for different lengths of time, it was found that the logarithm of the reaction constant plotted against the reciprocal of absolute temperature gives straight lines intersecting at a point. Above this point the reaction constant increases with aging, below it decreases. Hence the conclusion that a certain oil should be used in a transformer only if the point of intersection occurs at a temperature which is above that of operation. Applying this principle experimentally, the authors conclude that a moderately refined oil is better than either a poorly refined oil or a highly refined oil, a conclusion in agreement with practical experience. Making certain assumptions as to the hydrocarbon groups in the oils, the authors offer a quantitative explanation of their results.

The work of Muller[29] agrees with the foregoing as to the existence of a certain optimum in the refining of transformer oils, but in addition this author determines the nature of the oxidation products. Water is found to be an important product in the case of the colorless, highly refined oils, but the primary reaction products are probably peroxides, as established by other workers.

Gases

In the field of breakdown of gases an interesting experimental study of the spark lag of the sphere gap has been reported by Tilles,[48] with a new experimental set-up for the measurement of short time intervals

of the order 10^{-5} second. He concludes that the spark lag may fall into one of 3 distinct domains depending upon the conditions obtaining, notably the external ionizing forces. The sparkover mechanism may take different forms as related to these conditions.

There is a noteworthy revival of interest in corona formation, particularly as associated with continuous voltage. De Fassi[6] studies the laws of d-c critical voltage, current, and loss. He develops empirical formulas and adds a discussion of existing theories, as based on ionic mobilities and space charges. Misere[26] studies the a-c critical voltage and loss over a wide range of frequency, with particular reference to the early formulas of Peek and Whitehead. General agreement is found with suggestion of slight modifications of the constants for the upper ranges of frequency. At the Hanover conference, previously referred to, corona measurements with the Schering bridge were reported indicating a marked departure from the Peek formula for power loss. A new formula, as based on the experiments, is proposed.

Solids

In the field of solids, Böning[2] has extended his theory, that conduction in dielectrics arises from the motion of ions of one sign, to account for anomalous conduction, absorption, and nonuniform potential gradient in solids. Certain experiments in confirmation are reported. He proposes that the increase in loss under alternating stress and also final breakdown are caused by the formation of minute canals caused by the oscillating motion of the ions.

Of particular interest is the work of Tausz and Rumm[47] on the dielectric constant of materials containing water, such as starch, certain powders, and fibrous materials. The isodielectric method of suspension in a liquid of known specific inductive capacity is not reliable for materials which absorb water. The dielectric constant of many materials is influenced in characteristic manner by the water content and it is proposed that this method is available for an approximate determination of water content. From results of studies of the rise of dielectric constant with temperature it is proposed that the absorbed water is in 2 forms: (1) with very small dielectric constant, and described as "solidified" water; (2) described as "movable" water which strongly increases the dielectric constant and makes it much more susceptible to temperature variation. Whitehead and Greenfield[52] also have studied the influence of residual water upon the dielectric constant of cellulose paper, from which studies empirical relations are derived and the moisture content approximately computed. Where comparison is possible, their results are in general agreement with those of Tausz and Rumm.

Practice

In the field of practice may be mentioned the development by Meissner[25] of a new series of solid and molded insulating materials having high thermal conductivity. All are made from organic binding insulators, including the oils, with powdered crystalline substances added. The thermal conductivity is increased from 3 to 8 times with little or no reduction of the dielectric strength of the binder. Also may be mentioned the development by Handrek[18] of a group of rigid materials of ceramic type, of which the principal constituent is TiO_2, suitable for radio capacitors and in which the dielectric constant has a range of values up to 90 with phase difference of the order from 3×10^{-4} to 8×10^{-4} in the high frequency range.

Improvements abroad in oil impregnated paper insulation for power condensers are described by Gönningen[16] and Güthman.[17] The latter, particularly, claims a great advantage in this service for thin, highly purified oils, stating that they are available with low phase difference and loss with a smaller variation of the same with temperature and voltage than the heavier oils, and also that they have a higher and more stable dielectric strength.

In the United States particular attention has been directed to the problem of the stability of high voltage impregnated insulation. This has taken the form of a more intimate examination and analysis of the behavior of the insulation of high voltage cables, both initially and after service, as represented particularly by the study of the radial variation of power factor by the method of Wyatt and by extensive service records such as those reported by Roper.[34] While no definite conclusions as to the cause of ultimate instability are as yet evident from these studies, they have led already to improvements in the electrical characteristics of cables, and are paving the way for deeper researches as to the ultimate causes of oil and paper instability.

As conspicuous examples of the outcome of progressive and widely distributed research, may be noted the development of several new types of extra high voltage cable and the increasing confidence, as represented by several important installations, in the steady improvement of the earlier types of cable in this class. A new type of oil filled cable with type HH segmented conductor, impregnated after installation, is described by Borel.[3] Dunsheath[8] reports further experiments with the "gas-cushion" cable. A 50-kilovolt oil-filled cable with submarine section is reported from Copenhagen. Of outstanding interest are the installations in the Baltimore and Washington tunnels of the Pennsylvania Railroad of exceptional lengths of 132 kilovolt cable, cables of the pressure type with oil as the compression medium, and also of improved types of oil filled cable with oil feed through the hollow conductor.

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Spectacular floodlighting, as applied to Wanaque Dam of the North Jersey District (N. J.) Water Supply Commission. The dam, 1,600 feet in length and with a slope of 210 feet, is lighted by 50 1,000 watt lamps. At the base of the dam are 3 electric fountains 35 feet high floodlighted by 36 underwater 1,000 watt projectors with colored lenses, and 2 fountains 15 feet high floodlighted by 10 underwater 500 watt lamps. All of the underwater lamps have colored lenses

Magnetic Alloys of Iron, Nickel, and Cobalt

The unexpected magnetic properties of certain alloys of iron and nickel discovered some 20 years ago led to a thorough study of the entire range of iron-nickel alloys. The results of this study were so encouraging that alloys of these metals with cobalt, the only other ferromagnetic metal, also were studied, as well as various alloys of these metals with small amounts of nonmagnetic metals added. From the results of this extended investigation have emerged several alloys that are playing important parts in the continued advancement of electrical communication.

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SOME ALLOYS of iron, nickel, and cobalt have remarkable magnetic properties superior in many situations to those of the constituent metals. Many of these alloys have found wide use in the instrumentalities and circuits of electrical communication, and were developed primarily for that purpose. This paper reports the experience and techniques of the Bell Telephone System in the development and utilization of these materials.

The advantageous properties of these alloys were disclosed through exhaustive researches, during which the whole realm of combinations of these 3 metals was explored. That certain alloys of iron and nickel had unexpected properties at low flux densities had already been discovered in the Bell Telephone Laboratories. There was at that time no theoretical basis for predicting, or even explaining, the character of those alloys; and, therefore, a study was undertaken of the whole iron-nickel series. The results were so encouraging that combinations of these elements with cobalt likewise were studied; and finally those alloys of special interest were combined with varying amounts of nonmagnetic metals. In the course of this investigation several thousand specimens were made and tested in a period extending over 15 years.

A paper recommended for publication by the A.I.E.E. committee on communication, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 28–31, 1936. Manuscript submitted Oct. 2, 1935; released for publication Nov. 2, 1935.

Such an empirical investigation is time consuming and expensive, but in a field where so little theory was available for guidance it was the only certain means to determine the practical possibilities of these alloys. It has been justified by the large number of alloys it has developed for practical use in communication engineering. One of the first and most striking applications was to submarine telegraph cables. The largest field of application, however, has been in telephony, where the requirements generally are very exacting, and where other advances have imposed rigid demands on the magnetic materials.

In telephone circuits, standards of transmission efficiency require that the magnetic materials used as circuit elements shall produce maximum magnetic effect with minimum energy loss and distortion of the transmitted currents. Translated into magnetic characteristics, this means that at low magnetizing forces the material shall have high permeability in combination with low hysteresis loss, and, in many situations, constancy of permeability over the operating range. In circuits for voice and carrier currents it is often necessary to reduce the intrinsic permeability of the material to obtain the required constancy and low losses in the apparatus. Furthermore, to minimize eddy currents, a high resistivity is required and the material must be structurally suitable for fabrication into thin laminations. For other uses, such as for signaling and switching mechanisms, the magnetic properties at medium and high flux densities determine the suitability of the material. High permeability and low coercive force make for improved sensitivity and speed of operation. Low coercive force is of special interest in marginal apparatus where the difference between the operating and releasing currents is small.

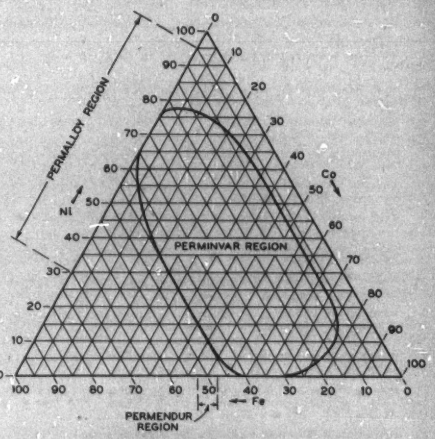


Fig. 1. Composition diagram for alloys of iron (Fe) nickel (Ni) and Cobalt (Co)

Preparation and Composition of the Alloys

A great many factors contribute to the final properties of an alloy. Among the most important of these are the purity of the elements used in the alloy, their preparation, and the heat-treatment. The magnetic properties attainable can be completely masked by the intrusion of small quantities of certain impurities or by improper heat-treatment. For iron the magnetic properties can be improved materially by removing extremely small quantities of carbon and other nonmetallic elements through heat-treating* in an atmosphere of hydrogen and at temperatures close to the melting point. This method of purification also improves the magnetic properties for alloys of iron, nickel, and cobalt. For communication purposes, it has not been found expedient as yet to introduce this method of refinement in the commercial production of these alloys. The purity of the constituents is controlled by ordinary methods of chemical analysis, by methods of melting, and by annealing processes which do not increase the amounts of important impurities. The magnetic properties recorded in this paper, therefore, have been confined mostly to those obtained on materials produced by standard metallurgical methods.

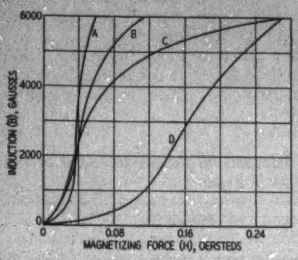


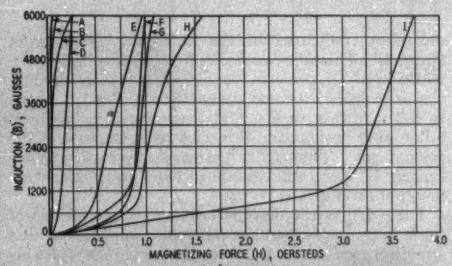
Fig. 2. Magnetization curves for several permalloys for flux densities less than 6,000 gausses

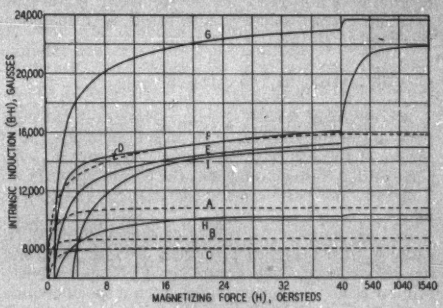
A—78.5 permalloy
B—3.8–78.5 Mo-permalloy
C—3.8–78.5 Cr-permalloy
D—45 permalloy

In the commercial method of producing these alloys the best grades of commercial iron, nickel, and cobalt are used. The melting is done in an electric furnace, and after the mechanical fabrication into suitable shapes these alloys are heat-treated to develop the desired magnetic properties.

Early in an investigation of these alloys it was found that some of them required special heat-treatments to develop the desired magnetic properties. For some the slow cooling incident to the ordinary process of annealing was not suitable, and a rapid cooling was necessary. For another group the slow cooling in the annealing process was not slow enough, and the best results were obtained when the alloys were held at a constant high temperature for a considerable time. It was evident that to determine the most suitable temperature of heating and rate of cooling for each alloy would require more time than was warranted in the exploratory work. Three methods of heat-treatment that, in a general way, would separate the alloys into groups, were developed. These heat-treatments are designated in this paper as "annealing," "quenching," and "baking."

The annealing process consists of heating the samples in closed containers to a temperature of 1,000 degrees centigrade, and cooling with the furnace. The cooling ordinarily requires 7 hours before room temperature is reached. This heat-treatment is primarily for the purpose of removing the effects of mechanical strains necessarily resulting from the rolling and stamping of the alloys into suitable shapes. All the alloys discussed in this paper received this heat-treatment before any of the more special processes were applied.





Figs. 3 (above) and 4 (right). Magnetization curves for permalloys, perminvars, and permendur

A—78.5 permalloy
B—3.8–78.5 Mo-permalloy
C—3.8–78.5 Cr-permalloy
D—45 permalloy
E—Silicon steel
F—"Armco" iron
G—Permendur
H—7–45–25 Mo-perminvar, baked
I—45-perminvar, baked

* There is a rapidly growing technical literature relating to the effects of very small percentages of impurities on magnetic properties and the methods for their removal, with notable contributions by T. D. Yensen of the Westinghouse Electric and Manufacturing Company, W. E. Ruder of the General Electric Company, and P. P. Cioffi of the Bell Telephone Laboratories.

The quenching process consists of heating the alloys for a short time at 600 degrees centigrade, and cooling in air at room temperature for small samples with large surfaces, and in oil for larger samples. The rate of cooling attained by these methods is approximately 40 degrees centigrade per second. It has been found that the best rate of cooling for maximum permeability does not always develop the highest initial permeability. The difference, however, is not large, and often is masked by other variations in the manufacturing process.

Table I—Designations and Compositions of Some Magnetic Alloys

Designation	Composition, Per Cent					
	Ni	Fe	Co	Cr	Mo	V
78.5 permalloy	78.5	21.5				
80 permalloy	80	20				
45 permalloy	45	55				
3.8–78.5 Cr-permalloy	78.5	17.7		3.8		
3.8–78.5 Mo-permalloy	78.5	17.7			3.8	
2–80 Mo-permalloy	80	18			2	
45–25 perminvar	45	30	25			
7–45–25 Mo-perminvar	45	23	25		7	
Permendur		50	50			
1.7 V-permendur		49.15	49.15			1.7

Ni = nickel; Fe = iron; Co = cobalt; Cr = chromium; Mo = molybdenum; V = vanadium.

The baking process consists of heating the alloys for 24 hours at 425 degrees centigrade, and then slowly cooling to room temperature. The rate of cooling does not affect the development of the magnetic properties unless it is so rapid as to introduce mechanical strains.

Classification of the Alloys

A convenient way of showing graphically the compositions of the alloys of iron, nickel, and cobalt is by means of the composition triangle in figure 1. The sides of this triangle represent the binary alloys of the 3 metals, and points inside the triangle, the ternary alloys.

In this diagram the alloys of special interest because of their magnetic properties are indicated, and, for convenience, each group in which the magnetic properties are similar has been given a specific name.

On the iron-nickel side of the triangle the permalloy region is indicated. In this group several compositions have been developed for commercial use in the Bell System. The method of identifying these alloys consists of prefixing a numeral indicating the per cent of nickel, for example, 45 permalloy contains 45 per cent nickel and 55 per cent iron. To some of these permalloys small amounts of other metals also are added. In designating ternary permalloys the same scheme is extended, so that the name gives everything except the iron content, and this is obtainable by difference. Thus, 3.8–78.5 Cr-permalloy contains 3.8 per cent chromium, 78.5 per cent nickel, and 17.7 per cent iron.

The perminvar region, enclosed by the curved line, contains those compositions that require baking to develop completely their characteristic magnetic properties. The specific compositions of these alloys are indicated by 2 prefixed numerals, the first indicating the nickel and the second the cobalt percentages, respectively. Thus the 45–25 perminvar alloy contains 45 per cent nickel, 25 per cent cobalt, and 30 per cent iron. Another alloy of the perminvar group, in which the nickel and cobalt percentages are the same as the alloy just mentioned, but which contains 7 per cent molybdenum and 23 per cent iron, is designated as 7–45–25 Mo-perminvar.

In the iron-cobalt series of alloys the composition 50 per cent iron and 50 per cent cobalt has been developed for commercial use. This is the permendur alloy, indicated in the triangular diagram in figure 1. This alloy is difficult to cold roll, but the addition of 1.7 per cent vanadium improves the mechanical properties and makes it sufficiently ductile to roll into thin sheets. The same system has been followed in designating this alloy as in the case of the permalloys. Thus 1.7 V-permendur is an alloy containing 1.7 per cent vanadium with iron and cobalt in equal proportions.

Table II—Magnetic Constants for Alloys Discussed in This Paper

Material	μ_0	μ_m	$W_{H=\infty}$	B_r	H_c	$(B-H)_{H=\infty}$	ρ
"Armco" iron	250	7,000	5,000	13,000	1.0	22,000	11
4% silicon-steel	600	6,000	3,500	12,000	0.5	20,000	50
78.5 permalloy, quenched	10,000	105,000	200	6,000	0.05	10,700	16
45 permalloy	2,700	23,000	1,200	8,000	0.3	16,000	45
3.8–78.5 Cr-permalloy	12,000	62,000	200	4,500	0.05	8,000	65
3.8–78.5 Mo-permalloy	20,000	75,000	200	5,000	0.05	8,600	55
45–25 perminvar, baked	400	2,000	2,500	3,000	1.2	15,500	19
7–45–25 Mo-perminvar, baked	550	3,700	2,600	4,300	0.65	10,300	80
Permendur	700	7,900	6,000	14,000	1.0	24,000	6

Here μ_0 and μ_m are the initial and maximum permeabilities, respectively; $W_{H=\infty}$ is the hysteresis loss in ergs per cubic centimeter per cycle for saturation value of flux density; B_r is the residual induction in gausses; H_c is the coercive force in oersteds; $(B-H)_{H=\infty}$ is the saturation value of the intrinsic induction in gausses; ρ is the resistivity in microhms-centimeter.

Table I lists the designations and compositions of those alloys, developed for particular purposes, which are discussed more fully in the remainder of this paper.

In figures 2, 3, and 4 are shown the magnetization curves for low, medium, and high magnetizing forces for these alloys, except the 80 permalloy and the 1.7 V-permendur, for which the curves are substantially the same as for 78.5 permalloy and permendur, respectively. Curves for "Armco" iron and ordinary commercial 4 per cent silicon steel also are shown in these figures. All these materials were annealed, and in the case of the 78.5 permalloy and the perminvars the annealing was followed by quenching and baking, respectively. It may be seen from these curves that the permalloy group reaches almost saturation values long before the iron and silicon steel and the other alloys have reached the lower bend in the magnetization curve. With the exception of the

45 permalloy, which saturates at a fairly high value, the permalloys have low saturation induction and the permendur the highest. The permeability curves computed from these curves are plotted in figures 5 and 6. In figure 5, curves for the permalloy alloys are plotted at a smaller vertical scale than in the figure (6) containing the curves for the other alloys.

The permeability for alternating current of small constant amplitude as a function of superposed d-c magnetizing force is shown in figure 7 for some of the alloys. In most apparatus where both alternating and direct current are involved, this "butterfly curve" must be relatively flat over the expected range of d-c excitation. The important magnetic constants for these alloys are given in table II.

Permalloys

In figure 8 the initial and maximum permeabilities and the coercive force and resistivities are plotted for quenched alloys of the iron-nickel series. These curves show the remarkable variations in magnetic properties with composition in this series of alloys. The permalloy region includes alloys between 30 and 95 per cent nickel, as indicated in figure 1. Some of the alloys in this region, particularly from 50 to 85 per cent nickel, require rapid cooling to develop the magnetic properties indicated in the curves. If they are merely annealed, both the maximum and initial permeabilities are much lower. The greatest effect in reducing the permeabilities by slow cooling appears to be for the alloys containing between 70 and 80 per cent nickel; for example, 78.5 permalloy with a standard anneal has its initial permeability reduced to 1,200. If the alloy is baked for several hundred hours this permeability can be reduced still further to about 500. There is a very rapid decrease in the coercive force as the nickel increases above 27 per cent, and the lowest values are reached in the region between 70 and 80 per cent nickel. The resistivity increases rapidly just below the permalloy region, and reaches maximum at about 31 per cent nickel. It should be noted that the large changes in the coercive force and the resistivity are at the lower end of the permalloy region, while the highest permeabilities are developed in the alloys containing between 75 and 80 per cent nickel.

45 Permalloy. One of the alloys developed for commercial use is 45 permalloy. This attains a saturation flux density as high as any of the permalloys. At 40 oersteds the flux density is 16,000 gausses, substantially the same as for "Armco" iron, and considerably higher than for ordinary silicon steel (figure 4). The initial and maximum permeabilities (under standard practice of heat-treating) are 2,700 and 23,000, respectively (figure 5 and table II). For cores requiring flux densities between 8,000 and 12,000 gausses this alloy is specially useful. The resistivity of the alloy is 45 microhms-centimeter, which is high enough to make it superior for use in cores in a-c circuits. The higher permeability at fairly high values of superposed d-c field, shown in figure 7, also favors its use for some purposes.

78.5 Permalloy. Another alloy long used in the telephone plant is 78.5 permalloy. Quenching develops a higher maximum permeability in this than in any of the other permalloys. Initial and maximum permeabilities of 10,000 and 105,000 readily are developed. The hysteresis loss and the coercive force of quenched 78.5 permalloy are minimum. The saturation flux density of this alloy is between 10,000 and 11,000 gausses, and it is reached with a very low magnetizing force. The rapid rise in the flux density of this alloy for small increments in the magnetizing force and the low saturation flux density are shown in figures 2, 3, and 4.

Initial and maximum permeabilities of 78.5 permalloy are improved by elimination of impurities and also by special care in the quenching process. As

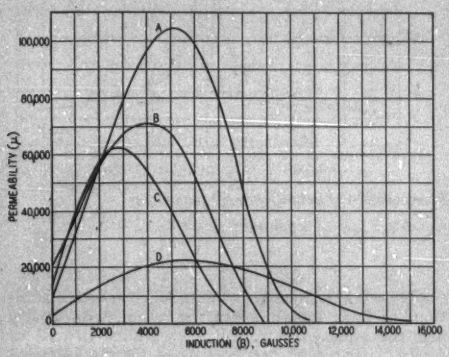
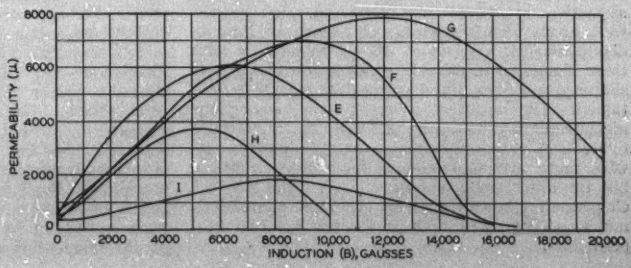


Fig. 5 (above). Permeability curves for permalloys

Fig. 6 (right). Permeability curves for perminvars and permendur

A—78.5 permalloy
B—3.8–78.5 Mo-permalloy
C—3.8–78.5 Cr-permalloy
D—45 permalloys
E—Silicon steel
F—"Armco" iron
G—Permendur
H—7–45–25 Mo-perminvar, baked
I—45 perminvar, baked



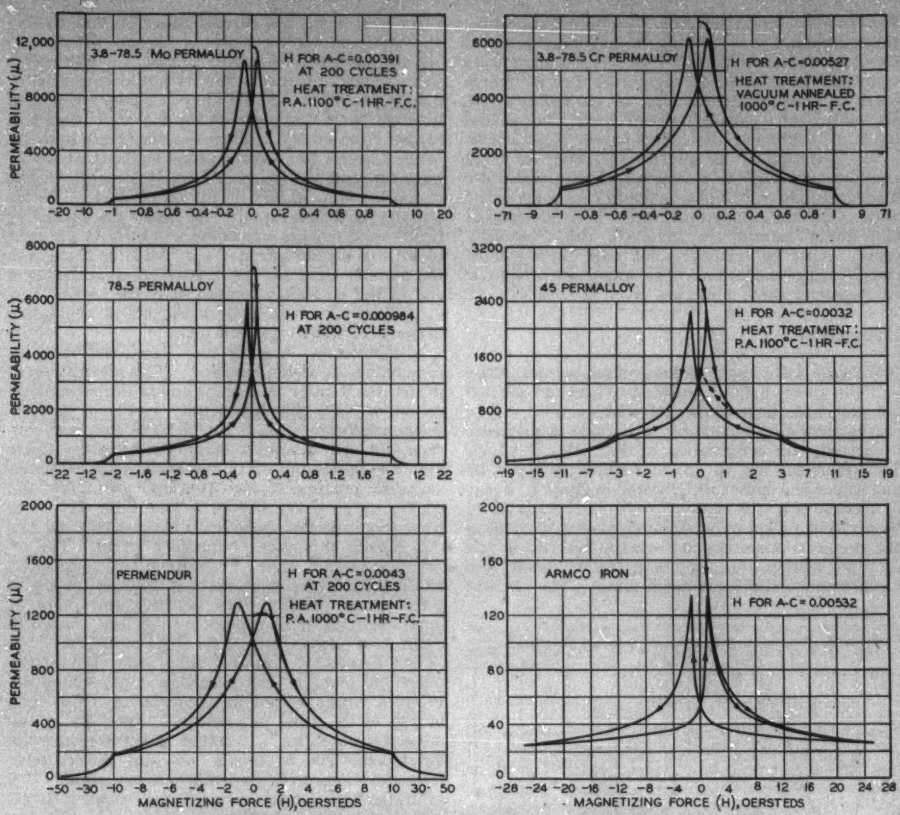


Fig. 7. Effect of superposed d-c fields on the a-c permeability of permalloys and permendurs

P. A.—Pot annealed. F. C.—Furnace cooled (i. e., cooled with furnace)

stated earlier, the rates of cooling required to develop the highest initial permeability differ from those for the highest maximum.

Chromium Permalloy and Molybdenum Permalloy. When other metals are added to permalloys their resistivities, in general, are increased. In research work at the Bell laboratories chromium and molybdenum mostly were used. It was found that with these elements a desirable combination of high resistivity and high initial permeability could be obtained. The variation in resistivity, keeping the nickel content constant at 78.5 per cent, is shown in figure 9. Chromium increases the resistivities somewhat more than molybdenum for a given addition, but the difference is not very large. The 3.8–78.5 Cr-permalloy has a resistivity of 65 microhms-centimeter, as compared with 55 for the 3.8–78.5 Mo-permalloy.

Figure 9 also illustrates the manner in which additions of these metals affect the initial permeability and the sensitivity of the permeability to rate of cooling. The solid line curves are for the annealed and the broken-line curves for the quenched specimens. For the quenched alloys the highest permeabilities are obtained when the added chromium and molybdenum are 2.4 per cent and 1.6 per cent, respectively. For this cooling rate the chromium permalloy seems to develop a slightly higher initial permeability. The difference, however, is small, and a greater spread between different samples has been observed. For the annealed alloys the largest value of initial permeability is obtained with molybdenum permalloy. For 3.8 Mo-permalloy an initial permeability of 20,000 is obtained. With the same heat-treatment the initial permeability of the corresponding chromium alloy is 12,000. It is surprising to note

that small additions of these nonmagnetic metals increase the initial permeability to values considerably higher than that for quenched 78.5 permalloy. Beyond 5 per cent this improvement ceases. All additions decrease the saturation induction values and the maximum permeabilities.

Several of these alloys have been developed for commercial use. Of these the most important are 2–80 Cr-permalloy, 3.8–78.5 Cr-permalloy, and 3.8–78.5 Mo-permalloy.

Perminvar

The distinctive magnetic properties of the perminvars are constancy of permeability at low flux densities, a low hysteresis loss in the same range, and, for medium flux densities, a characteristic constriction in the middle of the hysteresis loop. In some alloys this constriction is so extreme that the coercive force vanishes, making the 2 branches of the loop coincide when the magnetizing force is reduced to zero, in spite of the considerable hysteresis loss involved in the entire cycle. At high flux densities this constriction disappears and the loops have normal shapes.

The degree to which these properties can be developed depends on the composition and the heat-treatment. For the most typical alloys slow cooling

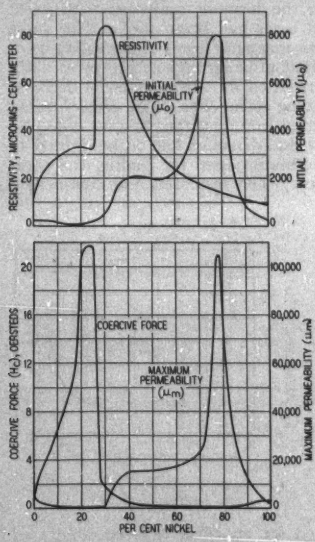


Fig. 8. Resistivity, initial and maximum permeabilities, and coercive force of iron-nickel alloys

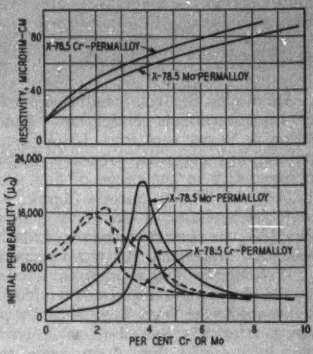
in the annealing process produces this effect to a certain degree. Baking for 24 hours in the 400–500 degree (centigrade) temperature range brings most alloys into a stable condition in which no further baking materially will affect the magnetic properties.

As indicated in figure 1, some of the binary alloys tend toward the perminvar characteristics with long baking. Of the permalloys a considerable proportion of those that must be quenched to develop the desirable magnetic properties show perminvar characteristics when they are baked.

45–25 Perminvar. The perminvar characteristics

Fig. 9. Resistivity and initial permeability of 78.5 permalloy with chromium or molybdenum replacing part of the iron

In the curve designations, x indicates the percentage of chromium (Cr) or molybdenum (Mo) as read from the abscissa



have been developed most intensely in 45–25 perminvar. The magnetization curve in figure 3, and the permeability curve in figure 6, illustrate this fact. The constancy of permeability at low magnetizing forces and the necessity of "baking" to attain this condition are illustrated in one of the sections of figure 10, where the permeabilities are plotted for the quenched and baked conditions. The permeability of the quenched alloy begins to change at very low magnetizing forces, but that of the baked alloy, though lower, remains constant for magnetizing forces up to 3 oersteds.

Hysteresis loops for this alloy in the 2 conditions are shown in figure 10 for maximum flux densities of less than 1,000 and more than 5,000 gausses. For the baked alloy the hysteresis loops for maximum flux densities less than 1,000 gausses cannot be measured by ordinary ballistic methods, because the 2 sides of the loop coincide in a straight line. For loops with higher maximum flux densities the area begins to appear, but the 2 branches of the loop still meet at the origin. Although the coercive force is sensibly zero for the baked alloy until the maximum flux density exceeds 5,000 gausses, the hysteresis loss represented by the loop may become considerably greater than that for the quenched alloy.

7–45–25 Mo-Perminvar. The extremely low hysteresis loss and constancy of permeability at low flux densities makes 45–25 perminvar a suitable material for applications where distortion and energy loss are fatal to good quality of transmission. The resistivity of this alloy is only 18 microhms-centimeter, but it can be increased without serious sacrifice of the low hysteresis characteristic by adding molybdenum. The alloy chosen for commercial use is

7–45–25 Mo-perminvar, having a resistivity of 80 microhms-centimeter.

The manner in which molybdenum affects the magnetic properties is illustrated in figures 3, 4, and 6. The permeability is not quite so independent of the magnetizing force as for the alloy without molybdenum, nor is the hysteresis loss quite so low. The initial permeability for the alloy baked the customary 24 hours is somewhat higher. When baked for a longer period the magnetic characteristics tend more toward those of 45–25 perminvar.

Permendur

An alloy in the iron-cobalt series used in communication apparatus is permendur. The typical composition is 50 per cent iron, 50 per cent cobalt. The outstanding magnetic property of this alloy is high permeability in the range of flux densities between 12,000 and 23,000 gausses (figures 4 and 6). The high permeability of this alloy "endures" to higher flux densities than does the permeability of any other magnetic material. Its initial permeability is about 700, though values as high as 1,300 have been observed for some samples. In addition to the high permeability at high flux densities permendur also has a relatively flat "butterfly" curve, as may be seen in figure 7. For a superposed d-c magnetizing force of 10 oersteds the a-c permeability of "Armco" iron is 40, as compared with 200 for permendur.

1.7 V-Permendur. Permendur is difficult to roll into sheets, because of its brittleness. To overcome this difficulty 1.7 per cent vanadium is added. With this addition it may be rolled into sheets as thin as a few thousandths of an inch. This amount of vanadium affects the magnetic properties only slightly, although larger amounts decrease the permeability at high flux densities.

Another improvement incident to the addition of vanadium is a fourfold increase of resistivity from its value of 6 microhms-centimeter for simple permendur. Permendur, it may be noted, has the lowest resistivity of the iron-cobalt series.

Laboratory Results

As stated hereinbefore, all the alloys that have been discussed have been made on a factory scale for some use in the telephone plant. This paper, however, would be incomplete without mention of some of the remarkable magnetic properties obtained in laboratory samples. In table III some of these magnetic achievements are tabulated. The special treatments given these specimens are noted also in this table.

Engineering Applications

One of the first uses of the permalloys was for continuous loading of a telegraph cable between New York and the Azores laid in 1924. For this project 78.5 permalloy was used in the form of a 0.125 by 0.006 inch tape wrapped helically on a stranded copper conductor. The average initial permeability of this alloy in the laid cable was 2,300, considerably less than can be obtained under the best conditions of heat-treatment and absence of strains. With this loading, the speed of transmitting messages was increased fivefold.[4] By the time a second cable project was undertaken the chromium permalloys had been developed, and 2–80 Cr-permalloy was selected. This alloy has a resistivity of 45 microhms-centimeter, and the initial permeability of the loading on the laid cable was in the neighborhood of 3,700. The increase in permeability and in resistivity increased materially the message carrying capacity.[5]

The largest use of permalloys in the telephone plant has been in cores of loading coils,[6] where the alloy is used in the form of compressed insulated dust. Iron dust cores had been standard for these coils.[7] The lower magnetic losses of permalloy dust, however, permitted utilizing higher core permeabilities. This has resulted in a very material decrease in the size of loading coils. For a high grade loading coil core made from iron dust the effective core permeability at low flux densities had to be limited to 33. The first permalloy used for loading coil cores was 80 permalloy. The insulated and compressed core was designed for an effective permeability of 75—more than double that for the iron dust. Development work on an improved compressed magnetic dust core in which molybdenum is used, is now approaching completion. It is expected that the new material will have a substantially higher permeability than that of the 80-permalloy dust cores,

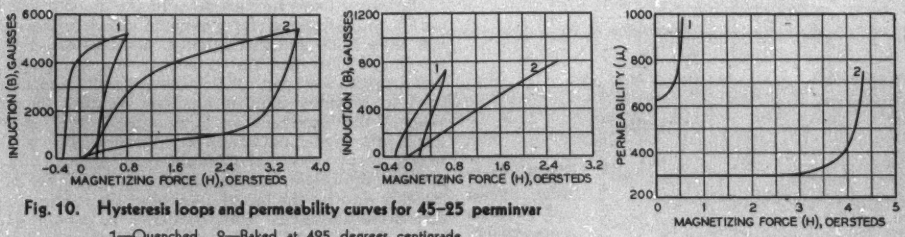


Fig. 10. Hysteresis loops and permeability curves for 45–25 perminvar

1—Quenched. 2—Baked at 425 degrees centigrade

4. For all numbered references see list at end of paper.

and that it will have intrinsically superior eddy current and hysteresis loss characteristics. By virtue of these properties, it will be practicable to make a further substantial reduction in the size of loading coils without sacrifice in service standards. The decrease in the size of the cores with improvement in the core material is illustrated in figure 11.

In d-c apparatus where high permeability and low coercivity are of importance, and where high resistivity does not add to the usefulness of the core material, 78.5 permalloy is suitable. It is used in certain relay structures, usually of marginal type, in which the difference between operating and releasing currents is small.

Table III—Some Remarkable Magnetic Properties Obtained in Laboratory Specimens*

Material	μ_s	μ_m	H for μ_m	H_r	Heat Treatment
"Armco" iron	20,000[1]	340,000[1]	0.021	0.03[1]	18 hr at 1,480 deg C, followed by 18 hr at 880 deg C, both in hydrogen
45 permalloy	11,000	227,000	0.025	0.0145	Melted in vacuum; electrolytic iron and electrolytic nickel; 18 hr at 1,300 deg C in hydrogen
65 permalloy	2,500	610,000[2]	0.0148	0.012[2]	18 hr at 1,400 deg C in hydrogen; heated to 650 deg C 1 hr, cooled in magnetic field of 16 oersteds in hydrogen
78.5 permalloy	13,000[3]	405,000[3]	0.0101	0.0153	$2^1/_2 \times 2 \times 0.109$ in. tape; annealed; wrapped in 2 layers of 3 mil tape and quenched from 600 deg C in tap water
3.8–78.5 Mo-permalloy	34,000[1]	140,000[1]	0.025[1]		1,400 deg C in hydrogen
Permendur	1,000	37,000	0.22	0.20	940 deg C in hydrogen for 18 hr, slowly cooled to room temperature
Permendur	1,300	29,000	0.27		940 deg C in hydrogen, 6 hr; slowly cooled to room temperature
45–25 perminvar		189,000	0.052	0.059	Heated to 1,000 deg C in hydrogen, reheated to 700 deg C and cooled in hydrogen in a magnetic field of 14 oersteds

For explanation of symbols in headings see footnote to table II.
* Except as noted, the values in this table have not previously been published.

For audio transformers, for retardation coils, and for other apparatus in which high permeability and high specific resistance must be combined, both 3.8–78.5 Cr-permalloy and 3.8–80 Mo-permalloy have been used. The former has slightly higher resistivity, but the latter has higher initial permeability and is more ductile.

While the initial and maximum permeabilities of 45-permalloy are not as high as those of 78.5 permalloy, the higher flux densities attained by the former and its higher resistivity favor its use for certain types of relays and transformers where high flux densities are required. It is used also in some instances for cores of coils that require high a-c permeability when d-c magnetizing forces are superposed.

The magnetic characteristics of the perminvars make them especially suitable for use in circuit elements in which distortion and energy loss must be a minimum; but their relatively high cost, and the advisability of avoiding high magnetization throughout the life of the apparatus, have prevented their extensive use in telephone plant. One use for which perminvar is especially suitable is the loading of long submarine telephone cables. Here a high resistivity is very desirable, which has been shown to be obtainable in the 7-45-25 Mo-perminvar. The increase in resistivity resulting from the addition of molybdenum more than offsets the accompanying increase in hysteresis loss, and results in a continuous loading material satisfactory for certain types of loaded cables.

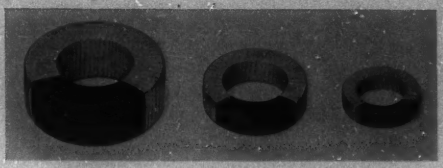


Fig. 11. Equivalent cores for loading coils

Iron dust core (left), permalloy dust core (center), molybdenum permalloy dust core (right)

Permendur was developed for use in apparatus where very high flux densities are desired. For a moderate magnetizing force flux densities of 18,000 and 23,000 gausses readily are obtained. It is used for cores and pole pieces in loud speakers, certain telephone receivers, light valves, and similar apparatus.

It may be seen from this survey that there is a great variety of magnetic materials with widely different properties from which an engineer may choose in designing magnetic elements in which magnetic flux changes are essential. Already these alloys have an important place in telephone plant. However, iron and silicon steel still are used extensively, and will continue to hold their own on a cost basis for some purposes. There is no doubt, however, that alloys of iron, nickel, and cobalt will continue to supplant iron and silicon steel in many places where circuits and apparatus are redesigned to take full advantage of their magnetic properties.

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Breakdown Curve for Solid Insulation

A volt-time breakdown curve for solid insulation, constructed from test data obtained with the use of square edged electrodes, is given in this paper, considerably extending the range of information available on this subject.

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INTRODUCTION, within the past few years, of the co-ordination of transformer insulation (with that of the station equipment and adjacent line insulation) has made the question of the dielectric strength of various types of insulation over the complete range of time a very important one.

The 60 cycle characteristics of solid insulation for periods ranging from about one second to several hours is well known. Some information also has been available, for 2 or 3 years, on the impulse volt-time curve of breakdown of pressboard and linen paper insulations for short periods of time. These data showed that the breakdown strength became constant at 3 microseconds and remained constant as far as tested, from 15 to 20 microseconds for the pressboard and from 800 to 1,000 microseconds for thin linen papers. Until just recently very few, if any, reliable data have been available on the breakdown characteristics of the heavier insulations (pressboard) for periods ranging from around 20 microseconds to 1,000,000 microseconds (one second). The importance of this range of the characteristic curves of insulation has been forced upon the attention of the industry by the disclosures of field investigations that lightning waves having a duration of more than from 15 to 20 microseconds quite often are imposed on a substation and the connected apparatus. This apparatus also is often subjected to switching surges where the voltage may last only a few cycles, and the phenomena fall in this range of the characteristic curve.

In figure 1 are shown the results of breakdown tests recently made on single sheets of oil treated $^1/_{16}$ inch pressboard immersed in oil at a temperature of 25 degrees centigrade, where the time ranged from a fraction of a microsecond to 480,000,000 microseconds (8.16 minutes). It may be noted that the curve can be divided into 3 distinct regions.

The first region, marked A, extends from the beginning up to 3 microseconds. In this region the dielectric strength decreases quite rapidly with increase in the time of application of the voltage. This portion of the curve agrees very closely with the average of the data recently published[1,2,11] on barriers composed of solid insulation (pressboard) and oil in series tested between a flat plane and a square edged electrode. A 2.5 x 40 microsecond positive wave was used in making these tests. Overvoltages were applied to obtain the short-time breakdown values which were measured by the cathode ray oscillograph.

The second region, marked B, starts at the 3 microsecond point and extends to around the 50,000 microsecond ($^1/_{20}$ second) point. The dielectric strength is seen to be constant throughout this region.

In the third region, marked C, the strength again decreases, rapidly at first and then more slowly, gradually becoming constant again.

These 3 regions of the curve are somewhat similar to the "Three Regions of Dielectric Breakdown," given in 1930 by Moon and Norcross,[3] except that their case dealt with "strength vs. temperature," whereas this case deals with "strength vs. time of voltage application."

It has not been possible to derive any single equation of "breakdown vs. time" that fits the entire curve of breakdown, and it is very doubtful if one can be derived. It has been shown,[4] however, that from 1 second to several hours' time the volt-time curve can be expressed by a general equation of the form

$$KV = K\left(a + \frac{1-a}{\sqrt[4]{T}}\right) \qquad (1)$$

where

K = the one minute strength
a = constant depending on the material, temperature, etc.
T = time in minutes

The 60 cycle test points so far obtained on this particular material indicate that the value of "a" in equation 1 is 0.35. Time did not permit tests to be obtained for periods long enough to settle definitely whether or not the curve flattens out at 35 per cent of the one minute strength as indicated by the formula. This part of the curve will be determined later.

The $^1/_4$ cycle breakdown points were made by applying a $^1/_2$ cycle wave starting from zero time. Breakdown occurred on the crest. Solid insulation, when subjected to an impulse wave, seldom breaks down beyond the crest of the wave, breaking down either on the front or crest, depending upon the magnitude of the applied voltage.

It may be noted that there is very little change in the breakdown values when going from $^1/_4$ cycle to an alternating voltage of 3, 7, 11, and 18 cycles of 60 cycle frequency.

Aside from the practical value of knowing the shape of the complete volt-time curve of solid insulation, as already mentioned, there is the interest-

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1. For all numbered references, see list at end of paper.

ing question of the mechanism of breakdown throughout the entire range of time. Within the past few years the general theory of breakdown has received, perhaps, more speculation and experimental attack than any similar subject. In 1904 Townsend[5] attributed the breakdown to ionization by collision, and in 1922 K. W. Wagner[6] proposed the pyroelectric theory. This was later modified by Karman,[7] Rogowski,[8] and Drefus.[9] Later, around 1927, Fock[10] gave a complete mathematical solution not only for the resistivity law, $\rho = \rho_0 \epsilon^{-\gamma T}$, but also for the dielectric loss law, $\rho = \rho_1 \epsilon^{-B_1/T}$.

In any of these theories, it is questionable whether very short "time intervals" were experimentally investigated.

It seems quite certain that a mechanism in which "time" plays an important rôle, as it apparently does in region C, does not apply to the entire curve; otherwise the dielectric strength would not remain constant over so long a period of time—from around 3 microseconds to 50,000 or 100,000 microseconds.

As to the cause of the decrease in the dielectric strength for very short intervals of time down to around 3 microseconds, it is suggested that this may be caused by a mechanical effect; that is, by a shattering effect of the voltage on the fibers. Another possible explanation is that the breakdown from near zero to 3 microseconds time is by ionization by collision of the electrons with the molecules during which period "time" is a factor. Beyond this "time" nothing really happens (when voltage is slightly less than the 3 microseconds breakdown value) until heating or corona or both enter as factor.

As to the effect of the sharp edges of the electrodes on the shape of the curve, regions A and C probably were affected to some extent inasmuch as most of the breaks (90 per cent or more) occurred at or near the edges. However, region B apparently was not affected, as the $^1/_4$ to 18 cycle breaks were not confined to any particular part of the surfaces.

The reason for using square edged electrodes instead of electrodes producing a uniform voltage field was that, as already stated, for co-ordination purposes it was desirable to know the shape of the curve under the worst electrode conditions because many insulations in electrical apparatus are not in uniform fields. To test solid insulation as a *material only*, of course, a uniform dielectric field should be used.

It should be understood that this paper is in the nature of a progress report, and that more exhaustive tests may change slightly some of the values, particularly the values at the 2 ends (regions A and C) of the curve. It is believed, however, that no material change will be found in the shape of the flat part of the curve (region B) when using square edged electrodes.

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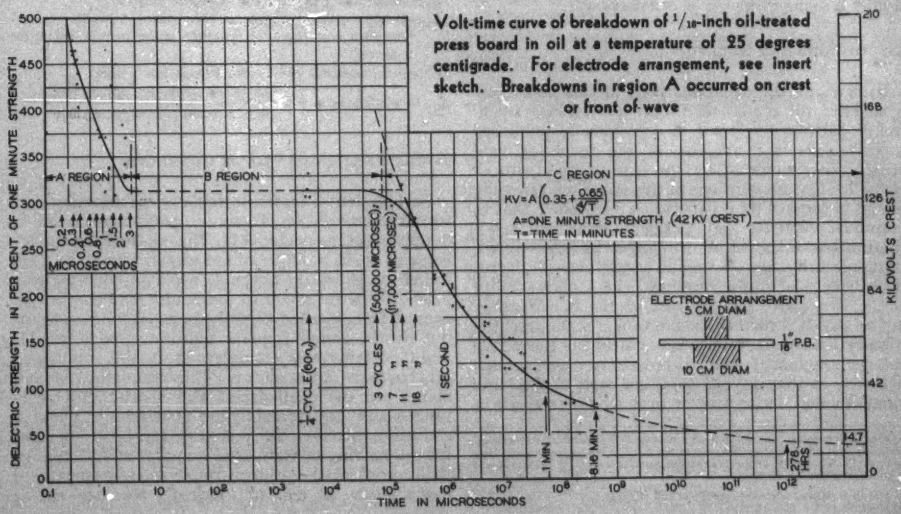

Segregation of Losses in Single Phase Induction Motors

Methods of segregating the load losses in single phase and capacitor induction motors are presented in this paper. Segregation of losses affords a means for checking the accuracy of input-output tests, and is valuable in comparing motors of various designs.

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TO DATE, there are apparently no means published for segregating the load losses of a single phase induction motor. Because of this lack, and for other reasons, the proposed A.I.E.E. Test Code for Polyphase Induction Machines had to be limited to *polyphase* induction machines. This paper makes available methods applicable to the segregation of load losses in single phase and capacitor induction motors. Segregation of losses affords a means for checking the accuracy of input-output tests as well as being of valuable assistance in analyzing and comparing various designs, and can pave the way for extension of the test code. Methods given in this paper have been in practical use for about 5 years on motors ranging from $^1/_{30}$ to 3 horsepower.

Assumptions and Notation

In deriving the equations used in this paper, use is made of the cross field theory as first developed[1] and as further developed in a previously published paper.[2] Use is made also of the revolving field theory,[3] as illustrated by the equivalent circuit of figure 2. The assumptions in this paper are generally similar to those of the 3 papers just mentioned, that is, sinusoidal currents and voltages, sinusoidal space distribution of the stator windings—in other words, harmonic fields are considered negligible—90 degree displacement of stator windings, and a permeability of the iron parts independent of the flux density. In this paper, a further assumption is made that the primary leakage reactance is equal to the secondary leakage reactance; the procedure is clear enough however, so that anyone could go back to the basic equations and derive similar ones by the methods of this paper, except taking into account unequal distribution of reactance.

The notation used in this paper is summarized as follows:

E = impressed volts
r_1 = primary resistance of main winding
r_2 = secondary resistance, referred to main winding
X = "ideal" short-circuit reactance. This is the reactance the motor would have if the secondary winding had zero resistance and were short-circuited
$= x_1 + \dfrac{x_2 X_m}{X_m + x_2}$
X_0 = reactance of primary winding with secondary winding open-circuited
K_r = flux factor $= \dfrac{X_0 - X}{X_0}$
$K_p = \sqrt{K_r}$
$i_m = E/X_m$
I_1 = primary current
I_2 = secondary current in transformer axis (used with cross field theory)
I_3 = secondary current in cross field axis (used with cross field theory)
I_0 = no load current
$S = \dfrac{\text{actual speed}}{\text{synchronous speed}}$
$s = \dfrac{\text{slip speed}}{\text{synchronous speed}}$
R_f = apparent resistance to forward revolving field (see figure 2, also equation 26)
R_b = apparent resistance to backward revolving field (see figure 2, also equation 27)
I_L = measured primary current with rotor locked
W_L = measured primary watts input with rotor locked
$P + r_1$ = real component of impedance with rotor locked, defined in equation 2
Q = reactive component of impedance with rotor locked, defined in equation 3, or "apparent short-circuit reactance"
A = real component of main phase current (capacitor motors)
B = reactive component of main phase current (capacitor motors)
I_m = total main phase current (capacitor motors)
g = real component of capacitor phase current (capacitor motors)
h = reactive component of capacitor phase current (capacitor motors)
I_a = total capacitor phase current (capacitor motors)
K = winding ratio $= \dfrac{\text{effective conductors in auxiliary phase}}{\text{effective conductors in main phase}}$

Determination of Motor Constants

Segregation of losses in single phase motors differs from the segregation of losses in polyphase motors in 3 important respects; (1) The no-load secondary copper loss in a single phase motor cannot be neglected, as shown in figure 4, when determining core loss; (2) the rotor copper loss under load conditions, cannot be computed directly from the slip and output by the simple familiar relation of equation 11; and (3) it is necessary to determine certain fundamental constants of the motor. These fundamental constants are the open-circuit and short-circuit reactances and the actual rotor resistance. These 3 constants, namely, X_0, X, and r_2, can be determined from a reading of watts and amperes at full voltage with rotor locked—primary resistance to be measured immediately at end of "locked" reading—and a

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1. For all numbered references, see list at end of paper.

reading of no load amperes. The primary resistance r_1 can be measured directly by means of a bridge, as eddy current losses in the primary conductors usually can be neglected.

Unfortunately, the interpretation of the no load and "locked" readings is slightly more involved than might be supposed. Using the cross field theory as developed in a previous paper[2] by the author, P. H. Trickey (Diehl Manufacturing Company, Elizabethport, N. J.) gives the following expression for locked-rotor current in some unpublished work:

$$I_L = \frac{E}{(r_1 + P) + jQ} \tag{1}$$

where

$$P = \frac{r_2 K_r}{1 + (r_2/X_0)^2} = \frac{r_2(X_0 - X)}{X_0[1 + (r_2/X_0)^2]} \tag{2}$$

$$Q = \frac{X\left(1 + \frac{r_2}{X}\frac{r_2}{X_0}\right)}{1 + (r_2/X_0)^2} \tag{3}$$

Equation 1 was derived directly from equation 9 of the author's previous paper[2] by putting $S = 0$. Trickey later derived the same identical equation by using the circuit of figure 2.

The no-load current from equation 44 of this same paper,[2] is

$$I_0 = \frac{2E}{X_0 + X} \tag{4}$$

Equation 4 is also very readily derivable from the equivalent circuit of figure 2 by putting $s = 0$. Thus, equations 2, 3, and 4 are valid either on the basis of

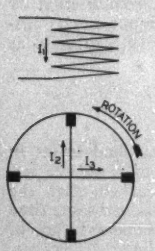


Fig. 1. Representation of the single phase induction motor, based upon the cross field theory

the cross field theory or on the basis of the revolving field theory, as all 3 were derived by each theory separately.

In terms of test results, P and Q are, of course, as follows:

$$P = \frac{W_L}{I_L^2} - r_1 \tag{5}$$

r_1 being measured directly after the locked reading.

$$Q = \sqrt{\left(\frac{E_L}{I_L}\right)^2 - \left(\frac{W_L}{I_L^2}\right)^2} \tag{6}$$

The most accurate method for determining the desired quatities r_2, X, and X_0 from the known values I_0, P, and Q is by simultaneous solution of equations 2, 3, and 4, which yields

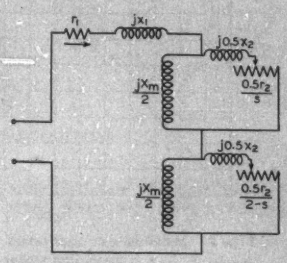
$$X = \frac{E}{I_0} - \sqrt{\left(\frac{E}{I_0} - Q\right)^2 + P^2} \tag{7}$$

$$X_0 = \frac{2E}{I_0} - X \tag{8}$$

$$r_2 = \frac{PX_0}{X_0 - Q} \tag{9}$$

It should be noticed that Q, the apparent short-circuit reactance of the motor is always larger than the "ideal" short-circuit reactance, X. This increase in apparent reactance is actually attributable

Fig. 2. Equivalent circuit of single phase induction motor, based upon the revolving field theory



to the rotor resistance. Except for high resistance rotors, such as found in single-value capacitor motors, it is usually accurate enough for segregated loss measurements to take simply $X = Q$ and to proceed using equations 8 and 9. When doubt exists, however, it is safer to use equation 7.

The necessary fundamental constants having been determined, one now can proceed to segregate the losses.

Primary and Secondary Copper Losses

The primary copper loss is simply $I_1^2\, r_1$, care being taken to correct r_1 to the proper temperature.

In polyphase induction motors, secondary copper loss is a simple function of slip and output:

$$\text{Secondary } I^2R = \frac{s}{1 - s}\,(\text{output} + \text{friction}) \tag{11}$$

In single phase motors, no such simple relationship exists, as will be shown in the following analysis. Let b and c be arbitrary constants, defined by the following relations:

$$b = \frac{\text{secondary main field copper loss}}{\text{output} + \text{friction} + \text{cross field core loss}} \tag{12}$$

$$c = \frac{\text{secondary cross field copper loss}}{\text{output} + \text{friction} + \text{cross field core loss}} \tag{13}$$

(The cross field core loss and friction are treated here as part of the mechanical output.)

Referring now to the performance calculation

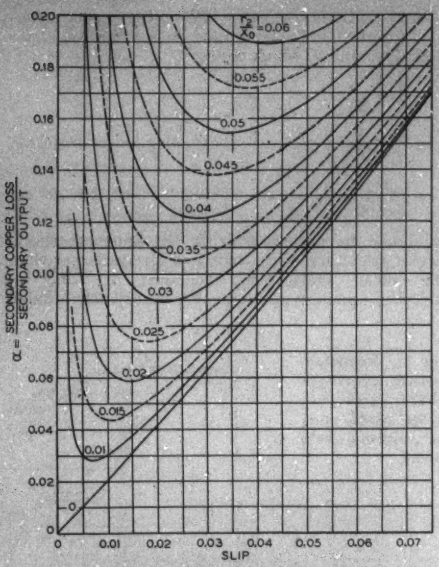


Fig. 3. Secondary copper losses in a single phase induction motor

Slip is expressed as a decimal fraction of synchronous speed

schedule for single phase induction motors, given in a previously published paper,[2]

$$b = \frac{\text{Item 27}}{\text{Item 30}} \tag{14}$$

$$c = \frac{\text{Item 28}}{\text{Item 30}} \tag{15}$$

When r_1, r_2, X, and X_0 are substituted into equations 14 and 15 in accordance with the formulas given in that paper, and the resulting expressions are simplified, r_1 and X drop out and equations 14 and 15 become

$$b = \frac{(1 - S^2)^2 + (r^2/X_0)^2}{[(1 - S^2) - (r^2/X_0)^2]S^2} \tag{16}$$

$$c = \frac{(r_2/X_0)^2}{(1 - S^2) - (r_2/X_0)^2} \tag{17}$$

Now, let

$$\alpha = b + c = \frac{\text{total secondary copper loss}}{\text{output + friction + cross field core loss}} \tag{18}$$

Adding equations 6 and 7 and simplifying there is obtained for the total secondary copper loss,

$$\alpha = \frac{1 - S^2}{S^2} + \frac{2\,(r_2/X_0)^2}{[(1 - S^2) - (r_2X_0)^2]\,S^2} \tag{19}$$

or in terms of slip, equation 19 is

$$\alpha = \frac{s(2 - s)}{(1 - s)^2} + \frac{2\,(r_2/X_0)^2}{[s\,(2 - s) - (r_2/X_0)^2]\,[1 - s]^2} \tag{20}$$

Equation 20 is the relation sought between secondary copper loss and output. In figure 3, the ratio α is plotted against slip, s, with the quantity r_2/X_0 as parameter. Thus, in a single phase induction motor, the ratio r_2/X_0 must be known in addition to the slip, to determine the rotor copper loss at any given output.

Core Loss and Friction

Both primary and secondary copper losses must be subtracted from the running-light input to obtain core loss and friction as shown in figure 4. The secondary copper loss when running light is, using the cross field theory,

$$I_2^2 r_2 + I_3^2 r_3 = 2 I_2^2 r_3 \tag{21}$$

since $I_2 = I_3$ at synchronous speed. Since I_2 is not directly measurable, it is convenient to express it in terms of the primary current, I_0 as follows:

$$I_0 = \frac{2}{2 - K_p^2}\, i_m \qquad \text{(Equation 42 of a previous paper[2])} \tag{22}$$

$$I_2 = \frac{K_p}{2 - K_p^2}\, i_m \qquad \text{(Equation 43 of a previous paper[2])} \tag{23}$$

Dividing equation 23 by equation 22,

$$I_2 = \frac{I_0 K_p}{2} \tag{24}$$

and

$$\text{No load sec } I^2R = 2 I_2^2 r_3 = \frac{2(I_0 K_p)^2 r_3}{4} = 0.5\, K_r\, r_3\, I_0^2 \tag{25}$$

which is a simple, convenient equation for practical use. Core loss may be separated from friction by extrapolating the curve of total input minus primary and secondary copper losses to zero volts as shown in figure 4.

Stray Load Losses

In the author's experience, stray load losses in single phase induction motors are of negligible importance. This conclusion was reached after the methods of this paper had been in use for some time to check brake tests, and no noticeable evidence of stray load losses was found. Undoubtedly, however, this point ought to be investigated and reported upon by others.

Three reasons for the apparent absence of stray load loss may be offered:

1. The per cent increase in primary current from no load to full load is much less in a single phase motor than in a polyphase motor; therefore, part of the losses that would appear as stray load losses in a polyphase motor actually would appear in a single phase motor as core loss.

2. Since a tested value of r_3 must be used to compute rotor copper loss in a single phase motor, it is possible that part of the stray load loss appears as rotor copper loss.

3. Since the methods of segregation of losses in single phase induction motors are inherently less accurate than those for polyphase motors, it may be more difficult to detect stray load losses by input-output tests.

Illustrative Example

A $^1/_8$-horsepower, 6-pole 60-cycle 110-volt split-phase motor tested as follows:

	By Brake Test
r_1 cold = 2.48	Full load current = 3.17 amperes
r_1 hot = 1.15 × 2.48 = 2.85	Full load input = 205 watts
r_1 after locked reading 2.54	Full load speed = 1,160 rpm
r_1 after running saturation 2.65	Full load slip = 0.0333
Locked-rotor watts, at 110 volts = 851	Efficiency = 60.6 per cent
Locked-rotor amperes, at 110 volts = 11.65	Power factor = 0.588

Induced voltage at full load = 110 − (3.17 × 2.85 × 0.588) = 104.7 volts

No load current I_0 at 104.7 volts (from figure 4) = 2.58 amperes

From equation 5, $P = \frac{851}{11.62^2} - 2.54 = 3.76$

From equation 6, $Q = \sqrt{\left(\frac{110}{11.65}\right)^2 - \left(\frac{851}{11.65^2}\right)^2} = 7.04$

From equation 7, $X = \frac{104.7}{2.58} - \sqrt{\left(\frac{104.7}{2.58} - 7.04\right)^2 + 3.76^2} = 6.8$

From equation 8, $X_0 = \frac{2 \times 104.7}{2.58} - 6.8 = 74.2$

From equation 9, $r_2 = \frac{3.76 \times 74.2}{74.2 - 7.04} = 4.15$

r_2 at 25 deg C $= 4.15 \times \frac{2.48}{2.54} = 4.05$

r_2 hot $= 4.05 \times 1.15 = 4.66$

$r_2/X_0 = \frac{4.66}{74.2} = 0.0629$

$K_r = \frac{74.2 - 6.8}{74.2} = 0.910$

The primary copper loss during the running saturation is $2.65\ I_1^2$. The rotor copper loss during the running saturation is, from equation 25,

$$I_1^2 \times 0.5 \times 0.910 \times 4.05 \times \frac{2.65}{2.48} = 1.97\ I_1^2$$

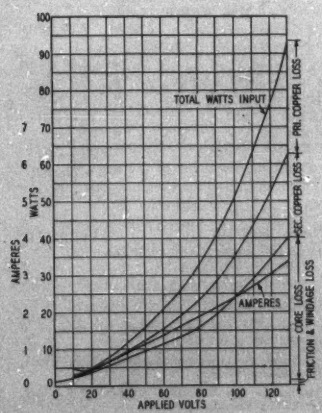


Fig. 4. No-load saturation curve of a typical single-phase induction motor

From the foregoing, the primary and secondary copper losses were computed at each voltage step in the running saturation curve of figure 4 and subtracted from the input as shown. From figure 4,

Core loss + friction loss (at 104.7 volts) = 26.2
Friction loss = 1.5
Full load core loss = 24.7

The full load core loss may be divided arbitrarily into,
Cross field core loss = 12.3
Main field core loss = 12.4

From equation 20

$$\alpha = \frac{0.0333 \times 1.967}{0.967^2} + \frac{2 \times (0.0629)^2}{[0.0333 \times 1.967 - 0.0629^2]\ 0.967^2} = 0.207$$

Now, the losses may be computed:

Cross field core loss	= 12.3 watts
Friction loss	= 1.5 watts
Output	= 124.3 watts
Output + friction loss + cross field core loss	= 138.1 watts
Secondary copper loss = 0.207 × 138.1	= 28.6 watts
Main field core loss	= 12.4 watts
Primary copper loss = $3.17^2 \times 2.85$	= 28.6 watts
Total input	= 207.7 watts
Efficiency, by losses = 124.3/207.7	= 60.0 per cent
Efficiency by input-output	= 60.6 per cent

Segregation of losses on this motor is now complete.

Alternative Method of Computing Secondary Copper Loss Under Load by the Revolving Field Theory

Using the equivalent circuit of figure 2, it may be shown that

$$R_f = \frac{\frac{0.5\ K_r\ r_2}{s}}{1 + \left(\frac{r_2/X_0}{s}\right)^2} \tag{26}$$

$$R_b = \frac{\frac{0.5\ K_r\ r_2}{2 - s}}{1 + \left(\frac{r_2/X_0}{2 - s}\right)^2} \tag{27}$$

The secondary copper loss is

$$I_1^2\ sR_f + I_1^2\ (2 - s)\ R_b = I_1^2 \left[\frac{0.5K_r\ r_2}{1 + \left(\frac{r_2/X_0}{s}\right)^2} + \frac{0.5K_r\ r_2}{1 + \left(\frac{r_2/X_0}{2 - s}\right)^2}\right] \tag{28}$$

In the illustrative example,

$$\text{Secondary copper loss} = 3.17^2 \times \left[\frac{0.5 \times 0.91 \times 4.66}{1 + \left(\frac{0.0629}{0.0333}\right)^2} + \frac{0.5 \times 0.91 \times 4.66}{1 + \left(\frac{0.0629}{1.967}\right)^2}\right] = 26.0 \text{ watts}$$

This value checks quite well with the value, 28.6 found by use of the cross field theory. Equation 28 is probably a trifle easier to use than equation 20.

In thus making use of the revolving field theory, the rotor copper loss is computed from the measured value of primary current instead of from the output as was done when the cross field theory was used. Whether it is inherently and fundamentally more

accurate to use output in preference to primary current, is undoubtedly a debatable question. For polyphase induction motors, the output is used for computing the secondary copper loss.

Segregated Loss Measurements in a Capacitor Motor

Core loss and friction in a capacitor motor may be determined by testing the motor running solely on the main winding. The method is the one described in the preceding paragraphs. The primary copper losses under load can be computed very simply from the measured values of currents in each of the 2 phases and the respective primary resistances of the 2 phases. The loss in the capacitor unit is determined by making a separate measurement of the watts input to the unit at rated frequency and at a voltage which gives capacitor phose current at full load.

There remains, then, only the secondary copper loss to be found. Morrill has shown, in equation 8 of his paper[3] that the equation for the average torque of a capacitor motor, in synchronous watts is

$$T = [I_m^2 + (KI_a)^2][R_f - R_b] + 2K[Ah - Bg][R_f + R_b] \quad (29)$$

The terms of this equation may be rearranged to show the torque components produced by the forward and backward fields, thus:

$$T = [I_m^2 + (KI_a)^2 + 2K(Ah - Bg)]\, R_f - [I_m^2 + (KI_a)^2 - 2K(Ah - Bg)]\, R_b \quad (30)$$

Now, the secondary copper loss of a polyphase induction motor is equal to the synchronous watts multiplied by the slip. Since the slips of the forward and backward fields are s and $2 - s$, respectively, it is evident that

$$\left.\begin{array}{l}\text{Secondary } I^2R \text{ due to}\\ \text{forward field}\end{array}\right\} = [I_m^2 + (KI_a)^2 + 2K(Ah - Bg)]\, sR_f \quad (31)$$

$$\left.\begin{array}{l}\text{Secondary } I^2R \text{ due to}\\ \text{backward field}\end{array}\right\} = [I_m^2 + (KI_a)^2 - 2K(Ah - Bg)]\,(2 - s)\, R_b \quad (32)$$

By substituting from equations 26 and 27,

$$\left.\begin{array}{l}\text{Secondary } I^2R \text{ due to}\\ \text{forward field}\end{array}\right\} = [I_m^2 + (KI_a)^2 + 2K(Ah - Bg)] \times \left[\frac{0.5\, K_r\, r_2}{1 + \left(\frac{r_2/X_0}{s}\right)^2}\right] \quad (33)$$

$$\left.\begin{array}{l}\text{Secondary } I^2R \text{ due to}\\ \text{backward field}\end{array}\right\} = [I_m^2 + (KI_a)^2 - 2K(Ah - Bg)] \times \left[\frac{0.5K_r\, r_2}{1 + \left(\frac{r_2/X_0}{2 - s}\right)^2}\right] \quad (34)$$

In equations 33 and 34, K is the only unknown. Sometimes it is obtainable from design data. If not it can be obtained by means of a winding ratio test.

Winding Ratio Test. Run the motor at rated voltage, E_m, on the main winding only and measure E_a', the auxiliary winding voltage. Impress E_a, arbitrarily chosen as approximately 18 per cent more than E_a' (the underlying idea is to operate the motor at normal airgap flux), upon the auxiliary winding, and run the motor on the auxiliary winding; then measure E_m', the voltage across the main winding. The winding ratio is,

$$K = \sqrt{\frac{E_a' \times E_a}{E_m \times E_m'}} \quad (35)$$

Illustrative Example—Capacitor Motor

A $^1/_4$-horsepower 60-cycle 1725-rpm 2-value capacitor motor yielded the following constants:

Hot resistances:

Main winding	$= r_{1m}$	$= 1.68$	$X = 4.79$
Auxiliary winding	$= r_{1a}$	$= 3.97$	$X_0 = 74.2$
r_2	$=$	3.75	$K_r = 0.935$
r_2/X_0	$=$	0.0505	Core loss $= 20.1$
$0.5K_r\, r_2$	$=$	1.753	Friction loss $= 11.0$

Effective resistance of capacitor $= R_c = 2.88$

The primary resistances were measured by a bridge, and r_2, X, X_0, core loss, and friction were determined by the methods of this paper.

	Test Values		Full Load Amperes Computed From Test	
	Full Load Watts	Full Load Amperes, Total	Real	Reactive
Main phase	150	2.31	$A = 1.362$	$B = -1.87$
Auxiliary phase	99	1.09	$g = 0.90$	$h = 0.61$
Line	249	2.55		
Full load slip $= 0.0333$				

K (known from design constants) $= 1.274$

$I_m^2 + (KI_a)^2 = 2.31^2 + (1.09 \times 1.274)^2 = 7.26$

$2K(Ah - Bg) = 2 \times 1.274\,[1.362 \times 0.61 - (-1.87 \times .90)] = 6.40$

$$\text{From equation 26, } sR_f = \frac{1.753}{1 + \left(\frac{0.0505}{0.0333}\right)^2} = 0.531$$

$$\text{From equation 27, } (2 - s)\, R_b = \frac{1.753}{1 + \left(\frac{0.0505}{1.967}\right)^2} = 1.753$$

The losses may be summarized as follows:

Secondary I^2R due to forward field, by equation $23 = (7.26 + 6.40) \times 0.531$	$=$	7.25 watts
Secondary I^2R due to backward field by equation $34 = (7.26 - 6.40) \times 1.753$	$=$	1.51 watts
Main winding copper loss $= 2.31^2 \times 1.68$	$=$	9.0 watts
Auxiliary winding copper loss $= 1.09^2 \times 3.97$	$=$	4.7 watts
Capacitor unit loss $= 1.09^2 \times 2.88$	$=$	10.2 watts
Core loss and friction loss	$=$	31.1 watts
Total losses	$=$	63.8 watts
Output	$=$	186.5 watts
Input	$=$	250.3 watts
Efficiency by losses $= 186.5/250.3$	$=$	74.5 per cent
Efficiency by brake test $= 186.5/249$	$=$	74.9 per cent

Segregation of losses on this motor is now complete.

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1. The Cross Field Theory of Alternating Current Machines, H. R. West. A.I.E.E. *Jl.*, v. 45, Feb. 1926, p. 160–6.

2. Performance Calculations on Induction Motors, C. G. Veinott. A.I.E.E. Trans., v. 51, Sept. 1932, p. 743–54.

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Measurement of Telephone Noise and Power Wave Shape

Since the original introduction of devices for measuring or rating the wave shape of power system currents and voltages in terms of their influence on exposed telephone circuits, much additional work on this problem has been done; the results of this work are reported in this paper. In part I, a curve of relative interfering effects based upon recent studies is presented, the characteristics of a meter for measuring telephone circuit noise are described, and the results of a comprehensive series of tests on the adequacy of this meter are presented. In part II, a new telephone influence factor weighting curve is presented, and a comparison is given between results obtained by meters embodying weighting networks based upon the new and old curves.

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STUDIES of noise frequency induction problems involving power and telephone systems have shown that power system wave shape and telephone circuit noise commonly contain a number of harmonic frequencies, the important ones lying in the range between about 150 and 3,000 cycles. Due to the characteristics of telephone equipment and the human hearing mechanism there is a wide range in the relative effect of the different frequencies. In the evaluation of inductive co-ordination problems, and the determination of the effectiveness of remedial measures, it is not sufficient to know the magnitudes of the various frequencies present. It is also necessary to have some over-all measurement of the wave shape and noise which bears a definite relation to the effects of noise on a person using a telephone.

A paper recommended for publication by the A.I.E.E. committee on communication, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 28–31, 1936. Manuscript submitted Sept. 27, 1935; released for publication Nov. 1, 1935.

1. For all numbered references see list at end of paper.

Of fundamental importance in this problem are the relative interfering effects of various frequencies and the manner in which the individual frequencies combine to produce the over-all result. These factors were discussed in a paper presented before the A.I.E.E. in 1919 by H. S. Osborne,[1] in which the telephone interference factor meter for measuring power system wave shape in terms of its influence on telephone cirucit noise was first proposed. Since that time a large amount of additional work has been carried out on this problem. Part I of this paper discusses a curve of relative interfering effects based upon the results of this work, describes the characteristics of a meter for measuring telephone circuit noise, and gives the results of a comprehensive series of tests on the adequacy of this meter, with particular reference to the accuracy of the curve of relative interfering effects, carried out under the auspices of the Joint Subcommittee on Development and Research of the Edison Electric Institute and the Bell Telephone System. Part II presents a new telephone influence factor weighting curve for rating wave shape based on the data on relative interfering effects of the single frequencies, reviews the factors included in the derivation of the telephone influence factor curve, and compares the results obtained by meters embodying weighting networks based on the new and old curves.

Part I—Measurement of Telephone Circuit Noise

General

The effect of a given amount of noise on a telephone circuit is a complex one, including the masking of speech sounds, distraction of the listener's attention, and annoyance, and may be modified by various factors such as the noise in the room where the telephone is used, talking volume, efficiency of the telephone circuit, and the reactions of the listener, including the manner in which he uses the telephone. It is not practicable in the day-by-day maintenance of telephone circuits to measure all these effects of noise directly. Rather, it is necessary to make some measurement of the circuit noise which may be related to its effect on telephone transmission. It is desirable that the measuring devices used should measure different circuit noises as equal when they produce equal interfering effects on telephone transmission.

Two methods of measuring telephone circuit noise are at present in use in the Bell System. One of these methods is subjective, i. e., uses the human hearing mechanism as a part of the measuring apparatus, and the other is objective or yields noise measurements without the aid of the human hearing mechanism.

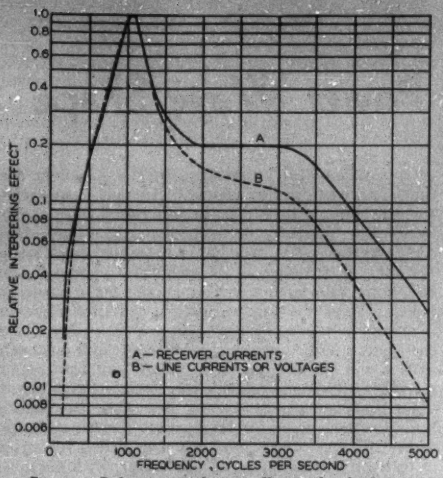


Fig. 1. Relative interfering effects of telephone circuit noise currents

The subjective method is the older of the 2 and has been in use for a number of years. It consists of comparing, in a telephone receiver, the noise to be measured with a noise generated by means of a standard buzzer. The observer may control the magnitude of the buzzer noise by means of a potentiometer until in his judgment it is as disturbing as the noise to be measured. When a balance has thus been made, the result is read directly from the potentiometer.

The objective method of noise measurement has been made available within the last 6 years. It consists chiefly of an electrical network for the weighting of the various single frequency components of a noise in as close accordance as practicable with their interfering effects on telephone transmission, and a calibrated amplifier to raise the energy level of the weighted components sufficiently to operate an electric meter.

One advantage claimed for subjective methods is that they employ the human hearing mechanism, so that it would seem that noises of different types should be measured as equal when they produce equal interfering effects. This apparent advantage is accompanied by the disadvantage, however, that the sensation produced by a given stimulus varies widely for different individuals and for the same individual at different times, so that the average of several measurements by each of several observers is needed for a reasonably accurate result. Also, the theoretical advantage claimed for a subjective method of the comparison type described above is somewhat doubtful, as tests have indicated that even when the average results from several observers are used, the results for noises of different types do not always agree with tests of the interfering effects of these noises made in the presence of transmitted speech.

The chief operating advantages of the objective method are the reproducibility of the results and the ease and speed of making measurements. Its disadvantage lies in the difficulty in determing the complex nature of the hearing mechanism and simulating its characteristics sufficiently well in objective apparatus. Some of the qualities which would be desirable in circuit noise measuring instruments will be discussed as well as the means employed in realizing these qualities.

Indicating Noise Meters

Noise currents of the same magnitude but of different frequencies may produce different effects on telephone transmission. The earliest work of importance in the development of the objective noise meters was directed toward a determination of the relative interfering effects of different single frequency tones. Two types of tests have been used for this purpose, (*a*) judgment tests and (*b*) articulation tests.

In general, judgment tests are set up in such a manner that the observer may compare directly 2 noises in the presence of speech heard over a representative telephone circuit. One of the noises is usually variable in magnitude and is controlled either by the observer or by the person conducting the tests. The 2 magnitudes which the observer judges to be equally disturbing can be measured at a given point in the telephone circuit and, in the case of single frequency tones, the relative weighting which should be applied at that point in the telephone circuit to the 2 tones of different frequency may thus be determined. By using results from a number of observers an average judgment of the relative interfering effects of the 2 noises may be obtained.

An articulation test consists essentially in calling a number of meaningless monosyllables over a circuit to a group of observers, each of whom records the sounds that he hears. The percentage of sounds correctly received is termed the sound articulation for the particular condition tested. Usually each syllable is made up of three sounds (consonant-vowel-consonant) placed in, or at the end of, a sentence, though variations in this technique are sometimes used.[2] On a given circuit 2 different noises which produce the same loss in articulation would usually be considered as equally interfering. As before, in the case of 2 different single frequency noises, measurements at a given point in the circuit could be used to determine the relative weightings to be applied to the 2 noise frequencies.

In 1919 the results of judgment and articulation tests on the relative interfering effects of different single frequency tones were published in the paper by H. S. Osborne.[1] Since that time several other sets of tests have been made, both of the articulation and of the judgment types, in order to check values previously obtained and to bring them up to date.

Noise in the frequency range containing the transmitted speech frequencies most important to understanding, interferes with understanding more than noise in some other frequency range. On the other hand, certain noises produce a harmful effect through annoyance rather than through masking. Thus the

relative interfering effects of different single frequency tones on a telephone circuit are dependent not only upon the characteristics of the human hearing mechanism but also upon the characteristics of the telephone system and may change as the transmission characteristics of the telephone plant change.

From the results of 2 sets of judgment tests and 3 sets of articulation tests, made between 1914 and the present time, a single curve of relative interfering effects of different single frequency tones[3] has been derived. This is shown in curve *A* of figure 1. In deriving it, account has been taken of the trend toward telephone message channels having a more uniform frequency reponse than those used in the past, so that it is expected that this curve and the apparatus based upon it will be useful for a period of years.*

The types of noise usually encountered on telephone circuits are not single frequency but are relatively complex. Hence, it is necessary not only that the proper weighting be used, but also that the method by which the different single frequency components are summed in the human hearing mechanism be simulated in the noise meter.

Information on how single frequencies combine in the human ear is at present incomplete, but it is evidently a very complicated function depending on, among other things, the frequency separation of the components, their levels, their frequencies and probably upon their steadiness. Under these circumstances it was thought best to incorporate a definite rule of combination in a noise meter and then make tests to see how near it came to measuring as equal various complex noises of the types ordinarily encountered in practice which, by tests, produced equal interfering effects. The rule of combination adopted was the rule by which each single frequency contributed to the total meter reading in proportion to its weighted power. (This is the equivalent of the familiar root-sum-square rule for summing currents or voltages.)

In addition to requirements for weighting and rule of combination, it was thought desirable to employ an indicating instrument in which the change of reading was about as rapid as the change in appreciation of loudness in human hearing. From published results[4] and confirming tests it was determined that, on the average, the indicating instrument should reach a full deflection for sounds lasting 0.2 second or longer.

Under these general specifications a few models of circuit noise meters were built and 2 series of tests were made to determine their adequacy for measuring circuit noise. These tests were made by the Joint Subcommittee on Development and Research of the Edison Electric Institute and the Bell System. The first was a rather extensive series of articulation tests on open-wire toll circuit noise, and the second was a series of judgment tests on noise of the type arising by induction in telephone circuits exposed to a-c circuits supplying rectifiers.

* The articulation and judgment tests mentioned here also contributed largely to the selection, by the C.C.I.F. (international advisory committee on telephony), of a curve of relative interfering effects of single frequency tones expressed in terms of voltage across the receiver, which it has recommended as a basis for noise measurement on international circuits. The weighting given in curve *A* of figure 1, when expressed in similar terms is in conformity with the weighting recommended by the C.C.I.F.

Articulation Tests on Open-Wire Circuit Noise

In preparation for the articulation tests[5] on open-wire circuit noise, 2 surveys were made: one of open-wire circuit noise at 6 of the important toll centers in the United States (New York, Chicago, Pittsburgh, Cincinnati, St. Louis, Atlanta) in order that the circuit noises tested might be representative of those actually encountered in practice; and the other of room noise in telephone locations, in order that the room noise conditions used in the articulation tests might simulate those at telephone locations.

In the circuit noise survey, frequency analyses were made of the circuit noises found on a representative number of the toll circuits entering each toll center. These analyses were studied and classified and actual circuit noises, representative of each classification, were recorded on phonograph records. It was found possible to represent the noises measured in the survey by means of nine samples of actual circuit noise, phonographically recorded. These noises were used as a means of determining the adequacy of the noise measuring devices, using articulation as the criterion of interfering effect. A frequency analysis of a representative of these noises is shown in figure 2.

In connection with the room noise survey[6] a study was made concerning the distribution of telephone calls, among cities of different population and among business and residence locations in the United States. Room noise was measured in about 205 telephone locations selected in accordance with the results of this study. After studying the results of the survey a room noise was recorded in which the frequency composition and the sources of noise (people talking, doors closing, etc.) were representative of the room noise present in an average telephone location.

The telephone circuit used in the articulation tests was a representative toll connection consisting of a toll circuit having about 10 decibels loss connected

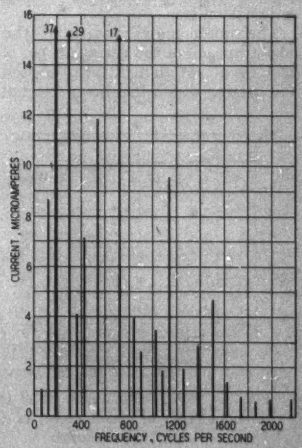


Fig. 2. Frequency analysis of noise current recorded phonographically

at either end to toll switching trunks, local loops, and telephone sets.

The weighting to be applied to single frequency noises depends upon the point in the circuit at which the noise is measured. The weighting shown in curve *A*, figure 1, is for current in the receiver of the telephone set. Curve *B* of this same figure shows the weighting at the end of the toll circuit, which is somewhat different from that in the receiver, due to the transmission characteristics between these 2 points. In practice it is more convenient to measure toll circuit noise at the end of the toll circuit than at the subscriber's receiver. Based on curve *A* of figure 1 and measurements relating current in the receiver to current in the toll circuit, the weighting shown on curve *B* for use at the end of the toll circuit was derived and built into the model noise meter used in these tests. This noise meter also contained a weighting suitable for use in making measurements of noise voltage across the receiver rather than measurements of noise current in the receiver. This was done only for convenience, the weighting employed being directly related to that shown on curve *A* of figure 1 by means of the impedance of the receiver at the various frequencies. Because of the small amount of distortion between the end of the toll circuit and the telephone set terminals of the subscriber's loop, weighting *B* of figure 1 applies about equally well to all points in a telephone circuit between telephone sets.

Both the noise meter and the ear balance measuring device (subjective method described in an early paragraph of part I) were used in measuring the various types of noise tested. It was assumed that when under a given set of conditions, certain magnitudes of the different types of noise produced the same articulation loss, the magnitudes should be measured as equal by a desirable noise measuring device. The extent to which a noise measuring device approached this desirable requirement was determined by examining the difference between measured amounts of the various types of noise which produced a given articulation loss.

The noise meter measured the weighted noise power in each of the various types of noise in terms of decibels above an arbitrarily chosen reference power. The power which has been selected as the reference for circuit noise meter readings is 10^{-12} watts at 1,000 cycles.

In the ear balance measuring device, the potentiometer is calibrated in terms of millionths of the current output of the buzzer flowing through the receiver used in making the balance. Thus the readings of this device are current type units, and have been named "noise units."

Either type of unit may be converted to the other type by means of experimentally determined relations.[5]

The articulation tests showed that when toll circuit noises of various types produced equal losses in articulation under the given set of telephone conditions, they were measured as substantially equal by both objective and subjective methods of measurements. The objective method gave a slightly better correlation than did the subjective even though 18 observers were used in the ear balance tests. The relations between articulation and meter readings of

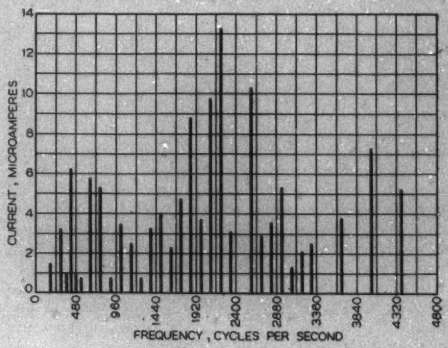


Fig. 4. Analysis of average rectifier noise

noise for 9 types of noise, obtained with handset telephone instruments, are given in figure 3. These relations show fairly good agreement among meter readings of the different noises for a given value of articulation. Similar relations obtained for the desk stand telephone instrument showed about equally good agreements. These agreements among meter readings of different noises were obtained both when the measurements were made at the end of the toll circuit and when they were made at the receiver of the telephone set, using the weightings designed for use at these respective points.

By comparing the relation between meter readings and articulation for the more complex noises with that for those less complex, it was found that the method of allowing each single frequency to contribute to the total meter reading in proportion to its weighted power (root-sum-square rule of addition for currents or voltages resulted in meter readings for complex noises which were somewhat lower than those for less complex noises producing equal articulation loss. This indicated that the rules of com-

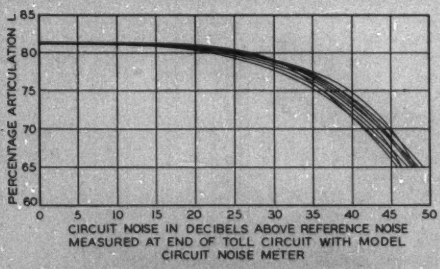


Fig. 3. Articulation versus noise magnitude for 9 different types of circuit noise, as determined with handsets

bining different component frequencies in the human ear and in the noise meter were somewhat different. It was considered, however, that because of the small differences between the results with complex noises and those less complex, the rule of summing the weighted powers in the various single frequencies would be sufficiently accurate for meter measurements of noise of the type tested.

These results were gratifying since it was apparent that a meter which would rate noises somewhat more consistently than a subjective method employing a group of 18 experienced observers was a distinctly superior noise measuring device. Moreover, the tests were sufficiently extensive to make the results quite reliable. A total of approximately 300 articulation tests were made on the 9 types of noise, in each test about 2,300 syllables being recorded, corresponding to about 7,000 sounds. Thus, in the noise tests with the 2 telephone sets, over 2 million sounds were recorded. In successive tests, the percentage of sounds correctly received could be repeated to within about one per cent.

Judgment Tests on Rectifier Noises

None of the 9 noises used in the articulation tests had components of importance above 2,000 cycles. With the trend toward the greater use of rectifiers on power circuits it appeared desirable to make some further tests of the noise meter on noises arising from such sources, since these noises may contain important components at frequencies above 2,000 cycles. Arrangements were therefore made for judgment tests to be carried out on representative rectifier noise and high-frequency noises derived therefrom. A representative open-wire noise from the 9 noises used in the articulation tests was used as a comparison noise so that the 2 series of tests could be related. Judgment tests, rather than articulation tests, were used both because they were more practicable to make in this case, and because in cases where the chief interfering factor may be annoyance, observers' judgment is probably as good a criterion of interfering effect as articulation.

A representative telephone circuit was used similar to the one used in the articulation tests. In some of the tests 10, in others 20, observers were used. Papers and periodicals were read over the telephone circuit to each observer who was able to switch on alternately the fixed amount of open-wire noise or one of the other noises which he could vary in magnitude. When, in his judgment, one noise was as interfering as the other, measurement of each noise was made both with the model noise meter and with the ear balance noise measuring device.

The noises tested included, in addition to the representative open-wire noise used as a comparison noise, (*a*) a noise with a frequency make-up about the average of the rectifier noises so far analyzed in surveys made under the auspices of the Joint Subcommittee on Development and Research of the Edison Electric Institute and Bell System, and (*b*) 3 bands of noise derived from this, each 500 cycles wide with centers at 2,050, 2,560, and 3,150 cycles, respectively. These bands of noise were intended

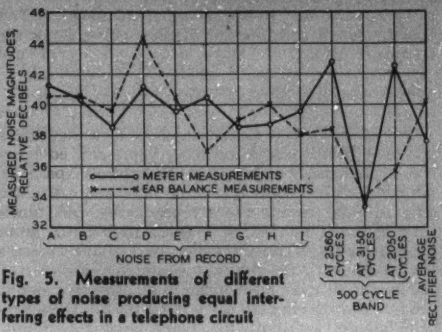


Fig. 5. Measurements of different types of noise producing equal interfering effects in a telephone circuit

to simulate conditions in which resonances in coupled power supply and telephone systems might effectively amplify harmonics falling in certain frequency ranges. A frequency analysis of the average rectifier noise is shown on figure 4.

The tests showed that for amounts of these rectifier noises judged to be equally interfering, neither the meter measurements nor the ear balance measurements were as nearly equal as in the case of the open-wire noises tested by means of articulation. For each of the noises tested appreciable deviations were observed in the magnitudes judged to be equally interfering by different observers. Since this could easily be due to perculiarities in acuity of hearing of the various individuals, the hearing of each observer was tested and no result was used from any observer whose acuity departed greatly from normal in any of the frequency ranges occupied by important components of the noise. The average deviations were of the order of 50 per cent of the average magnitude of noise current. This serves to illustrate the difficulty in judging relative interfering effects when there is a great difference in the types of noises compared. In practice, where the telephone system is used by persons with widely different hearing acuities, the aural effects of bands of noises such as those tested will, of course, vary still more widely.

On the average, the noise meter rated the rectifier noises as well as did the ear balance method with ten observers. Figure 5 shows meter and ear balance measurements of both open-wire noises and rectifier noises producing the same interfering effect as determined by articulation and judgment tests, respectively. The 2 sets of tests have been related by means of the open-wire noise shown in figure 2 which was used as the comparison noise in the judgment tests. Since all the noises produced the same interfering effect, an ideal measuring device would measure them all as equal. Hence, a horizontal line connecting measured magnitudes would indicate an ideal measuring device. The approach to the ideal can therefore be studied by noting how nearly horizontal are the lines connecting the magnitudes given by any measuring device. It may be seen that the values given by the meter are somewhat more constant than are those given by the ear balance method

of measurement. It is also apparent that the correlation is not so good for the rectifier noises as for the open-wire noises.

Meter Method of Measuring Circuit Noise

The advantages of measuring noise by meter methods have been realized for many years and have become increasingly apparent in the light of experience obtained with models of circuit noise meters. Not only are the results more reproducible but much time is saved in making a given number of noise measurements. The tests discussed above indicate that, even with the present incomplete simulation of the human hearing mechanism in an objective meter, the fact that the human ear is not a part of the measuring apparatus is not a disadvantage of importance.

It is, of course, quite possible that for some types of noise not yet tested the meter rating will not be as consistent as for those so far tested. Obviously, not all types of circuit noise have been covered. Further tests are contemplated on other types of noise for the purpose of improving circuit noise meters so that results obtained with them will correlate more and more accurately with effects of noise as determined by the average human ear.

Part II—Measurement of Influence of Power System Wave Shape on Telephone Circuit Noise

General

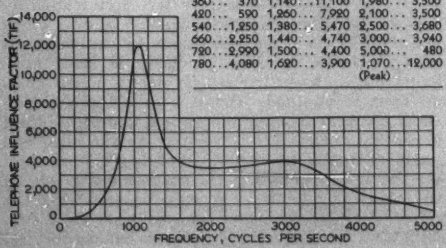
A device called the "telephone interference factor meter" for measuring or rating the wave shape of power system currents and voltages in terms of their influence on exposed telephone circuits was described in the Osborne[1] paper of 1919. With this instrument an indication was obtained of the total harmonic content of a given voltage wave, the individual components present being weighted approximately in proportion to their relative interfering effects. The telephone interference factor was expressed in terms of the total microamperes (square root of sum of squares of weighted harmonic components) in the meter branch of a weighting network per volt (effective) applied to the input terminals. Since 1919, this method of measuring wave shape has been used extensively both by the electrical manufacturers and in the field, and telephone interference factor (usually contracted to TIF) has been found a useful quantity both in rating the wave form of electrical machinery and in evaluating the inductive influence of power systems.

The weighting curve of the original TIF meter was based upon the data on relative interfering effects of single frequencies, obtained during the period from 1914 to 1918, which were limited to the frequency range up to 1,500 cycles. The data obtained from the more recent studies of relative interfering effects described in part I of this paper have made possible a revision[7] of the method of measuring TIF in which the basic principle of the old TIF meter has been retained but in which the frequency weighting characteristic has been revised somewhat and its range extended to approximately 5,000 cycles. In connection with the revision of the weighting curve, the name has been changed to *telephone influence factor* as being a more accurate designation of its function. The new arrangement includes a circuit for measuring the TIF of power system currents as well as that for the measurement of voltages as provided in the original meter. The development of this revision in the method of measuring TIF has been carried on under the direction of the Joint Subcommittee on Development and Research.

Fig. 6. Frequency weighting characteristic for TIF measurements

TIF of Various Single Frequencies

Frequency	TIF	Frequency	TIF	Frequency	TIF
60...	1	900...	7,270	1,740...	3,660
180...	15	1,020...	11,600	1,800...	3,580
300...	205	1,080...	11,980	1,860...	3,570
360...	370	1,140...	11,100	1,980...	3,500
420...	590	1,260...	7,920	2,100...	3,500
540...	1,250	1,380...	5,470	2,500...	3,680
660...	2,250	1,440...	4,740	3,000...	3,940
720...	2,990	1,500...	4,400	5,000...	480
780...	4,080	1,620...	3,900	1,070... (Peak)	12,000



Significance of Telephone Influence Factor

The telephone influence factor (TIF) of a voltage or current wave is the ratio of the square root of the sum of the squares of the weighted effective values of all the sine wave components (including in alternating waves both fundamental and harmonics) to the effective value of the wave. The weightings to be applied to the individual components are given in figure 6. The TIF of a power system current or voltage in an inductive exposure is an index to the influence of that particular current or voltage on the noise-frequency induction in the exposed telephone circuits.

As discussed in detail below, the frequency weighting used in determing TIF is derived from the relative interfering effects of single frequencies in a telephone receiver, the frequency characteristic of the transmission path between the toll or trunk circuit terminals and the receiver of the telephone subscriber's set, and the variation with frequency of the inductive coupling between the power and telephone circuits. It will be noted that the above include all the factors relating the voltage and current on the power system to the noise in the receiver of a telephone subscriber's set connected to an exposed telephone circuit, with the exception of the telephone circuit unbalances. In a large majority of cases involving open-wire telephone toll circuits or open-wire telephone subscribers' circuits employing bridged ringers, experience has shown that such telephone circuit unbalances as contribute appreciably to the noise are practically independent of frequency. However, there are certain types of unbalances

which are not independent of frequency, as for example is the case with certain apparatus used in the exchange plant. In these cases, therefore, the TIF may not be a reliable index to the influence of the power system current or voltage. It should also be observed that as a result of the harmonic frequency transmission characteristics of power circuits, the TIF measured at a point on a power system remote from the exposure location may be considerably different from the TIF in the exposure.

It is apparent from the above that the quantitative evaluation of noise in a given situation requires a knowledge of several factors in addition to TIF. Methods of noise calculation have been described in Engineering Reports Nos. 9, 13, 16, and 17 of the Joint Subcommittee on Development and Research. As regards the influence of the power system, it is evident from the manner in which TIF is measured that it expresses the weighted harmonic content of a given voltage or current wave as a fraction of the effective value rather than in absolute units. The total inductive influence of a particular power system voltage or current is, therefore, a function of its effective magnitude as well as its TIF. It is the usual practice to express the influence of a current in terms of the product of its magnitude times its TIF, this quantity being represented by the contraction "$I \cdot T$." Similarly, the influence of a voltage is frequently expressed as the product of its magnitude, in kilovolts, and its TIF, this quantity being represented by the contraction "$Kv \cdot T$."

Use is commonly made of the residual component of the phase-to-neutral open-circuit voltage TIF of 3 phase machines as an index of their influence when directly connected to a power system and operating with grounded neutral. This quantity, termed "residual component TIF,"[8] is the ratio of the square root of the sum of the squares of the weighted residual harmonic voltages to 3 times the effective phase-to-neutral voltage.

Revised Frequency Weighting Characteristic

The frequency weighting characteristic developed for use in the revised method of measuring TIF is shown in figure 6. TIF weightings taken from the curve for a number of important harmonic frequencies are also given in this figure in tabular form.

In deriving the revised frequency weighting characteristic, the following factors representing distortion occurring in the various media intervening between the power circuit current or voltage and the telephone subscriber's ear were considered:

1. Relative interference effects of single frequency components in the receiver of a subscriber's telephone set.

2. Distortion occurring between the terminals of the circuit in which the noise is induced and the subscriber's receiver.

3. Variation in coupling between power and telephone circuits with frequency.

4. Variation of effects of telephone circuit unbalances with frequency.

As discussed in part I of this paper, data on items 1 and 2 above were combined to derive the line weighting characteristic of the telephone circuit noise meter indicated by curve B of figure 1. It was, therefore, possible to use this curve directly to represent the combination of these 2 factors.

The work of the Joint Subcommittee has indicated[9] that the noise directly induced in an exposed metallic telephone circuit by a given magnitude of power system harmonic voltage or current is directly proportional to frequency. The noise-longitudinal induced in the circuit composed of all wires of the telephone line in parallel with ground return is similarly proportional to frequency except for that component caused by residual magnetic induction.

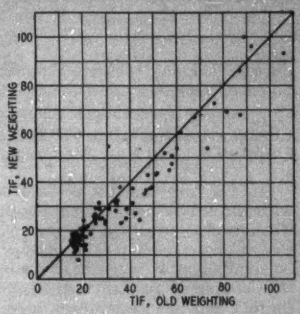


Fig. 7. Correlation of new and old TIF's of open-circuit voltage of a-c generators

However, the effect of departure from proportionality with frequency of this particular component within the noise frequency range at a given location is generally not large and is less than the effect introduced by the differences in coupling at different locations resulting from variations in earth conditions. In deriving the revised weighting curve, therefore, coupling between the power and telephone circuit (item 3 above) has been represented by a factor directly proportional to frequency.

Noise-longitudinal acts on such telephone circuit unbalances as may be present to cause noise in the metallic circuit. Experience has shown that in open-wire toll circuits unbalances can, in general, be approximately represented as independent of frequency. This is also true of open-wire subscriber circuits employing bridged ringers. However, unbalances in certain telephone apparatus used in the exchange plant cannot generally be thus represented. Some of these unbalances increase with frequency, some decrease with frequency, and still others increase over one part of the frequency range and decrease over another part. In view of these differing characteristics no type of frequency weighting for unbalances has been incorporated in the TIF curve. Thus, TIF is a correct index for those cases where unbalance is independent of frequency, and in other cases some empirical modification may be necessary.

To summarize the above, the shape of the revised TIF curve was derived from (1) curve B of figure 1 which represents the relative interfering effects of single frequency currents present in the line and (2) a factor proportional to frequency representing in-

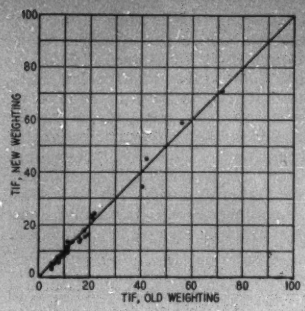


Fig. 8. Correlation of new and old residual component TIF's of open - circuit phase - neutral voltage of a-c generators

ductive coupling between a power line and an exposed telephone circuit.

Correlation Between TIF Measurements With Old and New Weighting Networks

Since a large amount of data has been obtained with the old TIF meter, it was considered desirable, if practicable, to adjust the scale of the revised set so that readings made by this method would in general be approximately the same as readings obtained with the old meter. In this connection calculations using the old and new weightings were made on a large number of machines and circuits of various types on which harmonic analyses were available. These calculations were supplemented by a considerable number of comparative measurements in the factory and in the field using meters employing the old and new weightings. In these measurements particular emphasis was given to the open-circuit voltage wave shape of synchronous machines and to the current and voltage waves on a-c circuits supplying rectifiers. These calculations and tests indicated that, in the average case, reasonably satisfactory correlation between the readings made with the 2 meters would result if a peak value of 12,000 were assigned to the new weighting characteristic as indicated in figure 6. This corresponds with a peak value of 16,400 used with the original TIF meter.

The correlation between TIF magnitudes using the old and new weightings on the open-circuit voltage wave shape of a number of synchronous machines is illustrated in figure 7. The reference line shown is drawn at an angle of 45 degrees. For perfect correlation between measurements by the 2 methods, therefore, the points should fall directly along this line. Comparison of corresponding results obtained (1) for values of the residual component TIF of synchronous machine, (2) from voltage TIF measurements on a-c lines supplying rectifiers, (3) from current TIF measurements on these circuits, are similarly illustrated in figures 8, 9, and 10, respectively.

Calculation of TIF From Harmonic Analyses

Since TIF is the ratio of the square root of the sum of the squares of the weighted components in a current or voltage wave to the effective value of the wave, its value can be calculated if the various component frequencies in the wave are known. The procedure consists in (1) multiplying each component frequency by the corresponding weighting factor shown in figure 6, (2) squaring each of these products, (3) obtaining the sum of these squares, (4) extracting the square root of this sum, and (5) dividing by the effective value of the wave. The quantity obtained in step 4 of this process gives the $I \cdot T$ or $Kv \cdot T$ product.

The following example illustrates this process as applied to a current wave:

Frequency, Cycles per Second (a)	Frequency Composition, Amperes (b)	Weighting Factor (Fig. 6) (c)	Product of (b) × (c) (d)	Squares of (d) (e)
60	11	1	11	121
180	.6	15	9	81
300	.3	205	62	3,840
540	.02	1,250	25	625
900	.04	7,270	291	84,700
1,500	.02	4,400	88	7,740
1,620	.015	3,900	59	3,480
				100,587

The square root of 100,600 gives 317 as the $I \cdot T$ product. Dividing by the effective value of the current gives 28.8 for the TIF.

Devices for Measuring New TIF

Several experimental models of TIF measuring sets meeting the new weighting characteristic have been constructed. The latest of these is designed to operate along the same basic lines as the original TIF meter. It employs a voltage measuring circuit having a somewhat higher input impedance than the original instrument and includes in addition a circuit which may be used, in conjunction with an external shunt, for measuring the TIF of currents. These experimental models have been used on the test floors of the manufacturers and in the field in obtaining the comparative data described above.

The adoption of the rule that coupling will be considered proportional to frequency also makes it possible to use a circuit noise meter and a small amount

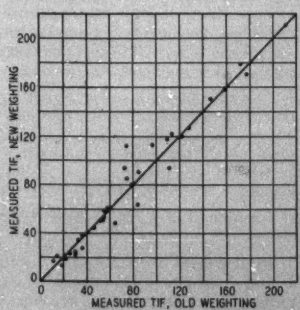


Fig. 9. Correlation of new and old voltage TIF's on a-c circuits supplying rectifiers

of auxiliary apparatus to form a TIF meter. For example, by connecting the input of the noise meter to a power supply circuit through a small capacitance having a much larger impedance than the meter input impedance or the power circuit impedance, a meter reading may be obtained which is equal to 20 log $(A \cdot K_v \cdot T)$ where A is a constant of proportionality. Again by connecting a small inductance

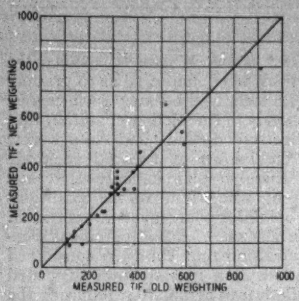


Fig. 10. Correlation of new and old current TIF's on a-c circuits supplying rectifiers

in series with the secondary circuit of a current transformer and connecting the noise meter input across the small inductance, a reading of the noise meter can be obtained which is equal to 20 log $(B \cdot I \cdot T)$ where B is a constant of proportionality. In either case, the proportionality constant may be determined by a single-frequency calibration.

With results from tests made with instruments such as those described above, and a knowledge of the coupling between power supply circuits and telephone circuits, estimates may be made of noise on the telephone circuits. In the past, this method of noise estimation has proved valuable in inductive co-ordination problems. In the future, with revised weighting and improved measuring devices, the method should yield more accurate estimates and should therefore be of greater usefulness.

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* The designation "Engineering Report" refers to reports of the Joint Subcommittee on Development and Research, Edison Electric Institute and Bell Telephone System.

Effect of Total Voltage on Breakdown in Vacuum

The results of a series of high voltage breakdown tests between metal electrodes in high vacuum are reviewed, with consideration of the observed inverse relation between cathode gradient at breakdown and gap length. This leads to the conclusion that the current that flows between electrodes as the conditions for high voltage breakdown are approached must involve positive ions from the anode. The deposition of anode material upon the cathode, which would occur in the event of such positive-ion emission, was found to take place. As final proof of this hypothesis, interelectrode current at constant cathode gradient was found to vary with voltage.

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As a part of a recent investigation[1] of the insulating properties of high vacuum, measurements were made to determine the limiting values of voltage that might be applied between electrodes in vacuum. As the voltage between such electrodes is increased, the attainment of the limiting value is indicated by a very sudden change of the region between electrodes from a condition of insulation to conduction, which occurrence is called breakdown in this paper. The apparatus used for the measurement of breakdown voltage is described in a previous article.[2] It consisted principally of a vacuum tank with a shielded lead-in bushing 38 inches in height, an electrostatic generator, a voltmeter, and auxiliary equipment. A vacuum of the order of 10^{-5} millimeter of mercury could be maintained in the tank, which value was found to be well below that at which results ceased to depend upon pressure. Voltages as high as 500 kv were used. Breakdown data were obtained principally with electrode configurations

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* A doctorate student in the electrical engineering department of the Massachusetts Institute of Technology, Cambridge, during the investigation upon which this paper is based.

1. For all numbered references see list at end of paper.

that would produce between the nearest points of opposite polarity an approximately uniform electrostatic field.

Breakdown Tests

Parameters that were varied during the breakdown measurements were: (1) electrode materials, (2) means of electrode conditioning, and (3) interelectrode distance. A study of the resulting data has led to the phenomenon indicated in the title of this paper, which is considered to be by far the most important outcome of the investigation. The data to be treated in the present article are mainly those which relate to this phase of the results. Consequently, the effects of variation of parameters 1 and 2 are included briefly as a matter of incidental information, while the effect of variation of parameter 3 is considered in detail.

In order to give a comparison of values for different electrode materials, the average voltage required to produce breakdown of a one-millimeter gap after the most effective means of conditioning is given in table I. Various kinds of machinery steels produced surprisingly similar results, and therefore no distinction has been made among them. Though it also gave results practically equivalent to other steels, stainless steel (18 per cent chromium and 8 per cent nickel) is listed separately.

Different methods of electrode preparation and conditioning were tried most thoroughly with steel, which material appeared to give the highest values of breakdown voltage. If it was necessary to smooth the surface of an electrode before it was placed in the vacuum tank, the use of fine emery paper was found to be the best means. The process of polishing and buffing was found to be unessential and often detrimental because of the material that would become imbedded in the electrode. In the vacuum, bombarding the steel electrodes with electrons from a filament usually produced surprisingly little increase of breakdown voltage. Desirable conditioning, however, was obtained with the following treatment. With hydrogen at a pressure of about 1 millimeter of mercury, a discharge was run between electrodes for a period of 3 minutes with a current density of the order of 0.25 ampere per square centimeter. After this the tank again was pumped to a high vacuum, and spark-over between electrodes was produced with the electrostatic generator, the polarity of which occasionally was reversed. This combination of hydrogen discharge and high vacuum sparking usually would result in the attainment of a final breakdown voltage more than double that at which the first spark-over occurred. Sparking with a more powerful source than the electrostatic generator produced about equal breakdown voltages, but was accompanied by serious electrode roughening.

The result of the variation of parameter 3, as stated hereinbefore, leads to the main point of this paper. As the distance between a pair of electrodes (of any of the materials tested) is increased, breakdown voltage is in general not increased at an equal rate. Accordingly, as interelectrode distance and voltage are increased, the average potential gradient at which breakdown occurs is reduced. Since the electrodes of this work were shaped so as to produce an approximately uniform field between their nearest points, this corresponds to the further condition that increases of interelectrode distance and voltage were accompanied by breakdown at reduced electrode gradients. Thus these results indicate that the interelectrode current, which flows as the conditions for high voltage breakdown are approached, must involve more than the mere cathode gradient phenomenon of cold emission that has been considered to be its explanation. An investigation suggested by these results is described hereinafter, following the statement of some essential details of the measurement of breakdown voltage as a function of interelectrode distance.

Table I—Breakdown Voltages for One-Millimeter Gap of Various Electrode Materials in High Vacuum

Material	Voltage in Kv
Steel	122
Stainless steel	120
Nickel	96
Monel metal	60
Aluminum	41
Copper	37

Configuration and Polarity of Electrodes

Electrodes for the breakdown tests consisted of a one-inch sphere opposite a plane. For most of the work, the plane had a rectangular boundary approximately 3 by 4.5 inches and was placed against a larger plate with rounded edges. For the data carried to 500 kv, the plane was reduced to a 2-inch circle but was surrounded by a group of intermediate-voltage shields.[2]

These dissimilar electrodes would be expected to give a higher value of breakdown voltage with the polarity that corresponds to the lower cathode gradient, i. e., with the plane negative; this was found to be true, especially with the longer gaps. Because of certain deductions (in the discussion that follows) that can be made for the negative polarity, this paper is concerned with the sphere and plane, respectively, as anode and cathode.

Typical Results of Breakdown Voltage Versus Distance

A curve of breakdown voltage versus interelectrode distance is given in figure 1, which represents a run with steel electrodes. Also in this figure the corresponding curve of average breakdown gradient is given; and it should be noted that this quantity varies inversely with distance. Between 0.2 and 4 centimeters, the data for the curve of breakdown voltage very closely fit the empirical relation,

$$v = \frac{590d}{0.77 + d}$$

in which v and d represent, respectively, voltage in kilovolts and interelectrode distance in centimeters.

Though the curves of figure 1 do not represent the best electrode conditioning, they were chosen for inclusion here because of their voltage range. The continuously decreasing slope of the curve of breakdown voltage versus distance, however, is characteristic of all of many breakdown tests covering the variations of materials and conditioning mentioned. That the shape of the curve of figure 1 is thus typical of all the curves of breakdown voltage versus distance is to be emphasized because of its importance in the discussion to follow. Another matter to be pointed out in connection with figure 1 is that these results were usually reproducible to within a few per cent when all conditions of a test carefully were reproduced. This may be judged to some extent by the amount of the deviations from the curve. It does not follow, however, that after taking data for the upper points of such a curve the lower points could be closely checked. The lower portion of the curve would be found to have shifted somewhat as a consequence of the electrode treatment represented by the high voltage spark-over. The resulting curve, however, would still be of the same general character as that given here.

Variation of Maximum Cathode Gradient

The first phase of the investigation suggested by the foregoing variation of average gradient consisted in scrutinizing to some extent the manner in which the maximum gradient upon microscopic surface irregularities of the cathode might vary under conditions of constant average gradient. With the plane cathode and the spherical anode of the breakdown tests, maximum cathode gradient will exist at the base of the perpendicular from the plane to the nearest point of the sphere. With the assumption of a very large plane, an otherwise isolated sphere, and smooth surfaces, maximum cathode gradient may be expressed in terms of the average value on this perpendicular by means of a factor given by Peek.[3] This factor, being a function of interelectrode distance d, will be designated $f_1(d)$. From a value of unity for $d = 0$, it decreases toward the limit zero for $d = \infty$.

Let it be assumed that interelectrode distance d and voltage v are varied proportionately so that a constant average gradient E is maintained along the perpendicular from the plane to the nearest point of the sphere. Obviously, $E = v/d$. On the basis of smooth geometric surfaces, maximum cathode gradient e_s is related to E by the factor $f_1(d)$, or $e_s = Ef_1(d)$. Since $f_1(d)$ is an inverse function of d, maximum smooth-surface cathode gradient varies in an inverse manner with distance.

To determine the manner in which the foregoing reasoning should be modified in order to take into account the effect of a surface irregularity, first reference is made to Bateman.[4] By representation of a surface peak as an ellipsoidal column projecting above a plane, it is shown for a mathematically infinite separation from another plane that there will be a definite ratio of concentration of gradient on the peak of this projection. This ratio of concentration for infinite separation will be designated $f_2(\infty)$. Maximum gradient on the projection will equal, of course, that which would exist on a smooth surface multiplied by $f_2(\infty)$.

Obviously, if the plane with the projection and the opposite smooth plane be moved toward each other, the ratio of concentration will increase continuously, becoming very large as separation becomes comparable with the height of the projection. Thus, the ratio of concentration of gradient is an inverse function of d; it will be designated $f_2(d)$.

In the foregoing case the projection is situated in a region where the electrostatic field would have been uniform in its absence. In the case of a plane and a spherical electrode, an essentially similar condition is obtained if such a hypothetical peak, small compared with the sphere, be mounted on the plane at the base of the shortest line between the plane and sphere. The gradient e_p at the peak of the projection then is related to e_s by $f_2(d)$, or

$$e_p = Ef_1(d)f_2(d)$$

Since both $f_1(d)$ and $f_2(d)$ are inverse functions of d, it follows that the foregoing variation of voltage in direct proportion to interelectrode distance will result in an inverse type of variation of maximum gradient on the assumed cathode peak.

For the actual case of a cluster of different types of irregularities on both the plane cathode and spherical anode, a similar statement regarding the variation of maximum cathode gradient might be vitiated in but one way. As the distance between the plane and spherical electrodes is increased, a larger area of the cathode comes under the influence of a relatively strong field. If the newly exposed region contain a peak sufficiently sharper than any at the center, it might seem possible for an increase of interelectrode distance to be accompanied with an increase of cathode gradient. However, if maximum cathode gradient be related to breakdown voltage, to account for the smooth experimental curves of breakdown voltage versus distance it would be necessary for the cathode to have surface irregularities graded in sharpness as a function of distance from the center of the test spot. Therefore, with the electrodes of the breakdown tests, an increase of electrode separation accompanied by a proportionate increase of voltage could not produce an increase of cathode gradient,

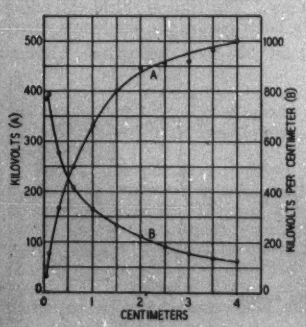

Fig. 1. Breakdown voltage (A) and breakdown gradient (B) versus interelectrode distance

unless there existed during the tests a very special type of distribution of cathode irregularities.

Conclusion From Breakdown Measurements

The experimental curves of breakdown voltage versus electrode separation have been curves of continuously decreasing slope. Therefore, either (1) breakdown occurs at a continuously lower maximum cathode gradient as electrode separation and voltage are increased, or (2) there exists during the tests a distribution of cathode irregularities similar to that contemplated, but accentuated sufficiently to account for the observed decrease of average gradient.

If the condition 1 be valid, the current that leads to breakdown must be attributable to more than the cold emission of electrons, because as gap length and voltage are increased breakdown occurs at continuously lower cathode gradient. This of course might be attributed to gaseous conduction except that the breakdown tests were made at pressures well below that at which results ceased to depend upon pressure. This, however, could be explained on the basis that, as gap length and voltage are increased, the higher voltage electron bombardment causes positive-ion emission from the anode. By bombarding the cathode, such emission could result in electron emission[5] at lower cathode gradients. In this manner, high voltage breakdown at lower cathode gradients could be explained.

Experiments to Check Positive-Ion Hypothesis

As a check upon the foregoing explanation involving the hypothesis that positive ions play a part in high voltage interelectrode conduction at voltages below breakdown, 2 experiments were made:

1. Electrodes of different materials were used to determine whether anode material actually is deposited upon the cathode, which would result if positive ions play the rôle stated hereinbefore.

2. Apparatus was constructed for the measurement of interelectrode current in a region of uniform field and constant electrode area, as voltage and gap length were increased proportionately toward breakdown conditions.

These experiments and their results are described in the following section of the paper.

Electrodes of Different Materials

For an experiment with electrodes of different materials, tests were made with a steel cathode and a copper anode. At the outset, this gap was found to give values of breakdown voltage definitely differing from those for steel electrodes but corresponding to those for copper electrodes. Since interelectrode current must be initiated by cathode emission, the fact that these electrodes displayed the characteristics of the anode material is alone an indication that this material was carried across to the cathode. Since a single instance of this sort might be attributed to the pulling off of loose anode material by electrostatic attraction, the electrodes were moved so that the same anode faced a fresh cathode region. In this way, at a succession of 3 cathode regions, identical results were produced. As a further check, the 3 regions on the steel cathode later were analyzed spectroscopically; strong copper lines were observed, which were entirely missing from other portions of the electrode. Thus it was shown definitely that anode material was transferred to the cathode.

Incidentally, about a 20 minute application of voltage near the breakdown value of these copper-steel gaps was sufficient to produce a visible light brown spot upon the cathode. This of course represents a very small deposition of material, of which quantitative determinations were not attempted.

Electrode for Current Measurement

A description of the apparatus for the measurement of interelectrode current in a region of uniform field and known electrode area follows. The conditions to be secured for this work suggest the use of flat circular electrodes with guard rings; but guard rings, however well fitted, would produce some edge effect. Since cold emission is a function of cathode gradient, any arrangement of cathode guard rings would be open to serious question. For the anode, however, the effects of a guard ring would be much less serious. An anode gradient of 35×10^6 volts per centimeter has been shown to produce no detectable current.[6] In view of these considerations it was decided to use a guard ring on the positive side of the gap.

To meet the second requirement of securing a region of uniform field, a design for that purpose[7] was followed and resulted in the outside contour of the left electrode of figure 2. Other experience of the writer with a pair of electrodes of this type had indicated that within proper limits of gap length they produce a substantially uniform field. (This was indicated by the fact that a large model of this type of gap, which was built for voltage measurement, was found to spark over at random points on the parallel surfaces if the gap length were less than the diameter of the flat area.) As may be seen in the figure, this design was applied in the present investigation only to the anode, and a plane surface was used for the cathode.

The central part of the anode was separated from the outer guard ring by 3 small mica spacers, and 3 mica-insulated clamping screws were used between these parts. The diagram of figure 2 shows one spacer and screw. The conical shield extending to the left from the outer part of the anode was a part

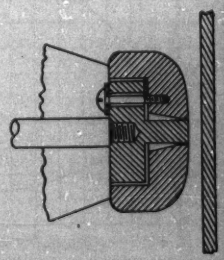

Fig. 2. Guard ring anode and flat cathode

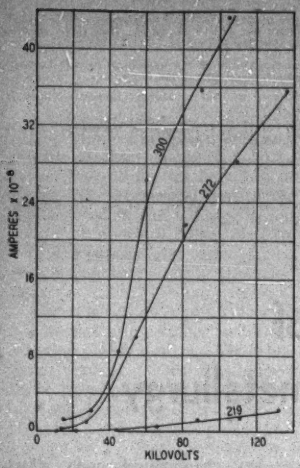

Fig. 3. Current at constant cathode gradient versus voltage

Average gradient (kilovolts divided by interelectrode distance in centimeters) is indicated on curves

of continuous shielding about the connections to the central part of the anode. On the face of this electrode, the radial clearance between the central core and guard ring was 3 mils. In order that the reader may have an idea of dimensions, the diameter of the central core was 0.244 inch, and the relative proportions of figure 2 are fairly accurate. The material chosen was rolled nickel with less than 1 per cent of impurity. Before being used, the guard ring anode and flat cathode were aligned with considerable care. The parts were connected electrically as follows: the cathode directly to the high voltage lead from the generator, the guard ring of the anode directly to ground, and the central portion of the anode through a galvanometer to ground.

Results of Current Measurement

The object of constructing this guard ring anode was to determine whether interelectrode current at voltages below that of breakdown is a function of cathode gradient alone, or whether it may depend also upon voltage. As the most direct experimental approach to this determination, current to the central core was measured while voltage and gap length were increased proportionately so that constant (or slightly decreasing) cathode gradient was maintained. The results of this experiment for 3 values of gradient are shown by curves of current versus voltage in figure 3. These curves show very strikingly that current is a function of voltage as well as gradient.

It might be expected that curves similar to those of figure 3 could be carried over a much greater range of voltage and distance than was done. However, the arrangement of electrodes for current measurement was capable of producing an essentially uniform field in its central region only with gap lengths less than about 0.4 centimeter. With greater separation the region of strongest field would move outward and spark-over likely would occur on the guard ring, especially during runs at the larger gradients. On account of the care taken in shaping and aligning these electrodes, sparking was to be avoided as much as possible. While the data for the curves of figure 3 were being taken, breakdown was avoided until an attempt was made to secure an additional point on the upper curve. After breakdown had occurred, previous data could not be checked; and it thus was indicated that the electrodes had been changed appreciably.

Portion of Total Conduction Attributable to Positive Ions

The positive-ion hypothesis, to explain the manner of variation of breakdown voltage with interelectrode distance in high vacuum, has been checked with 2 types of experiments. The first consisted in detecting the transfer of anode material to the cathode and, like the breakdown voltage analysis, represents a necessary but not a sufficient condition to prove the hypothesis. However, the second type of experiment, which consisted in showing that interelectrode current varies with voltage during the maintenance of constant cathode gradient, does represent a necessary and sufficient condition to prove the hypothesis. Thus it has been shown that positive ions from the anode play a rôle in high voltage conduction between metal electrodes in high vacuum.

In order to determine the fraction of total conduction attributable to positive ions, measurements were made of relative power dissipation on 2 steel electrodes for a few conditions of voltage and spacing. These electrodes consisted of a spherical shell opposite a solid sphere. The former was supported by 3 small wires, and the latter was in contact with another heavy metal part. By this means the temperature of the hollow electrode was made comparatively responsive to energy dissipation, so that its rate of temperature rise might be used as a relative measure of the power received by it. The solid electrode was made unresponsive so that its effects as a source of heat radiation would be minimized. From the voltage readings of a thermocouple, of which 2 of the supporting wires to the hollow electrode were a part, determinations were made of the rate of temperature rise of this electrode operated each way with regard to polarity. As anode the rate was several hundred times the rate as cathode. This indicated that only a small fraction of a per cent of total conduction is directly attributable to positive ions. Consequently, their principal effect is to cause electron emission at lower gradients by bombardment of the cathode.

Although the foregoing hypothesis concerning positive ions is quite unlike that based upon previous investigations, it should be pointed out that the voltage range considered herein far exceeds that of previous work. The upper limit of the breakdown tests, 500 kv, is 17 times the highest value for which similar data could be found in technical literature. In a 17-fold extension it is not surprising that a new effect might be observed.

As a designation for the dependence of interelec-

trode current upon voltage (in addition to cathode gradient), the term "total-voltage effect" has been suggested by R. J. Van de Graaff, who predicted its existence.[8]

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The Engineering Development of Electrochemistry and Electrometallurgy

Some notes on the engineering development of electrochemical and electrometallurgical industries are given in this paper, with particular attention to progress of these industries in France. A discussion of the general problem of supplying electric power to these industries is followed by data on the development of certain processes which significantly illustrate "direct uses" of electricity in industrial processes. This paper by a distinguished French engineer contains considerable information not readily available in the United States.

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THE transformation which the electrochemical and electrometallurgical industries have undergone during the first third of this century takes an entirely different aspect depending upon one's viewpoint. While one observer is impressed by the power of modern apparatus, its perfection, dependability, and the systematic organization of the plants, another observer considers rather the manufacturing processes, the chemical reactions which they bring into play, and according to the latter person, changes have been rather slow during recent years.

A paper recommended for publication by the A.I.E.E. committee on electrochemistry and electrometallurgy, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 28–31, 1936. Manuscript submitted Aug. 30, 1935; released for publication Oct. 2, 1935.

Translated from the French by L. A. Huguemont of the General Electric Company, Schenectady, N. Y.

The principal or key chemical methods, which were applied in the most important manufacturing processes, have remained the same, and most substances produced by these industries were manufactured long ago in the same manner as they are now; thus industries covering the production of calcium carbide, ferroalloys, chlorine and chlorates, aluminum, sodium, graphite, abrasives, and many others have remained practically unchanged from the purely chemical viewpoint.

However, the chemist does not ignore the progress made, often by adaptations of older methods, in industries more modest as regards quantity or value of the products. Among these processes may be mentioned the igneous electrolysis which produces alkaline and alkaline-earth metals (the most remarkable one of which is probably glucinium or beryllium), which are extensions of already-known preparations of aluminum and sodium. Cerium as incorporated in igniting devices such as cigar lighters has become a serious competitor of the match.

The same applies to the production of zinc by aqueous electrolysis permitting utilization of poor ores, to the plating by nickel, chromium and other metals, as well as for the preparation of superoxidized substances and to the preparation of cyanides.

The number of products which can be obtained by means of arc furnaces has increased, high temperature fusion has been developed, and fused silica is found in numerous applications.

The purely gaseous arc had given rise to hopes, especially as regards the direct fixation of atmospheric nitrogen, but notwithstanding its great simplicity, this method is now put in the background because of its poor electric efficiency. On the other hand, indirect rival methods, such as the fixation of nitrogen by means of calcium carbide for the production of cyanamide, the compression of a mixture of nitrogen and hydrogen—the latter even resulting from the electrolysis of water—which compression may be followed by the oxidization of the ammonia thus produced, so as to obtain nitrates, all these

methods require only $^1/_3$, or even less, of the electric energy required by the arc alone.

Effects of Fluctuations in Power Supply

Electrochemical and electrometallurgical processes require in most cases electric energy at very low cost. It can be seen easily that with the ordinary rate schedules—no matter how fair they are—which apply to the mechanical and textile industries (generally located in the vicinity of important centers of power production), that the cost of the energy for electrochemical and electrometallurgical processes would sometimes attain the sales price of the products.

For this reason water power plants were resorted to, necessitating higher installation costs than coal burning plants but once installed, operating without great expense. This advantage was formerly even more pronounced because of the moderate interest rate required for the capital investment.

Each hydroelectric plant produced the electric energy which was required for the manufacturing process or processes under consideration. The output of power from these plants is variable, depending upon the hour, day, and season. As a matter of fact, many old Alpine stations have their output reduced in winter to $^1/_4$ or even less of the maximum power obtained during the warm season. Another limiting feature is that the quantity of manufactured products must follow the market fluctuations.

To take care of such variations and fluctuations several manufacturing processes may be combined. Take, for instance, the electrolytic manufacture of aluminum which proceeds at temperatures exceeding 900 degrees centigrade and which demands rather careful supervision and is badly affected by fluctuations. Waterfalls subjected to strong annual variations necessitate the gradual shutting down of the plant and considerable slackening of the operation for several months. Not to mention the larger equipment and the more rapid wear and tear this condition entails, it requires besides a much higher specific consumption (in kilowatt-hours per kilogram of metal produced). Sometimes several weeks are necessary in order that the production of an aluminum cell (or furnace) may attain the production obtained during a very regular program, especially as daily fluctuations must be reckoned with. Among others, rather old observations may be mentioned relating to this point and showing that the specific consumption of the first 122 operating days of a group of 40 furnaces taking a total of 10,500 amperes was 31.4 kilowatt-hours per kilogram, while; when the first 30 days were deducted, the consumption was reduced to 26.7 kilowatt-hours per kilogram and when the first 60 days were deducted, the specific consumption became 24.9 kilowatt-hours per kilogram, a value which was then retained for the remainder of the operation, and became even somewhat lower. It has been estimated that an aluminum plant supplied from a hydroelectric installation under the condition of variations in power supply frequently encountered would have a specific

Fig. 1. General view of 2 16,000 kva single phase Miguet-Perron furnaces operated on a 2 phase circuit. See page 1326 for a description of this furnace

over-all energy consumption $^1/_5$th greater than that required, with a constant power supply.

In contrast to this, the manufacture of calcium carbide can withstand much better certain transient variations, the more so the larger the furnace. Moreover, the furnaces do not require that long starting period during which the output is mediocre; after a little time they reach normal operating conditions, and for this reason one can consider starting and stopping the furnaces for periods attaining sometimes 2 weeks at the most.

Aqueous electrolyses allow variations that are even more pronounced. One of the oldest industries, the electrolysis of sea salt solutions, that produce chlorine when diaphragms are used and chlorates when no diaphragms are used, bears readily limited variations in the case of chlorine, with some inconveniences however, but wide variations in the case of chlorates. For instance, a sodium chlorate cell with a normal rating of 2,500 to 3,000 amperes can be operated over the range of 3,500 to 100 amperes without affecting particularly the specific consumption. Another example of this kind is the electrolysis of water. Such processes can be used to absorb secondary power under widely varying conditions. However, such combinations of different industries are bound to be limited, not only because of the necessity of employing conjointly many engineering experts and much technical equipment, but also because of purely commercial considerations.

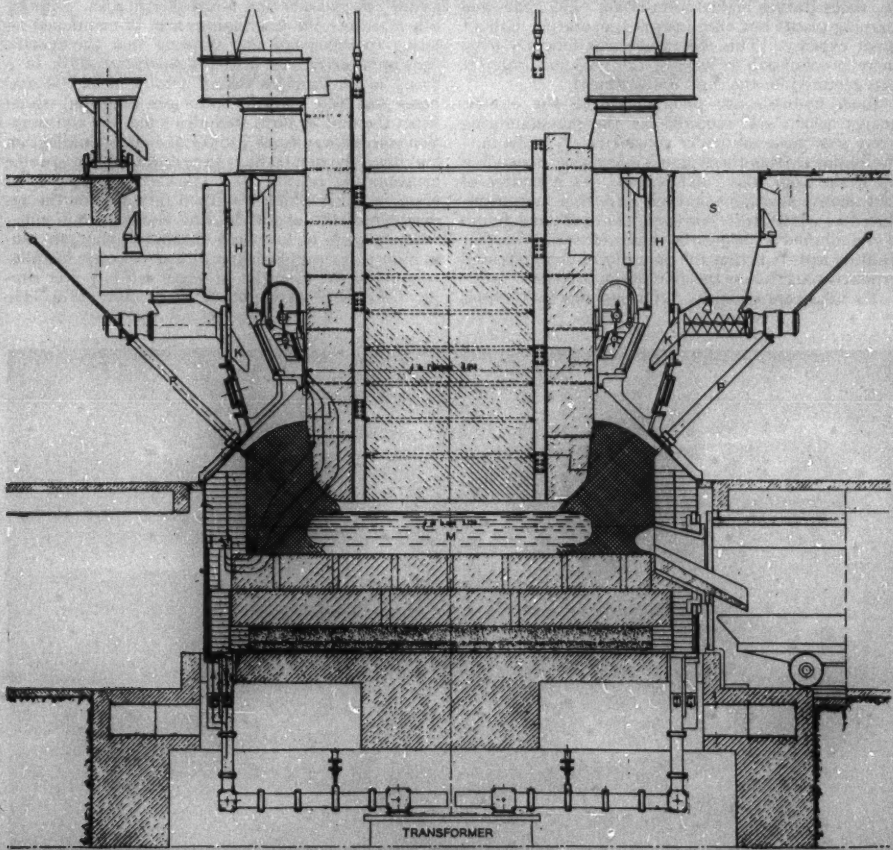


Fig. 2. Cross section of a 15,000-kw single-phase 50-cycle Miguet-Perron calcium carbide furnace, of the type shown in figure 1. Transformer (below furnace) rated 16,500 kva, 25/55 volts. Top of furnace, gas outlets, and upper end of electrode not shown (see figure 4)

H—Gas outlets *P*—Pokers *S*—Silos *K*—Hoppers *M*—Molten carbide

Use of Alternating Current or Direct Current

All this led, first to the combination of several plants by means of transmission lines, and then to the creation of networks in which all the producers operate in parallel, regardless whether their plants are hydroelectric or steam-electric plants. It is from these networks that the consumers—who are to a certain extent the producers themselves, especially the electrochemists and electrometallurgists owning waterfalls—derive the energy they require. The description of such networks is beyond the scope of the present article.

Such a principle leads readily to the production of alternating current (3 phase power being universally adopted), whereas many early plants with primitive installations operate with direct current. It is a well-established fact that it is nearly always advantageous to install alternators, even when direct current is utilized in the plant, as happens when aluminum, magnesium, sodium, chlorine, and its compounds are electrolytically produced. On some occasions direct current has been utilized for purely electrothermal operations; however, no noticeable advantage was derived from that practice.

With alternators it is possible to reduce the number of the generating sets; d-c machines cannot be built for comparable rates of power; the ratio is sometimes of an order of magnitude of 10 to 1. This leads to an appreciable decrease in the cost of the hydroelectric plant which needs less pipes, fewer valves, and discharge canals, etc. Certain hydroelectric plants with d-c machines contain up to 30 turbine-generator sets, while 3 alternators would have sufficed in installations built according to modern conceptions.

The efficiency of more powerful sets is appreciably higher; this applies to the turbine as well as to the electric generator and makes up, sometimes completely, for the loss caused by the necessary conversion into direct current. Because of these well-known reasons, the recent well-designed plants have been provided with alternators.

The transformation of alternating current into direct current is often accomplished by means of rotary converters which have a better efficiency than motor-generator sets. For instance, in a sodium chlorate plant thorough tests, which lasted several years, disclosed that the conversion from high voltage alternating current into 400 to 500 volts direct current took place at an efficiency of 92 per cent. This excellent result is due to the fact that the machines operated at full load without important variations, for more than $^{9}/_{10}$ of the time.

The direct voltage must be regulated, more or less depending upon the prevailing conditions. In practice, rotary converters permit a plus or minus 5 per cent regulation by means of their excitation, as an effect of added inductance or of high leakage transformers; the power factor remains about 92 per cent. Inasmuch as the starting takes place on the a-c side, the machines remain very simple, a very important point for the electrochemist who has sometimes more trouble with his electric equipment than with his electrolytic plant.

In some cases rotary boosters and starting motors are added to the rotary converters; also, voltage regulators have been installed between transformers and converters, and these voltage regulators require additional transformers when the primary voltage is too high. In general, all this complicates matters, reduces the efficiency, and it is just as well, if not better, to adopt under such conditions motor-generators which have at least the advantage of allowing any voltage variation desired.

Mercury rectifiers are little used, for in general the voltages required are low and the currents high, conditions which are not favorable to rectifiers. When prolonged high load operation is the rule, rectifiers will not improve the efficiency, or do so but very slightly. However, they have one advantage which is sometimes appreciated, they are noiseless. The progress accomplished in their manufacture will no doubt further their application in electrochemistry, especially if their price becomes somewhat advantageous.

Supplying Load From Power Systems

The success attained by the tying of electrochemical and electrometallurgical installations to general transmission lines to which they supply and from which they derive electric energy—thus becoming parts of a system which benefits everyone—has directed the attention of steam power plant operators to electrochemical manufactures, for the purpose of utilizing power during off-peak hours. For instance, plants for the production of calcium carbide have been so built. While the small 1,000 kw furnaces, which were in vogue in the year 1900, would not permit considerable power fluctuations which would entail serious temperature variations and thus interfere with production, modern furnaces of 10,000 kw and more can withstand power reduction lasting an extensive period of time and which, nevertheless, will not entail more than a moderate increase in the specific power consumption, while at the same time the purity of the product remains unaltered. This adaptability is partly due to their large weight giving an important heat reserve, partly to the relatively small heat losses through the furnace walls. It is possible to vary the voltage in the ratio of about 1 to 2, and also to alter the current. The result is that the producer of electric power has an apparatus at his disposal which allows fluctuations, amounting to thousands of kilowatts, sometimes in the ratio of 1 to 4.

The same results can be accomplished with other products. For instance, the electrolysis of sea salt has been considered, with the production of substances for industrial or domestic uses, such as liquid chlorine or hypochlorites, and the electrolysis of water.

Commercial considerations mainly hinder the development of such methods for regulating the power of large central stations. Consider, for instance, the production of calcium carbide. One can estimate that in France this industry absorbs, for local consumption and a certain amount of exports, approximately 600,000,000 kilowatt-hours per year. It will

be easily seen that only one large station of 100,000 kw capacity (a power which is often exceeded at present) which could supply an average of 20 per cent of that power, would devote to that purpose an annual energy attaining $^{3}/_{10}$ of the total energy absorbed throughout the entire country by the calcium carbide industry.

Many Applications in Smaller Industries

Power distribution systems in large cities and their suburbs have, nevertheless, to supply an increasing number of electrochemical and electrothermal installations. The electroplating industry, in which the individual installations are comparatively small but rather numerous, might be mentioned first. Also, the electric welding art must be included in that category.

The applications of electric methods in the foundry are becoming more and more important. The old furnaces for the production of bronze and other copper alloys, also cast iron, are being gradually superseded by the electric furnace. First, the arc furnace was utilized and later, with even greater success, the induction furnace with iron core, which is supplied at the normal network frequency and comprises a protruding heating loop (Schneider, Ajax, Weed, Russ). Because of this arrangement, the furnace has a much better power factor (ordinarily about 80 per cent) and a more favorable shape for the receptacle which is to contain the molten metal than the first models having only one large liquid turn or loop of molten liquid.

Large arc furnaces have also been installed in the vicinity of great cities, especially for the casting of medium and small steel parts. The capacity of these furnaces does not exceed, as a rule, 2 or 3 tons, and the power they absorb amounts to 1,000 kw, sometimes slightly less. With the electric furnace a large variety of steel castings can be obtained, the composition and the mechanical properties of which are maintained with precision. The prices of such castings can compete with the price of those obtained by means of rival methods. On the whole, the operation consists of the melting of scrap followed by some final treatment and requires scarcely more than 0.8 kw per kilogram of various castings ready to be delivered. The increase in cost above the cost of production by fuel burning furnaces—by means of which the operation would have been performed less perfectly—is small.

Induction furnaces, operating at a higher frequency, of the order of 1,000 cycles per second, are likewise utilized in smaller units. They permit very rapid fusion, a complete operation generally taking one hour and sometimes less. Because of these qualities the induction furnaces are sometimes adjoined to arc furnaces; with the induction furnace it is possible to bring rapidly to a high temperature a crucible which can be easily handled; this facilitates the production of small thin castings. They are also used to apply quickly to castings the metal which is necessary for the correction of defects, cracks, and blowholes.

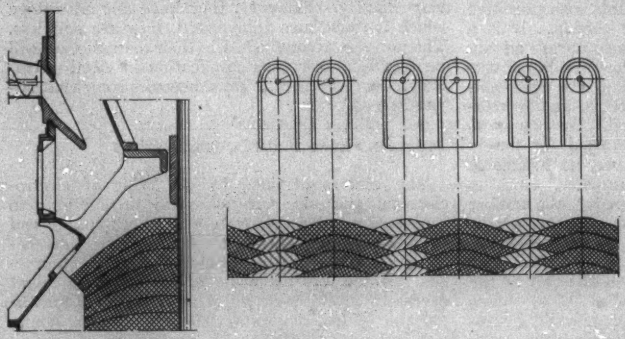


Fig. 3. Diagram of the distribution of lime mixed with coke and lime without coke, in the Miguet-Perron furnace

Cross-hatched areas represent conducting layers of 33 per cent limestone and 67 per cent coke; $7^{1}/_{3}$ turns of screw = 32 cubic decimeters

Lightly shaded areas in diagram at lower right represent layers of limestone; 3 turns of screw = 13 cubic decimeters

Note: Rate of feed varies with density and size of material

Consumption per metric ton of carbide: 855 kilograms limestone; 560 kilograms coke; 14 kilograms electrode

For the foundry operations mentioned hereinbefore radiation furnaces have been developed recently which consist simply of a rod of molded graphite which follows the axis of the cylinder constituting the furnace. The heating takes place at the normal frequency at about 20 to 30 volts and several thousand amperes. A value of 15,000 amperes has been attained with single phase current. One can also use several central rods, grouped for polyphase operation.

Calcium Carbide Furnaces

Consider, again, the large electrometallurgical and electrochemical industries. As a concrete example, attention will be given the furnaces used in the preparation of calcium carbide; these are quite similar to those which are used in the production of ferroalloys and abrasives, such as corundum and alundum. The dimensions of the apparatus which were used at the beginning of this century have been considerably increased, and enormous furnaces have been built recently, with the result that the specific energy consumption was reduced from 5 or more

kilowatt-hours per kilogram of carbide to 3 kilowatt-hours per kilogram.

For the 1,000 kw or 1,250 kva unit it was customary to use approximately 40 volts and 30,000 amperes, single phase current, generally at a frequency of 25 cycles per second, in some cases 50 cycles. With the advent of the more powerful furnaces, it became more difficult to obtain an acceptable power factor. The inductance of such a furnace can be easily estimated; it suffices to measure the mean perimeter of the loop formed by the furnace, i. e., its vertical electrode, its bottom electrode, the leads to their point of junction to a single bundle of suitably interlaced conductors, then to multiply that length by 4.8 (using the centimeter as a unit for the length as well as for the inductance). By multiplying by 10^{-9} and $2\pi f$ (f = frequency) one obtains the reactance in ohms. When the power of the furnace is increased without changing its general design, the reactance increases so that the reactive voltage, which is obtained by multiplying again by the current, attains the above-mentioned 40 volts and exceeds that value.

Two schools of thought of entirely different trends have found adherents: one school has followed the tendency to retain 40 volts or little more. In order to obtain this result, the loop dimensions had to be reduced as much as the service of the furnace and the operation of the electrode would permit, but this soon became insufficient. To overcome this difficulty, the following solution was worked out: an upper movable electrode was supplied by means of several loops operating in parallel, but running in different planes so as to have the lowest possible mutual induction. With this arrangement the reactive voltage will scarcely exceed that which corresponds to only one of the loops carrying its own current. The Miguet-Perron furnace constitutes a brilliant solution of these and many other engineering difficulties. In some of these furnaces the power can be varied by regulating the voltage from 25 to 55 volts, the current attaining several hundred thousand amperes (up to 400,000 amperes was attained in one particular furnace). Such large furnaces range from 5,000 to 16,000 kva capacity, and operate always with one single vertical electrode. These furnaces are usually combined in pairs on a quarter-phase secondary circuit. The power factor at the normal network frequencies is around 90 per cent and even higher.

According to the other school, the voltage was increased: at about 40 volts the furnace operates mainly as a resistance furnace, the resistance consisting of the molten carbide and a relatively small amount of extremely hot substances directly above it; but if the upper electrode is pulled up, successive arcs are formed between pieces of the charge going into reaction. Hence a deeper furnace is required, of somewhat different construction, since the distance between the vertical electrode and the bottom attains sometimes 1.8 meters instead of a few decimeters as in the old apparatus. Ordinarily, with this arrangement of deep furnaces the 3 operating zones are combined within 1 single apparatus under the 3 vertical electrodes of a 3 phase system, and then the furnace has no true bottom electrode but simply a neutral point which carries no current when the 3 star-connected arcs are well balanced.

Three Phase and Single Phase Calcium Carbide Furnaces

From the purely electric viewpoint the 3 phase furnace has the advantage of reducing the currents and thus the difficulties entailed by the enormous currents. For equivalent operating conditions the power per 3 phase unit with 100 volts per electrode (173 volts between electrodes) and 33,000 amperes is the same as with one 40-volt 250,000-ampere single-phase furnace. It is certain that in the second case the difficulties to be overcome by the transformer designer and those caused by stray currents are greater.

There is practically unanimous agreement as to the advantage of concentrating the heat in a zone of small volume for obtaining a very pure carbide (the highest possible power per unit volume of zone) and this is the main argument of the partisans of retaining the single phase furnaces and the low voltage. However, the 3 phase furnace has made considerable progress, and to cite an example, the new 12,000 kw apparatus of the "Société des Produits Azotés" produces, with a specific consumption of 3 kilowatt-hours per kilogram, carbide yielding 300 liters of acetylene per kilogram, the voltage between the electrodes amounting to 165 volts and dropping sometimes to 100 volts. The consumption of ready-made electrodes or of paste for Söderberg electrodes ranges with this type of furnace from 10 to 15 kilograms per ton of carbide. The above-mentioned degree of purity of the carbide, which corresponds to 86 per cent of calcium carbide, is usually deemed sufficient for the production of acetylene as well as of cyanamide. It is very possible that better results may be obtained with single-phase low-voltage furnaces, should a higher degree of purity of carbide be required.

The collection of the valuable carbon monoxide is no doubt easier in single phase furnaces, and the Miguet-Perron furnaces accomplish this task quite successfully. However, the 3 phase furnace also now permits the collection of a fair proportion of the carbon monoxide, 50 per cent at times and even more, according to certain authorities.

One detail which differentiates the 2 extreme types of furnaces is the formation of vaults which prevent the material of the charge from advancing to the zone of reaction. These vaults must be broken; formerly, they were broken through manual labor by means of pokers; in the Miguet furnaces this difficulty has been very cleverly overcome by means of a somewhat complicated pneumatic device which pokes the vaults. Builders of large 3 phase furnaces have now succeeded in entirely eliminating the necessity of breaking up the vaults, for in some 3 phase furnaces the distance between the electrodes and walls of the chamber is sufficiently large to prevent their formation.

In conclusion, it may be stated that the adherents of both systems vie with each other in the creation of ingenious devices, and it is impossible to attribute general superiority to either system.

The Miguet-Perron Furnace

There will now be discussed a few points concerning the large single phase furnaces of the Miguet-Perron type. (See figures 1 and 2.) In these furnaces the transformer is placed underneath the furnace, and it is equipped on the high voltage side with an automatic voltage regulator with tap changing under load. The low voltage current is conducted along the furnace by a certain number of interlaced or transposed bars reaching up to the bottom of the furnace. A metallic wall around the brick casing is double and consists, in the large furnaces, of 2 bronze cylinders 10 centimeters apart, insulated one from the other. The bars, for each of the polarities, are connected to their respective cylinders.

The internal cylinder is connected to plates sealed to carbon blocks acting as the bottom electrode. The upper part of the external cylinder has an extension in the shape of a truncated cone which surrounds the electrode and bears flexible leads. These leads terminate at the contact plates on the electrode, the number of which, distributed around the furnace, may reach at times 48. As a first result of this arrangement the furnace can be closed better and gases easily collected.

The external cylinder, as well as the electrode, is grounded, and this constitutes a considerable advantage, not only as far as the fabrication and the control of the electrode are concerned, but also as regards all the furnace operations in general. (In a 3 phase furnace the electrodes must be insulated one from another, and it is the bottom which is grounded.)

The continuous electrodes of Miguet-Perron furnaces consist of a peripherical part, which is progressively built on top of the electrode so as to compensate for its wear, and consists of sector-shaped prebaked carbon blocks, carefully adjusted, the clearance ranging between 0.5 and 2 millimeters. These sectors are dovetailed, and the joints are lined with an appropriate paste. The cylindrical interior of the electrode is filled from time to time by a cheap paste consisting of coke powder and tar, rammed by pneumatic hammers. The electrodes for 400,000 amperes have an outside diameter of 4.05 meters, and the carbon wall is 65 centimeters thick.

The use of such large electrodes bring up a special question with reference to the use of this furnace for the production of calcium carbide. With a resistivity of 5,000 microhms-centimeter (microhms per centimeter per centimeter square) at 50 cycles the skin effect reduces the effective peripheral thickness of the conductor to 50 centimeters (a little more because of the contacts of the fabricated electrode). Thus the core of the electrode serves only as a support for the peripheral blocks. This is true only at some distance from the extremities of a long electrode. At the ends, if connection is made to another conductor having a much higher resistivity (and not giving rise to such pronounced peripheral concentration of current) the current distribution is extended to near the center of the electrode at the plane of contact. In the case under consideration the bath of molten carbide has a resistivity much higher than that of the electrode (it requires a higher voltage for a much shorter length). As a result, the effective resistance is lessened and the zone of reaction is not so much diminished by the skin effect in the electrode.

The problem thus stated is interesting from a theoretical viewpoint. Practically, the inventor of the furnace considers that this current distribution over the face of the electrode is unfavorable (especially with such large electrodes) as it would superheat the already made carbide at the center of the bath with the effect of partial dissociation. This result is prevented by maintaining a small gap between the face of the electrode and the bath (see figure 2).

The large part of the current flows from the external cylindrical surface of the electrode through the incoming charge, as indicated by the arrows in figure 2. This requires a higher electrical conductivity of the charge than is general in calcium carbide furnaces, and this degree of conductivity is obtained by the use of a special coke in small pieces and by regulating the proportions of carbon and lime in the charge as it comes from the different hoppers. Thus the charge as it reaches the path of the current consists of a controlled distribution of layers with a small proportion of lime (for high conductivity) and complementary layers of lime only, as shown in the diagram of figure 3.

The inductance affecting the power factor is determined by 4 times the measure of the surface between the internal conducting wall, the flexible leads and the length of the average path of current flowing in electrode and charge, divided by its average diameter. Even in the largest furnaces this surface is very much reduced (a few square meters) and the power factor attains 90 per cent and sometimes up to 95 per cent. Exterior views of Miguet-Perron calcium carbide furnaces are shown in figures 1, 4, and 5.

Production of Aluminum

Take another example, that of an industry which, in France, consumes approximately as much energy as the calcium carbide industry; namely, the production of aluminum. Here the size of the furnaces has increased to a lesser degree. The voltage cannot be raised, since it is determined by the electromotive force required for the electrolysis, plus the voltage drops which every one strives to decrease. As regards the current, it has increased from 10,000 amperes or a little less, to 20,000 amperes or a little more; but this does not apply to all plants, since many of them have retained an equipment which was designed only for 10,000 to 15,000 amperes. Some pieces of apparatus operate at a higher current but rather in an experimental way. Finally, 100 kw per furnace is scarcely exceeded, and frequently even this figure is not attained.

From the chemical viewpoint the operation is always the same; alumina is dissolved in molten salts, the flow of direct current carries the aluminum to the bottom which is connected to the negative pole. As regards the composition of the bath, there is a tendency to simplify it, and the addition of divers

chlorides and fluorides (sodium, calcium) have not as many advocates as formerly, and cryolite or a double fluoride of aluminum and sodium of similar composition is more often used. These last substances melt at a higher temperature than certain other mixtures, but give rise to less evaporation and introduce fewer impurities. A certain diversity of ideas is apparent, within narrow limits, however, so that the operation of the furnaces and their output are not greatly affected thereby.

The natural Greenland cryolite has been supplanted to a considerable extent by artificial cryolite which is purer. In that bath the alumina is dissolved in a proportion generally attaining a maximum of 15 per cent, is reduced by electrolysis, and must then be re-established, etc.

The method of extracting pure alumina has changed little: bauxite with as little silica as possible is treated in digestors by a concentrated soda solution which is filtered, diluted, and stirred so as to cause the alumina to settle, then again concentrated and so on, according to Bayer's process. The presence of silica in the ore has the effect that a complex precipitate loses alumina and soda; its composition is rather variable, it has been found, for instance, that 1 part of silica will make insoluble 0.85 part of alumina and 0.8 of soda which are thus lost. Titanic acid acts in the same manner but about $^1/_6$ as much.

Fig. 4. The 16,000 kva Miguet-Perron calcium carbide furnace shown in figure 1. Top of furnace showing upper end of electrode and gas outlets

With certain disadvantages, among which are these losses, one can treat bauxite and other ores containing more silica and existing in inexhaustible quantities. However, it is quite understandable that the first treated bauxites had 2 to 4 per cent silica, containing generally more than 20 per cent ferric oxide which is less disturbing. In certain regions this material is becoming rare, but in others, such as British Guiana and India, it is still encountered in large quantities.

Alumina as obtained by the Bayer process has a purity which has never been exceeded and even reached by other methods; it amounts to 99.5 per cent and over in regular production.

More recent research aims at the utilization of the ores of lower grade more frequently encountered, such as certain clays, treated by means of sulphuric and nitric acids, which have been combined to processes of the fixation of atmospheric nitrogen, and of the production of ammoniacal or nitric salts for agricultural purposes.

The Aluminum Nitride Process

It would seem apposite to call attention again to Serpek's aluminum nitride process, the industrial exploitation of which 20 years ago was considered a failure, notwithstanding the ease with which the reaction can be obtained on a small scale. The ore, which can be a rather siliceous white bauxite, is treated in the electric furnace with carbon in a nitrogen stream. Above 1,800 degrees centigrade the alumina reduction takes place with the formation of carbon monoxide, the aluminum combining immediately with the nitrogen. The product obtained from the furnace, which in regular commercial production could contain 18 per cent of nitrogen, can be easily treated with soda in a simplified Bayer plant producing ammonia and alumina.

Some investigators are of the opinion that the difficulties which have been encountered could now be overcome, and that the process could be applied as far as its technical aspects are concerned, successfully, in view of the considerable progress which has been made in the construction of electrothermal equipment.

It would be necessary to furnish approximately 16 to 18 kilowatt-hours per kilogram of nitrogen contained in ammonia, that is to say, nearly the same amount that can be obtained by water electrolysis and the compression of hydrogen with nitrogen derived from liquid air. The process involving the carbide and calcium-cyanamide gave similar results, though at present the large apparatus which has been discussed in the preceding section allows the energy consumption to be reduced to approximately 10 kilowatt-hour per kilogram of nitrogen. The alumina which is obtained by the aluminum nitride method would, in this manner be a by-product, at least partly, and could be included in estimates at a rather low cost.

Electrothermal Production of Aluminum

Attempts have been made to eliminate the purely chemical part of the manufacture of aluminum by treating the bauxite or similar ores in arc furnaces until fusion, and bringing about the separation of impurities by the addition of carbon. This addition causes the reduction of oxides of iron, of silicon, of titanium, also a part of the alumina in the form of a complex alloy which is separated by tapping. On the whole, it is the application of the process by means of which abrasives, such as corundum and alundum which are crystallized impure alumina, are obtained; this process has been known for more than 40 years. For the aluminum manufacture, the

highest possible degree of purity is aimed at, but so far not very favorable results have been attained from that viewpoint, although the process has been sometimes conducted until a second fusion, which is rather expensive. Another disadvantage is that the product is hard to crush and dissolves less readily in cryolite than alumina chemically obtained. The lower degree of purity influences the metal. It has been proposed to purify that alumina by means of a stream of hot chlorine which would volatilize the main impurities.

An improvement consists in transforming the alumina into aluminum sulphide by introducing iron sulphide into the arc furnace (Haglund process). The aluminum sulphide thus obtained melts at 1,000 degrees centigrade and dissolves alumina. The product, when treated with water, produces alumina and hydrogen sulphide which can be used for reproducing the iron sulphide. The consumption in electric energy is reduced to 75 per cent of the amount required by the simple arc process. Moreover, the alumina is purer, although it does not quite attain the quality obtained with the Bayer process. The Haglund process is applied in an Italian plant.

Electrical Quantities Involved in Producing Aluminum

The electrolytic operation of producing aluminum, constituting in itself a reaction or sum of reactions, consists in decomposing the alumina into metal and into oxygen which burns the carbon of the electrode. From there, the dissociation voltage will amount to 2.79 volts if the oxidation of the carbon is not supposed to intervene, 2.22 volts if that oxidation produces carbon monoxide, and 1.76 volts if it produces carbon dioxide. As a matter of fact, the gas issue from the electrodes is a mixture of carbon monoxide and carbon dioxide. Theoretical questions are here arising which have not been perfectly clarified as yet.

The voltage is increased as a result of secondary effects (some of which are not quite well defined), and because of the resistance of the bath. Toward 950 degrees centigrade the ordinary cryolite baths, or similar mixtures of sodium fluoride and aluminum fluoride, and about 15 per cent alumina, have a resistivity of 0.55 ohm-centimeter, which drops somewhat when the temperature rises. Certain additions, now less frequently used, such as calcium fluoride, lower the resistivity toward 0.4 ohm-centimeter, but then the bath will dissolve the alumina with more difficulty and its density will be increased, a feature which impedes the separation of the metal.

According to Faraday's law, one kilogram of aluminum is produced with 2,980 ampere-hours. In practice, the yield is somewhat lowered by several secondary effects, and especially by the oxidation of the aluminum already formed, remaining in small drops in the bath, whose density differs little from its own. These aluminum droplets are encountered by the oxygen traveling toward the anode, and are oxidized again. Practically, 3,720 ampere-hours are sometimes required with the yield dropping to 80 per cent, and up to 3,975 ampere-hours with a yield of only 75 per cent.

The theoretical consumption calculated with 2.22 volts would be 6.6 kilowatt-hours per kilogram of metal. Practically, much more is needed, and the performance barely attains an energy efficiency of 30 per cent (always assuming a theoretical electromotive force of 2.22 volts).

The figures which have been published are much at variance; sometimes they are influenced either by pessimism or optimism, but they are often the result of appreciable errors in measurement. The first plants with d-c generators were usually not provided with apparatus for measuring the current and the power which were accurate and not influenced by the magnetic fields due to the intense adjacent currents. Moreover, one must bear in mind that some authors speak of the yield of the furnace, properly speaking, while others consider also the conductors between furnaces and to the machines. It is also necessary to introduce the effect of discontinuous operations, and of the stops, a very important factor as has already been indicated. This explains the variety of opinions concerning the progress which has been achieved.

As a matter of fact, since anodes of rather large cross section are generally used (over 30 by 30 centimeters and in small numbers), the current density dropping to one ampere per square centimeter, not

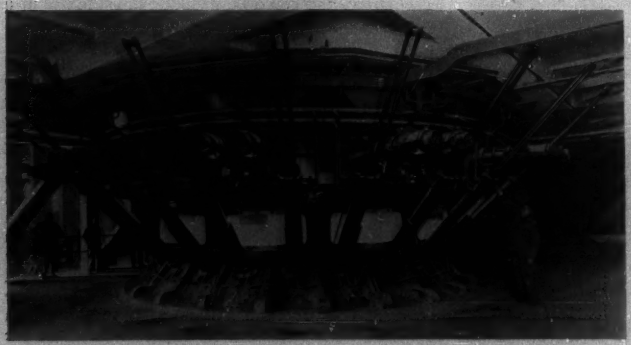


Fig. 5. Second floor view of the furnace of figure 1 showing the air driven pokers and the motor driven screw feeds

much progress has been accomplished as far as the power consumption is concerned, except on one point: the losses through the bottom of the hearth.

Even before 1900 the consumption required in furnaces designed by Heroult was little less than 25 kilowatt-hours per kilogram. Surveys conducted in 1910 in a number of well-equipped plants give similar figures, some a little lower. A large project, which had been worked out at that period for installations to be operated with 3-phase high-voltage current called for 30 kilowatt-hours per kilogram, including the transformation of current and other items, such as the various motors, among them those required for the manufacture of electrodes and the hoisting and conveying apparatus. In this case the plants were to receive their power with considerable fluctuations, and that alone would give an appreciable increase above the figure which could be obtained with a fixed amount of power. In this manner the series of 10,000 ampere furnaces with well-designed connecting bars and good electric contacts would have absorbed, in steady operation, approximately 25 kilowatt-hours per kilogram.

Present-Day Electrical Consumption

What figure has been reached today? The losses through the bottom of the former furnaces were far too high. It was then customary to use a cast iron or steel bottom plate and to cover it with a mixture of carbon powder and tar compound. This mixture was baked during the first operating period, and in this manner had a resistivity attaining 5,000 and even 10,000 microhms-centimeter, that is, respectively, $^1/_{200}$ or $^1/_{400}$ of the conductivity of hot iron. However, the heat conductivity remained about the same as that of iron or only a little less. As result with such an arrangement, a thin layer of carbon will limit the electric losses considerably, but it will allow a large quantity of heat to escape which is withdrawn from the bath, to such an extent that the bottom plate may become red hot and thus imperil the electric contact. In order to reduce the temperature of the bottom plate under these conditions, the thickness of the carbon lining had to be increased, beyond 40 centimeters at times, and then its electric resistance became too high. Formerly it was considered that a voltage drop of one volt between the metal bath and the incoming negative conductors was a good result notwithstanding the fact that this corresponded to a supplementary supply of 4 kilowatt-hours per kilogram of aluminum. Indeed, since more than 20 years ago, this point was taken into consideration. By lowering the voltage drop to 0.5 volt without increasing the heat conductance, 2 kilowatt-hours per kilogram can be gained and still more if the heat conductance is reduced as much as possible.

A scheme, which is frequently adopted, consists in using rather thick carbon blocks, prepared as are electrodes, which are placed on the bottom plate; cast iron is then poured between the blocks so that it will reach the bottom plate and after its solidification will combine the entire system into one solid block. The lower surface of the bottom plate is provided with heat insulation; nevertheless the part which projects outside the furnace, where the negative conductors are connected (steel is copper plated at times), may still become too hot.

A better construction is to provide each one of the carbon blocks with an iron rod which is preferably sealed by pouring cast iron just as in the case of the anodes. These bars are fastened to the bottom plate by means of suitable nuts which insure sufficient electric contact. The lower part of the blocks is separated from the bottom plate by a lining which constitutes a good heat insulation and through which the iron rods pass. In addition to this, cast iron may be poured between the blocks so as to unite the whole very solidly.

The increase of the rated current reduces somewhat the specific consumption, for the relative lateral surface of the furnace decreases slightly. The change-over from 10,000 amperes to 20,000 amperes brings a slight gain of scarcely one kilowatt-hour per kilogram.

A cross section of a 20,000 ampere aluminum furnace is shown in figure 6.

Several pieces of apparatus as described in the foregoing paragraph, rather similar in design, have been put in service by various manufacturers. These furnaces, of 20,000 amperes capacity on an average, will consume 22 kilowatt-hours per kilogram at constant power (including the connections) with 3,700 to 3,800 ampere-hours per kilogram and a voltage of 5.8 to 6. Sometimes a lower voltage can be obtained by placing the anodes closer to the bottom, but this causes a slight increase in the ampere-hour consumption, for some of the liberated aluminum swimming too near the anode oxidizes, especially when the distance between the anode and cathode becomes less than about 6 centimeters. A consumption amounting to a little less than 22 kilowatt-hours per kilogram can be arrived at, in average commercial operation by careful tending and supervising. Is it possible to attain 20, or even less, as some have claimed? This is the best which seems obtainable with modern furnaces, whose general conception dates back 40 years.

There remains little whereby these results could be improved. One could try to decrease the voltage between terminals by further decreasing the current density in the anodes, which at present has been brought down to approximately one ampere per square centimeter. But in order to maintain the necessary temperature—without appeal to a supplementary heating by coal or gas, already mentioned by Hall and Heroult—the heat losses must be reduced; most of these originate from the upper surface. It must be remembered that in the conventional arrangement the upper surface must be free and that room must be left for the regulating, the changing of the anodes, the introduction of alumina, and the agitation of the bath. The heat losses, originating from the upper surface, correspond from 8 to 10 kilowatt-hours per kilogram of aluminum produced. These high losses have led to the construction of closed furnaces, some of which, involving the use of removable walls, have been already built. Some designers would like to go one step further and surround the apparatus with a permanent vault accompanied with mechanical devices that would

insure automatic operation and especially an alternating motion of the anodes which will now be discussed.

Control of the Anode Effect

The dissolution of the alumina in the bath is rather slow. In the early models the round furnace rotated around a vertical axis, and the anodes remained stationary. The negative pole was connected to a contact in a mercury pool. This arrangement produced a permanent agitation, favorable to the dissolution of the alumina which was constantly added to the bath. When the current was raised, this arrangement had to be abandoned. The dissolution of the alumina must be facilitated by stirring the bath from time to time with rabbles, but without entirely preventing the disagreeable "anode effect." As soon as the bath contains too little alumina, its resistance increases, the gases caused by the reaction gather under the anodes, and the furnace (which forms a part of a series to which a constant voltage is applied) absorbs, instead of 6 volts, up to 15 volts, 30 volts, and more; this in turn creates excessive heating and the well-known trouble entailed thereby. For this reason much importance is attached to the transversal dimensions of the anodes which must not exceed certain limits. Tests which were conducted about 1910 have proved that it is scarcely advisable to go above 40 centimeters in one dimension; in 20,000 ampere circular furnaces built in 1912 the electrodes had a trapezoidal section (dimensions 60 by 40 by 10 centimeters) to provide outlets for the escape of the gases. At the same period a design for a square furnace with electrodes of 65 by 65 centimeter section was rejected because of these large dimensions.

It seems that these results have been all forgotten, as 15 to 20 years later furnaces with one single Söderberg electrode of 1.6 meter diameter made their appearance; these furnaces operated rather poorly, their voltage rose at times up to 80 volts, the escape of the gases from the anode surface being very difficult.

The use of continuous electrodes in a furnace, whose losses everybody insists should be reduced, seems rather debatable. The "lost heat" must be rather suppressed than utilized. But perhaps there may be some compromise in special rare cases.

The anode effect can be very much lessened by some stirring which aids the displacement of the alumina. For many years various devices to this end have been discussed, such as an alternating rotation of the furnace or the alternating displacement of the anodes (planer motion), the effect of which could be improved by inclining the anodes or by giving them a cross section in the shape of a parallelogram. Also an auxiliary alternating current has been advocated which would flow through the bath at right angles to the direct current producing the electrolysis. So far all these arrangements have found little application in practice. It might be worth while to give them again due consideration.

It is a well-known fact that the direct current is interrupted in a liquid bath when the aluminum is the anode and receives oxidizing ions. The following question arises: if an aluminum bath is supplied with alternating voltage preferably of low frequency, will the current appear only in the direction required by the electrolysis? If that were possible it would render the transformation of alternating to direct current unnecessary. It has been found by experience that this does not happen, and this might be foreseen for the alumina layer which is produced on the aluminum anode is too rapidly dissolved.

Other Uses of Igneous Electrolysis

Magnesium is also obtained by means of igneous electrolysis, but so far, little success has been made by the decomposition of magnesia dissolved in appropriate baths. Certain fluoric baths have been proposed; however, these baths have the disadvantage that they dissolve too small a proportion of oxide; moreover they are expensive. For this reason, the chloride is generally electrolyzed, but this process has the inconvenience of generating chlorine, a noxious gas which requires closed apparatus. Chlorine is used for the reproduction of chloride, for the ores conduct to the oxide or magnesia.

It may be mentioned that in the electrolysis for the production of sodium, one has the choice of electrolyzing sometimes the oxide, at other times the chloride. The latter, common sea salt, is much less expensive but requires another industry operating conjointly which will absorb the chlorine.

The size of the furnaces for the production of magnesium has considerably increased. The same principles which are applied to aluminum cells have made it possible to come closer to the theoretical consumption which corresponds to the decomposition of magnesia requiring 6.9 kilowatt-hours per kilogram with a theoretical electromotive force of 3.1 volts. Certain apparatus has been described which operates at about 7 volts and consumes about 20 kilowatt-hours per kilogram, corresponding to an efficiency of about 80 per cent as regards current and of about 34 per cent as regards energy.

It is to be feared that whatever improvements can be made in igneous electrolysis will lead only to a rather mediocre efficiency. This is the common fate of much apparatus operating at low voltage and high current, whose losses will never go below a certain limit. From a certain point which is now nearly reached, any improvement in the efficiency entails a relatively high cost which is sometimes prohibitive.

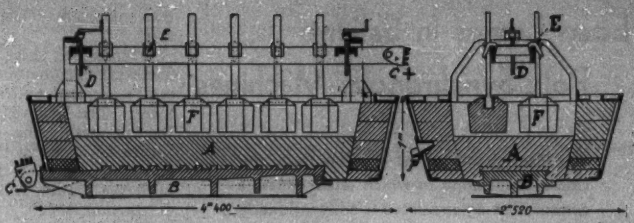
Does this mean that other processes must appear for obtaining metals such as aluminum and magnesium? This goal is perhaps not beyond reach considering the progress and improvements made in industrial electric heating, which were not thought of when other processes were abandoned for electrolysis.

Aqueous Electrolysis

A few words may be added regarding aqueous electrolysis. The decomposition of water was developed to a great extent because of the demand for pure hydrogen, which is mainly used for the production of ammonia (by compressing it with nitrogen). Very

Fig. 6. General arrangement of 20,000 ampere aluminum furnace

A—Carbon lining
B—Bottom plate
C—Terminals
D—Screw for vertical movement of all electrodes
E—Individual adjustment of electrodes on positive bus
F—Electrode
P—Spout



large plants have been started. In France one of these plants comprises a converter station aggregating 26,000 kw.

The electrolysis of sea salt for the production of chlorine or chlorates (depending upon whether a diaphragm is introduced or not) has attained a state of perfection where only details are subject to some improvements. One striking point may be mentioned in particular: the question of decomposing the chlorate which was already formed by the hydrogen produced at the cathode, which decomposition formerly reduced the current efficiency to 30 per cent at times, has been solved by adding to the bath small quantities of substances, especially bichromates; as a result of such a small change the current efficiency regularly reaches nearly 80 per cent.

It is always interesting to mention applications which represent progress realized in other industries. Thus, in the production of sodium chlorate, one obtains a solution containing approximately 100 grams of chloride and 450 grams of chlorate per liter, and it is necessary to extract the major part of the latter salt, and to return the liquor to the circuit after having brought the quantity of chloride to 280 grams per liter. Formerly $^2/_3$ of the water was evaporated. While the chlorate is very soluble in hot water, the solubility of the chloride is practically independent of the temperature, and thus the chloride would be deposited during the concentration and the chlorate during the cooling. In this manner, the expenditure of coal amounted to 0.5 kilogram per kilogram of chlorate obtained; the progress accomplished in the refrigerating industry has made it possible to cool the liquors below zero degrees centigrade economically. The chlorate which is not very soluble in the cold state, especially when the liquor contains chloride, is deposited alone; the coal expenditure is quite eliminated and the power consumption of the motors driving the refrigerating machines has been made only one per cent of the power required for the electrolysis, amounting to about 0.07 kilowatt-hour per kilogram of chlorate.

Choice of Voltage

The choice of voltage is very important to the electrical engineer. In general, it is preferred to apply a voltage which, though remaining moderate, will be as high as the apparatus and lines will warrant. The increase in power of the installation justifies this tendency more and more.

The arc furnaces for the production of steel have passed from 40 volts and 100 volts to 250 volts and beyond with good results. It is common practice to use 3 phase current with the neutral grounded. The workmen very seldom need to come into contact with the electrodes.

The induction furnaces comprise circuits of 2,000 volts and more, with a separation of only 4 to 5 centimeters between the conductors and the molten metal. Also these circuits are so located that the operators are likely to come near them. Will this apparatus, when used in large numbers, entail the trouble feared by certain experts? It must not be overlooked that, with certain precautions in the design, it is possible to build low voltage apparatus.

The igneous electrolysis of alumina is accomplished by connecting the furnaces in series up to 500 volts and beyond. It suffices to place the 2 ends of the battery of furnaces far enough apart to avoid any danger.

Also in the aqueous electrolysis a potential of 500 volts has been attained, even in those plants where the operating personnel has to perform certain operations with live parts. In these installations the middle is grounded and precautions as regards insulation are taken which have been shown in practice to be sufficient.

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Load Losses in Salient Pole Synchronous Machines

The short circuit test of a salient pole synchronous machine in which rated armature current is being circulated is conventionally used for determining the load loss. In certain cases, it is necessary also to know the load losses when the machine is operated at rated conditions of voltage, current, and power factor. Methods for predetermining the short circuit losses are given in detail in this paper, and the results of calculations are presented. Methods of predetermining the losses under rated conditions are given briefly.

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Membership Application Pending
Westinghouse Elec. and Mfg. Co., Pittsburgh, Pa.

THE segregated loss efficiency of a synchronous machine is demonstrated using losses obtained from tests performed in accordance with accepted test procedure. The component losses are friction and windage, no load iron loss, armature copper loss, field copper loss, and load loss. The copper losses are based upon the d-c resistances of the respective windings. The A.I.E.E. standard test for load loss is performed by operating the machine on short circuit with rated armature current. Then the load loss is defined as the total shaft input minus the friction, windage, and armature copper losses.

In order to predetermine the conventional load loss, it is necessary to study conditions existing within the machine during operation on short circuit. The alternating armature slot leakage flux, resulting in eddy currents in the armature copper, is the most obvious source of load loss. The eddy currents cause a copper loss in addition to that represented by the d-c resistance which is generally the largest single component of the short circuit load loss. The magnitude of this loss may be determined mathematically.

The magnetomotive force of the armature winding as distributed in the air gap may be regarded as composed of a sinusoidal fundamental, a series of phase belt harmonics due to connecting the winding in definite phases, and a series of slot harmonics due to concentration of the current in a finite number of slots.

During the short circuit test, the fundamental armature magnetomotive force is practically directly opposed to the field winding magnetomotive force. The latter is not distributed sinusoidally in the air gap. The resulting differential flux is a source of losses in the stator teeth and supporting end fingers. These losses are not a very large part of the total conventional load loss, except in machines of unusual design.

The phase belt and slot harmonics produce fluxes resulting in losses in the pole face and the damper winding. These losses may be predominant in low speed machines with short air gaps and high resistance damper bars. The phase belt losses are quite large in 2 phase machines under certain conditions.

Although the flux paths in the end zones are principally through air, appreciable flux densities can exist in adjacent iron parts due to currents in the end windings. This is partly due to the ineffectiveness of the field magnetomotive force in opposing that of the armature end winding and partly to the relatively small areas of the flux paths in the solid iron parts. The end bell and end plate losses are of importance in machines of large pole pitch.

When the machine is operated at rated conditions of voltage, current, and power factor, a high peak density appears at one edge of the pole, the magnitude of which is reduced by saturation of the stator teeth and of the pole tips. The peak density results in larger losses in the stator teeth and associated parts and in increased pole face and damper winding losses.

Eddy Current Loss in Armature Copper

The most obvious source of loss is the armature slot leakage flux which causes a nonuniform distribution of current in the armature winding. Although the combinations of strands and conductors in the armature winding may become complicated, the distribution of flux density across the armature slot is simple and the loss resulting from eddy currents may be determined mathematically. This has been done by Gilman,[1] whose formulas were used in calculating this component of the load loss in the examples of table II.

In addition to eddy currents arising from flux distribution in the slot, another type of eddy current is found in the end portions of the coil. Current in the end windings produces a flux density in the end zones having a component approximately perpendicular to the plane of the windings. This gives rise to eddy currents flowing along one side of each strand and returning along the other side. No attempt has been made to calculate the resulting loss. Allowance for this loss may be made quite roughly by assuming the strand loss in the end portions of the coils to be the same as in the embedded parts.

Losses Due to Air Gap Flux Distribution

The magnetomotive force of the armature winding as distributed in the air gap may be regarded as com-

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1. For all numbered references, see list at end of paper.

posed of a sinusoidal fundamental, a series of phase belt harmonics due to connecting the armature winding in definite phases and a series of slot harmonics due to concentration of the current in a finite number of slots.

Losses Due to Fundamental of Armature Magnetomotive Force

The power factor of a synchronous machine operating on short circuit is approximately zero. Only polyphase machines, in which the fundamental of armature magnetomotive force rotates synchronously with the field, are considered herein. The maximum of the armature magnetomotive force fundamental occurs approximately at the pole center line and opposes the magnetomotive force of the field. In salient pole machines the latter is distributed as a rectangular wave at the air gap. The resultant magnetomotive force sets up a flux in the air gap which, though very much distorted, must contain a large enough fundamental to induce a voltage in the armature winding equal to the armature leakage reactance drop. A large third harmonic is also present so that the total flux wave has high peaks near the pole tips and a minimum value, which may be negative, at the pole center line. This is illustrated in figure 1.

Since both field magnetomotive force and armature magnetomotive force fundamental rotate synchronously, the resulting flux cannot produce loss

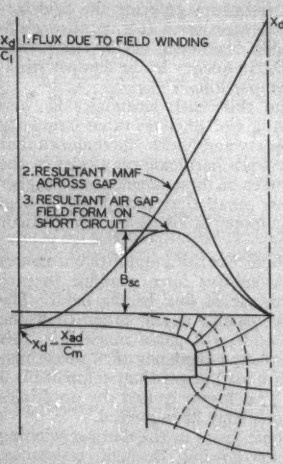


Fig. 1. Flux map of synchronous machine on short circuit, and corresponding distribution of flux density along stator surface

in the field member. The flux wave cuts only the armature and because of its peculiar shape and high peaks, is a source of loss in the armature teeth and supporting end fingers.

In the "per unit" system of notation used herein, rated voltage and current are considered as unit voltage and current, respectively. (In the "per unit" system, 1.5 per unit, for example, corresponds to 150 per cent in the more usual system.) Since only the condition of rated or unit current on short circuit is considered, reactance voltage drops are equal to the per unit reactances expressed as fractions of rated voltage. The air gap ampere turns corresponding to rated voltage and speed are defined as unit ampere turns.

Table I—Results of Calculations for Maximum Flux Density

No.	Poles	Kva	B_{sc}	B_{sc}/X_d
1	4	390	0.45	0.372
2	6	175	0.345	0.268
3	8	2,500	0.355	0.261
4	8	20,000	0.395	0.315
5	8	20,000	0.31	0.273
6	10	20,000	0.59	0.40
7	18	1,750	0.332	0.261
8	20	1,000	0.315	0.255

On this basis, the nominal voltage on short circuit is equal to the synchronous reactance, X_d. The field excitation in terms of unit ampere turns is also equal to the synchronous reactance. The demagnetizing ampere turns of the armature are equal to the magnetizing reactance, X_{ad}. The maximum value of the magnetomotive force of the armature is $X_{ad} \div C_m$, where C_m is the ratio of the fundamental of the direct axis field form obtained when the armature only is excited to the fundamental of the field form obtained when the field only is excited. The resultant magnetomotive force across the air gap, therefore, increases sinusoidally from a minimum of $X_d - (X_{ad} \div C_m)$ at the pole center line to a maximum of X_d at the center line between poles. This is represented by curve 2 on figure 1. This resultant magnetomotive force acting on the air gap reluctance produces the short circuit field form represented by curve 3 of figure 1, which is calculated from the flux plot shown.

The pole face contour, which determines the air gap reluctance at any point, varies in different machines and cannot readily be represented mathematically. In order to obtain a simple method of calculating the maximum gap density on short circuit B_{sc} a number of flux plots similar to that of figure 1 were made. The results are given in table I. These results indicate that with the exception of the first and sixth examples, $B_{sc} = 0.27\ X_d$ approximately. The exceptions are machines whose pole contours were concentric with the air gap and not "smoothed off" at the tips as is customary. In such cases B_{sc} should be obtained by plotting the field form for short circuit conditions.

Armature Tooth Loss

Since the loss at 60 cycles in silicon core punchings is mostly hysteresis loss, the load loss in the teeth will depend mainly upon B_{sc} and the shape of the hysteresis loop. The hysteresis cycle contains 2 large displaced loops whose total area is about equal

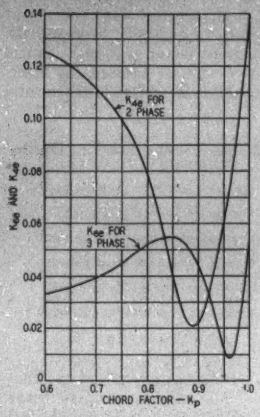


Fig. 2. Effect of coil pitch upon the phase belt harmonic losses as given by equations 15 and 19

to that of the normal loop. The maximum tooth density on short circuit is $B_{sc} \times$ (tooth density at no load rated voltage). The load loss in the teeth can be calculated from the same curves used to get the no load tooth loss, except the result must be multiplied by 2 to correct for the displaced hysteresis loops.

End Finger Loss

The loss in the supporting fingers at the ends of the core is almost entirely a loss of the eddy current type. This loss arises from the fringing flux entering the fingers from the ends of the pole. The no load finger loss is calculated in terms of the maximum density in the gap at no load, B_g. Since the finger loss is an eddy loss, it can be calculated for short circuit conditions as the sum of the losses produced by each individual harmonic of the short circuit field form. Assuming that the loss for each harmonic varies as the square of its frequency and maximum density, it may be calculated as follows. The maximum value of the fundamental is equal to the armature leakage reactance X_L, and the loss is $X_L^2 \times$ (no load finger loss). Since X_L seldom exceeds 20 per cent, the loss due to the fundamental may be neglected.

The maximum value of the third harmonic is roughly 0.6 B_{sc} for average proportions. The loss due to the third harmonic then is 9 $(0.6\ B_{sc})^2 =$ 3.24 $B_{sc}^2 \times$ (no load finger loss). Similarly, the fifth harmonic contributes 1.5 B_{sc}^2. The effect of higher harmonics decreases rapidly with the order of the harmonic. For a machine of average proportions, the sum of the losses of all harmonics is:

$$\text{End finger loss} = 5(B_{sc})^2 \times \text{(no load finger loss)} \tag{1}$$

Phase Belt Harmonic Losses

The magnetomotive force produced by current in one phase of the armature winding is trapezoidal in shape. The width of the base of the trapezoid is the pole pitch T_r. The width of the top is $T_r - 2L$, where $2L$ = width of one phase belt. Representing the trapezoidal wave by a Fourier series, the maximum value of the nth harmonic is,

$$\frac{4}{n\pi}\,\frac{\sin nL}{nL}$$

The ratio of the maximum value of the nth harmonic to that of the fundamental is,

$$\frac{K_{pn} \sin nL}{K_p n^2 \sin L} \tag{2}$$

where K_{pn} and K_p are the chord factors for the nth harmonic and fundamental, respectively. This ratio is also true for the total magnetomotive force of all phases acting together. Since the maximum value of the fundamental of armature magnetomotive force is $X_{ad} A T_g + C_m$ ampere turns, the maximum value of the nth harmonic is

$$A_n = \frac{X_{ad} A T_g K_{pn} \sin nL}{C_m n^2 K_p \sin L} \text{ ampere turns} \tag{3}$$

See appendix I for a list of symbols.

In a 3 phase machine the fifth harmonic rotating in the opposite direction from that of the fundamental at one fifth of synchronous speed cuts the field surface at 6 times fundamental frequency. The seventh harmonic rotating in the same direction as the fundamental at one seventh of synchronous speed also cuts the field surface at 6 times rated frequency. These 2 harmonics combine to produce a flux of 6 times fundamental frequency entering the field surface and causing pole face loss. If a damper winding is present, this flux is damped out by currents of 6 times fundamental frequency in the damper winding, resulting in damper loss.

The eleventh and thirteenth harmonics likewise combine to produce flux of 12 times rated frequency in the field, and Doherty and Nickle[2] have shown that all multiples of the sixth harmonic may exist in the field. The magnitudes of these harmonics of higher order are sufficiently small that they may be neglected from the standpoint of loss, even though their frequencies are high.

In a 2 phase machine, the third and fifth harmonics of armature magnetomotive force combine to produce a fourth harmonic of flux in the field. The resulting losses are usually much larger than the sixth harmonic losses in a 3 phase machine. This accounts for the observed tendency of 2 phase machines to have higher load losses than comparable 3 phase machines. The losses caused by multiples of the fourth harmonic may be neglected.

Phase belt harmonic losses in the damper winding result from current flowing through resistance. Since the pole laminations are of relatively high resistivity and thickness, the pole face loss is principally eddy current loss. It is, therefore, necessary to examine the way in which the 2 harmonics combine at various points along the pole surface and obtain an effective value of the resultant magnetomotive force averaged over the pole face. The fifth and seventh harmonics are in time phase at the pole

center line and rotate negatively with respect to the pole surface. They are 180 degrees out of phase at the center line between poles. At any intermediate point at an angle θ from the pole center line, the phase angle between A_5 and A_7 is 2θ. The resultant magnetomotive force at any point is the vector sum of A_5 and A_7. The effective value of the resultant averaged over the pole face for an average pole width of $^2/_3$ the pole pitch is:

$$A_{4t} = \sqrt{\frac{3}{\pi}\int_0^{\pi/3}(A_5 + A_7)d\,\theta}$$

$$= \sqrt{\frac{3}{\pi}\int_0^{\pi/3}[A_5^2 + A_7^2 + 2A_5A_7\cos 2\theta]d\,\theta} \tag{4}$$

$$A_{4t} = 0.98\sqrt{A_5^2 + A_7^2 + 0.866\,A_5A_7}$$

The corresponding value of A_{4t} for a 2 phase machine is:

$$A_{4t} = 0.98\sqrt{A_3^2 + A_5^2 + 0.866\,A_3A_5} \tag{5}$$

The numerical values of K_{6t} and K_{4t}, where

$$A_{6t} = \frac{K_{6t}X_{ad}AT_g}{C_m} \qquad A_{4t} = \frac{K_{4t}X_{ad}AT_g}{C_m} \tag{6}$$

are plotted as functions of the fundamental chord factor in figure 2.

Phase Belt Harmonic Loss in the Damper Winding

Taking the maximum value of the nth harmonic of magnetomotive force as unit ampere turns, the nth harmonic flux linked by a pair of damper bars is:

$$\phi_p = \frac{3.19 \times 0.636\,T_r \sin(\delta_n/2)}{n\,g_s} \tag{7}$$

where

$$\delta_n = \frac{N\,T_b \times 180 \text{ degrees}}{T_r} \tag{8}$$

The mutual flux which links the pair of bars in addition to ϕ_p, due to currents in the 2 damping circuits on each side of the one considered is:

$$\phi_m = 3.19\sqrt{2}\,I_c \times 2\,\lambda_s \cos\delta_n \tag{9}$$

where I_c is the current in each damping circuit.

$$I_c = \frac{\phi_p + \phi_m}{3.19\sqrt{2}\,(\lambda_g + 2\lambda_s)} \tag{10}$$

The resultant current in a damper bar is:

$$I_{rn} = I_c\sqrt{2(1 - \cos\delta_n)} \tag{11}$$

Substituting equations 7 and 9 in 10, solving for I_c, substituting the resulting value of I_c in equation 11, and rearranging gives:

$$I_{rn} = \frac{0.636\,T_r}{\sqrt{2}\,n\,g_s\left[\dfrac{\lambda_g}{1 - \cos\delta_n} + 2\,\lambda_s\right]} \tag{12}$$

The derivation of equation 12 is made very brief here, since the solution is given in detail in reference 3 at the end of the paper, equations 1 to 6.

The total sixth harmonic current at the pole center line of a 3 phase machine is:

$$I_6 = \frac{0.636\,T_r}{\sqrt{2}\,g_s}\left\{\frac{A_5}{5\left[\dfrac{\lambda_g}{1 - \cos\delta_5} + 2\,\lambda_s\right]} + \frac{A_7}{7\left[\dfrac{\lambda_g}{1 - \cos\delta_7} + 2\,\lambda_s\right]}\right\} \tag{13}$$

This equation may be simplified without great loss of accuracy by assuming that 5 and 7 in the denominators of the bracketed quantity equal 6 and that $\delta_5 = \delta_7 = 6\,T_b \times 180$ degrees$/T_r$. Making these approximations and substituting the effective value of the resultant of A_5 and A_7 given by equation 6 gives:

$$I_6 = \frac{0.636\,T_r}{6\sqrt{2}\,g_s}\left[\frac{K_{6t}\,X_{ad}\,AT_g}{C_m\left(\dfrac{\lambda_g}{1 - \cos\delta_5} + 2\,\lambda_s\right)}\right] \tag{14}$$

The effective damper bar resistance is $\rho l\,K_f + 10^6 a$. The constant C_m does not vary widely in different machines and is equal to 0.84, approximately. Then the total sixth harmonic loss in the damper winding is I_{6t}^2 multiplied by the effective bar resistance and the total number of bars N:

$$W_{D6} = \frac{0.792\rho l\,K_fN}{10^{11}a}\left\{\frac{T_r}{g_s}\right\}^2\left[\frac{K_{6t}X_{ad}AT_g}{\dfrac{\lambda_g}{1 - \cos\delta_6} + 2\,\lambda_s}\right]^2 \tag{15}$$

Equation 15 gives the loss in kilowatts.

The loss in a 2 phase machine W_{D4} is obtained by substituting 1.78 for the constant 0.792 and δ_4 for δ_6 in equation 15. $\delta_4 = 4\,T_b \times 180$ degrees$/T_r$. Also, the increase in bar resistance K_f must be calculated at 4 times instead of at 6 times rated frequency.

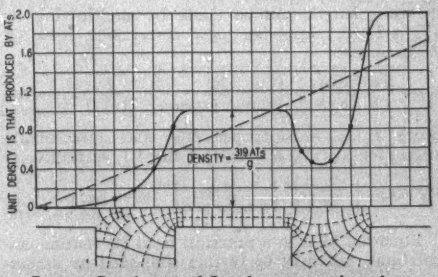


Fig. 3. Distribution of flux density at pole surface due to equal currents in 2 adjacent stator slots

Return currents are in slots to the right of these
$b_s/g = 4 \quad b_s/T_s = 0.4$

Phase Belt Harmonic Loss in the Pole Face

When a damper winding is present in the pole face, induced currents in the bars damp out most of the

harmonic flux which would otherwise enter the pole face. Consequently loss in the pole face is negligible. However, if the machine is not equipped with a damper winding, the pole face loss may become important, particularly in 2 phase machines.

Assume temporarily that the harmonic pole span is equal to the armature slot pitch T_s and that the harmonic cuts the pole surface at armature slot frequency. Then the total effective harmonic flux in a half cycle of the harmonic is:

$$\frac{3.19\, X_{ad}\, AT_g}{C_m\, g} K_g \times 0.636\, T_s$$

The total flux in a half cycle of the ripple producing the no load pole face loss is:

$$159\, T_s\, B_g\, K_{w1}\, K_s\, K_g \cdots$$

Assuming the pole face loss to vary as the square of the flux density, the harmonic loss in the pole face is:

$$W_p = \left\{\frac{3.19\, X_{ad}\, AT_g\, K_g\, T_s \times 0.636}{159\, T_s\, B_g\, K_{w1}\, K_s\, K_g\, g_e\, C_m}\right\}^2 \times \text{(no load pole face loss)}$$

Since $AT_g = 314\, B_g g_e$ and since $C_m = 0.84$ approximately,

$$W_p = \left\{\frac{4.77\, X_{ad}\, K_g}{K_{s1}\, K_s\, K_g}\right\}^2 \times \text{(no load pole face loss)} \qquad (16)$$

Spooner[4] has shown that the pole face loss varies as the 1.6 power of frequency and as the 1.3 power of the wave length of the pulsation. The harmonic frequency is nf and the armature slot frequency is $2f \times$ (number of slots per pole) so that the error resulting from assuming the harmonic frequency to be equal to armature slot frequency can be corrected by multiplying equation 16 by the factor $\left\{\frac{nf}{2f \times \text{(slots per pole)}}\right\}^{1.6}$ Correction for pole span or wave length can be made by multiplying by $(T_r/n\, T_s)^{1.3}$. Applying these corrections, equation 16 becomes:

$$W_p = \left\{\frac{4.77 X_{ad} K_g}{K_{w1}\, K_s\, K_g}\right\}^2 \left\{\frac{nf}{2f\ \text{(slots per pole)}}\right\}^{1.6} \left\{\frac{T_r}{nT_s}\right\}^{1.3} \qquad (17)$$

Since T_r/T_s = slots per pole and approximate values for K_{w1} and K_g are 0.97 and 1.1, respectively:

$$W_p = 6.57 \left\{\frac{X_{ad}\, K_g}{K_s}\right\}^2 \left\{\frac{n}{\text{slots per pole}}\right\}^{0.3} \times \text{(no load pole face loss)} \qquad (18)$$

Equation 18 is in a practical form for routine calculations, but may be further simplified by assuming an average number of slots per pole equal to 12. Then, since $n = 6$, the loss in a 3 phase machine is:

$$W_p = 5.35 \left\{\frac{X_{ad} K_g}{K_s}\right\}^2 \times \text{(no load pole face loss)} \qquad (19)$$

For 2 phase, $n = 4$ and the constant becomes 4.7 instead of 5.35.

Slot Harmonic Losses

At no load the nonuniform air gap permeance resulting from the stator slots superimposes a slot harmonic or ripple on the no load field form. Since the field poles are rotating with respect to the stator slots, this harmonic moves relative to the pole face from one tip to the other, resulting in losses in the pole face and in the damper winding. Methods given in references[3,4] are available for calculating these no load losses.

Under short circuit conditions a similar phenomenon exists and the short circuit losses can be calculated in terms of the no load losses. Distribution of the armature current among several slots in each pole results in a magnetomotive force wave with a saw tooth shape. The resulting flux wave also has a saw tooth shape, which is magnified by the nonuniform air gap permeance due to the open armature slots. A portion of such a flux wave, together with the flux map from which it was calculated, is shown in figure 3. The effect of the field magnetomotive force is neglected. Comparison with figure 1 shows that the left side of figure 3 corresponds to the point near the pole center line at which the resultant magnetomotive force becomes positive. Since the currents in both slots of figure 3 were assumed equal, the average flux density across the air gap increases linearly from left to right and the flux pulsation which produces the loss is represented by the difference between the actual density and the straight line average.

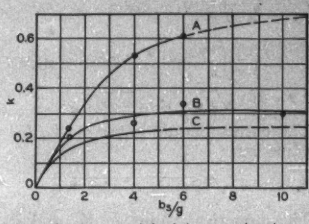


Fig. 4. Effect of slot/gap ratio on the constant k in the equation: $\phi_{sc} = \sqrt{2}kAT_sT_s/g$

A—Current in slot equals currents to left of slot considered, as in the right-hand slot in figure 3

B—No currents to left of slot; all ampere turn lines from the slot terminate to the right, as with the left-hand slot in figure 3

C—No currents to left of slot; ampere turn lines divide half to right and half to left of slot

For a uniform air gap and point concentration of armature current, the total flux across the gap for one slot pitch is:

$$\frac{3.19\sqrt{2}\, T_s\, AT_s}{g}$$

Defining k as the ratio of the total flux in $^1/_2$ cycle of pulsation to the flux represented by the area $T_s AT_s$, then the pulsation flux per half cycle is:

$$\phi_{ps} = \frac{\sqrt{2}\, k\, T_s\, AT_s}{g}$$

The curves of k as a function of slot to gap ratio, shown in figure 4, were obtained from several flux maps similar to figure 3 for various ratios of slot to gap. As indicated by figure 3, the value of k for a

given slot to gap ratio varies depending upon the proportion of ampere turn lines which terminate in slots to the left of the slot for which k is calculated. Three k curves are plotted in figure 4: for equal ampere turn lines terminating in the slot and to the left of the slot, for no ampere turn lines terminating to the left of the slot (corresponding to the left hand slot in figure 3), and for the condition when half of the ampere turn lines from a slot terminate on each side of the slot. The last condition corresponds to a slot whose center line is at the point at which the resultant magnetomotive force becomes positive, near the pole center line on figure 1.

The armature current per slot AT_s is distributed sinusoidally on short circuit and is zero at the pole center line, and maximum at the center line between poles. At any point along the pole surface the proportion of ampere turn lines terminating to the left of the point is represented by curve 2 of figure 1, from which the value of k at that point may be determined. The value of the product of k and current per slot at each point along the pole surface is plotted in figure 5 for a slot to gap ratio of 4. The effective value of this curve is 0.20. Then the effective value of pulsation flux per half cycle, averaged over the whole pole surface is:

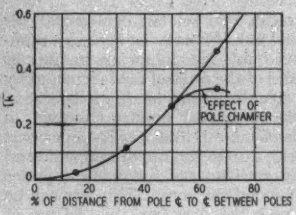


Fig. 5. Value of the product of k and current per slot at each point along the pole face, plotted for a slot to gap ratio of 4

$$\text{Effective value of } ik = 0.20\ K_{sc} = \frac{0.20\sqrt{2} \times 314}{0.097 \times 159 \times 0.55} = 1.05$$

$$\phi_{ps} = \frac{\sqrt{2}\ k_{eff.} T_s\ AT_s}{g} \tag{20}$$

in which $k_{eff.}$ is 0.20 for $b_s/g = 4$.

The magnitude of the flux per half cycle of the flux ripple producing the no load pole face and damper loss is:

$$159\ T_s\ B_g\ K_{w1}\ K_s\ K_g \cdots$$

Assuming that the loss varies as the square of the ratio of flux per half cycle of pulsation, the pole face and damper losses on short circuit are:

$$W_s = \left[\frac{\sqrt{2}\ k_{eff.}\ T_s\ AT_s}{159\ g\ T_s\ B_g\ K_{w1}\ K_s\ K_g}\right]^2 \times \text{(no load pole face plus damper loss)}$$

Since $AT_g = 314\ B_g\ K_g\ g$,

$$W_s = \left[\frac{314\sqrt{2}}{159}\ \frac{k_{eff.}}{K_{w1} K_s}\ \frac{AT_s}{AT_g}\right]^2 \times \text{(no load pole face plus damper loss)} \tag{21}$$

For a ratio of slot width to slot pitch of 0.4, which is a good average value of this ratio, $K_{w1} = 0.97$. Defining

$$K_{sc} = \frac{314\sqrt{2}\ k_{eff.}}{159\ K_{w1}\ K_s} = \frac{2.89\ k_{eff.}}{K_s},$$

$$W_s = \left[\frac{K_{sc}\ AT_s}{AT_g}\right]^2 \times \text{(no load pole face and damper loss)} \tag{22}$$

Since both $k_{eff.}$ and K_s are functions of the slot to gap ratio, the quantity K_{sc} may be plotted against slot to gap ratio as in figure 6.

End Zone Losses

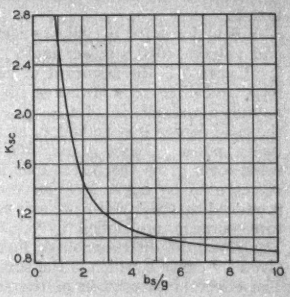
Leakage fields set up by currents in the end portions of the armature coils produce losses in the end bells, end plates, and coil supporting rings. The loss in the rings is an insignificant part of the total load loss and may be neglected from the standpoint of loss only, although it may result in serious local heating. A method of calculating the end bell and end plate losses has been developed by L. A. Kilgore,[5] which is presented in curve form in figure 7.

Losses at Rated Load Voltage, and Power Factor

The previous discussion has been confined to losses occurring during operation on short circuit, which are used in calculating the conventional efficiency. Engine and turbine builders must frequently guarantee over-all fuel consumption rates when the generator is operating at rated conditions. Consequently this class of purchaser is more concerned with the losses existing while the generator is operating not only with rated current but at rated voltage and power factor as well. The eddy loss in the armature copper and the end bell and end plate losses are practically the same as on short circuit.

Fig. 6. Short circuit pole face and damper winding loss

These losses, together, equal $\left(\frac{K_{sc} AT_s}{AT_g}\right) \times$ (no load pole face plus damper loss)



At zero power factor the phase belt losses are the same as for short circuit conditions. At higher power factors these losses may be reduced by as much as 8 per cent below the values obtained on short circuit. This is caused by the angular shift of the pole center line from the peak of the armature magnetomotive force wave $(\alpha + \theta)$ which changes the limits of inte-

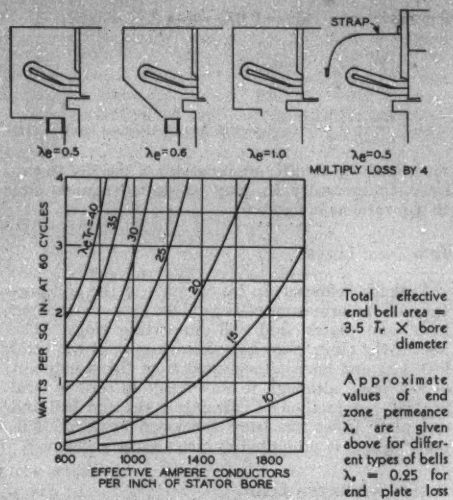


Fig. 7. Load loss in end bells and end plates

gration of the integral preceding equation 4 and reduces the constant 0.866 in equation 4 to as low as 0.43.

The load losses in the stator teeth and fingers are much higher than for short circuit conditions, since the field form in the air gap under load is highly distorted.

A field form for a typical machine at rated load and voltage, at 0.8 power factor, is shown in figure 8. Curve *a* is the resultant of field magnetomotive force and direct axis armature magnetomotive force, having a magnitude of $e_d - X_{ad}/C_m \sin(\alpha + \phi)$ at the pole center line and of e_d at the center line between poles. Curve *a* multiplied by the no load wave form gives the direct axis full load field form represented by curve *b*. Curve *a* is the field form produced by the quadrature axis component of armature current multiplied by $X_{aq}/C_m \cos(\alpha + \phi)$. The resultant distribution of flux in the air gap is given by curve *d* which is the sum of curves *b* and *c*. The effect of saturation of the stator teeth is neglected in curve *d*, which becomes curve *e* when corrected for saturation.

The load loss in the stator teeth is calculated in the same manner as for the no load tooth loss, except that a tooth density corresponding to the maximum value of curve *e*, of figure 8, is used and the effects of displaced hysteresis loops must be corrected for, if present. The no load tooth loss is subtracted from this since it is already included as a component of the no load core loss. The load losses in the fingers may be calculated in a similar manner.

The slot harmonic losses in the pole face and damper winding presents a more difficult problem. A rough approximation is to calculate these losses in the same manner as for no load, except based upon the effective density at full load averaged along the pole face, subtract the no load loss calculated at no load density, and add the pole face and damper loss for short circuit conditions.

Summary—Short Circuit Loss Calculations

In most cases the largest single component of the load loss is that of eddy loss in the armature conductors. The eddy loss may be minimized by multiple stranding of the conductors and by avoiding the use of less than 4 turns per coil. Where the latter is unavoidable, external or even internal transpositions may be justified.

Since the eddy loss is relatively large, it must be calculated accurately. It is particularly important to estimate carefully the temperature of the armature windings during the short circuit test, as the temperature is a controlling factor. It is also important to measure the temperature of the armature winding at the time the test is made or errors as large as 100 per cent may occur in the test results, if the load loss is small compared to the armature copper loss.

The armature tooth loss seldom exceeds 20 per cent of the total load loss. It may be kept to a minimum by shaping the pole face in such a manner as to round off the sides of the no load field form and by the use of silicon steel armature laminations.

The end finger loss is usually small. However, in the eighth example of table II this loss is 45 per cent of the total load loss, due to the use of magnetic end fingers in combination with large cast pole end plates extending axially beyond the core. This loss can be minimized by shaping the pole face, by the use of nonmagnetic fingers, and by preventing axial extension of magnetic parts of the pole head beyond the ends of the armature core.

The phase belt harmonic losses are generally low enough to be of secondary importance on 3 phase machines with low resistance dampers or without dampers. Even with high resistance dampers this loss is small, if a coil throw of 80 per cent is used. The phase belt loss may be quite large in 2 phase machines with full pitch coils, as in example 16 of table II. Figure 2 shows that the phase belt losses vary greatly depending upon the coil throw, and that a chord factor of 0.866 should be used for 2 phase machines when possible. An example of this is number 5 of table II, in which the phase belt losses are quite low for a 2 phase machine.

The slot harmonic losses are usually important in engine type machines which inherently have high no load pole face and damper losses and in machines with high resistance damper windings. Numbers 17 and 25 of table II are good examples of these 2 classes of machines, respectively. The slot harmonic losses may be kept low by designing for low no load pole face and damper losses, particularly by the use of many armature slots with low ampere turns per slot.

The magnitude of the end bell and end plate losses varies considerably with the type of construction and is seldom a very large proportion of the total load loss. It is negligible in engine type machines and is small in vertical machines. It is greatest for those

Table II—Short Circuit Load Loss Calculations (All Losses Are in Kilowatts)

No.	Kva	Poles	Eddy Loss	Tooth Loss	Finger Loss	W_P	W_S	W_R	W_B	Total Calc. Loss	Test Loss
1	500	4	0.34	0.18	0.06	0.14	0.15	0.04	1.8	2.71	2.9
2	1,500	6	4.96	0.93	0.13	2.3	1.35	0	1.7	11.37	11.4
3	285	8	0.20	0.11	0.05	0.10	0.165	0	0.04	0.67	0.60
4	10,000	8	28.9	12.8	3.5	1.07	6.3	0	2.4	76.7	71.9
5	20,000	10	33	7.3	0.91	1.9	7.0	0	4.5	54.6	54
6	30,000	10	31	9.8	1.8	1.2	13.4	1.2	7.8	66.2	71
7	1,500	12	2.8	1.0	4.5	0.42	0.62	0	1.1	10.4	9.85
8	30,000	12	43.8	10.9	2.3	8.6	9.1	0	12.3	87	76
9	875	14	0.81	0.38	0.08	0.16	0.87	0	0	2.3	2.2
10	30,000	14	59.2	12.6	2.8	8.4	14.6	0	6.1	103.7	99
11	250	32	0.30	0.38	0.03	0	0.55	0	0	1.26	1.0
12	781	54	2.29	0.75	0.17	0.57	0.93	0	0	4.71	4.86
13	2,000	58	6.85	2.37	0.31	0.38	4.7	0	0	14.6	15.9
14	23,000	64	15.8	9.7	1.0	2.4	9.3	4.0	0.6	42.8	43
15	31,000	66	90.2	1.5	1.3	0.7	26	0	0.8	133.5	90.5
16	5,000	88	10.1	1.4	0.68	2.9	7.1	0	0	22.2	22.5

horizontal machines combining the unfavorable features of large pole pitch, relatively short core length, with enclosing end bells brought in close beneath the armature end winding, and without shrouded blowers. Example 1 of table II is an exceptional case in which all of these factors contributed to the high end bell loss. To avoid high loss, the bells should be kept as far away from the coils as possible at all points and a shrouded blower is desirable, since it diverts part of the flux which otherwise would enter the end bell.

The comparison between calculated and test values of short circuit load loss given in the last 2 columns of table II provides a check for the accuracy of the formulas. The load losses as determined by tests of 2 duplicate machines built to the same specifications may vary by as much as 20 per cent, in exceptional cases. The causes of this are variations in materials and in manufacturing. The results set forth in table II may, therefore, be considered acceptable.

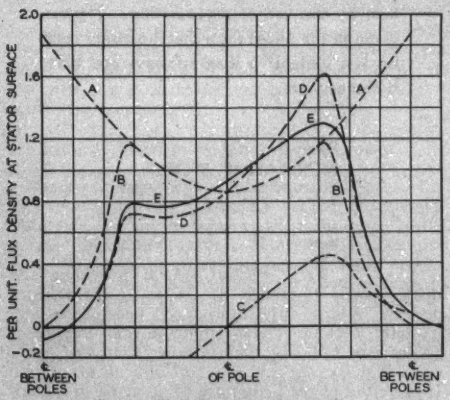


Fig. 8. Flux density at stator surface

A—Resultant of field magnetomotive force and direct axis armature magnetomotive force

B—Flux wave due to *A*

C—Flux wave due to quadrature axis component of armature current

D—Flux wave at full load, rated voltage, 0.8 power factor, neglecting stator tooth saturation. Resultant of *B* and *C*

E—Curve *D* corrected for tooth saturation

Unit density is density at center line of pole at no load and rated voltage

Summary—Calculations of Load Loss Under Rated Conditions

Although load losses at rated load and voltage and at 0.8 power factor have been calculated for a few of the machines listed in table II, the results are not given since corresponding test data are not available. Floyd and Dunbar[6] tested a 55,000-kva 16-pole 25-cycle generator under both short circuit and rated conditions and obtained losses of 104 and 135 kw, respectively. Using the methods suggested herein, the calculated short circuit load loss is 122 kw and the calculated load loss under rated conditions is 148 kw.

The load loss at rated voltage and current is minimum at zero power factor and maximum near unity power factor, since the field form distortion due to the quadrature axis component of current is absent at zero power factor and is maximum near unity power factor.

Delta Connection or Star Connection With Grounded Neutral

If the armature winding is connected in delta or in star with a grounded neutral, the third harmonic series of zero phase sequence currents circulate through the winding unless it is chorded to $^2/_3$ pitch. The additional losses in the armature and damper windings may increase the short circuit loss by as much as 50 per cent.

Appendix I—List of Symbols

a = area of damper bar in square inches

A_n = maximum value of nth harmonic of armature magnetomotive force in ampere turns

A_u = effective value taken over pole surface of the vector sum of maximum values of third and fifth harmonics of armature magnetomotive force in ampere turns

A_{ie} = same as A_{ie}, except is sum of fifth and seventh harmonics
AT_s = armature ampere turns per slot
AT_g = air gap ampere turns at no load
b_s = armature slot width
B_g = maximum density in air gap at no load in kilolines per square inch
B_{sc} = maximum density in air gap under short circuit conditions expressed as a fraction of Bg
C_m = ratio of fundamental of direct axis field form with armature alone excited to fundamental of no load field form
f = fundamental frequency of the machine in cycles per second
g = air gap length in inches
g_e = effective air gap length = gK_g
I_c = current in the closed circuit consisting of 2 adjacent damper bars
I_{rn} = resultant nth harmonic current in damper bar
I_{ie} = effective value of sixth harmonic current in damper bar
k = ratio of total flux in a half cycle of the slot harmonic to the flux represented by the area $T_s AT_s$ of figure 3, multiplied by 3.19
K_{ie}, K_{ie} = defined by equation 6
K_g = Carter's air gap coefficient
K_f = ratio of a-c to d-c resistances for damper bar
K_p = chord factor for the fundamental
K_{pn} = chord factor for the nth harmonic
K_s = ratio of double amplitude of slot ripple to B_g:

$$K_s = 1 - \frac{1}{\sqrt{1 - (b_s/g)^2}}$$

K_{sc} = $2.89k_{eff.}/K_s$
K_{w1} = ratio of fundamental of slot ripple to $^1/_2$ of K_s
L = width of one phase belt
l = core length
n = order of harmonic
T_b = damper bar pitch in inches
T_r = pole pitch in inches
T_s = slot pitch in inches
W_B = end bell loss
W_{D4} = phase belt harmonic loss in damper winding for 2 phase machines
W_{D6} = phase belt harmonic loss in damper winding for 3 phase machines
W_P = phase belt harmonic loss in pole face
W_R = loss in armature coil supporting rings
W_S = slot harmonic loss in pole face and damper winding
X_d = $X_l + X_{ad}$ = synchronous reactance in "per unit"
X_{ad} = magnetizing reactance in per unit
X_L = armature leakage reactance in per unit
δ_n = defined by equation 8
α = power displacement angle of rotor
ϕ_p = air gap harmonic flux linked by a pair of adjacent damper bars in lines per inch of length
ϕ_m = mutual flux linked by a pair of adjacent damper bars in lines per inch of length
ϕ_{ps} = slot harmonic flux per half cycle in lines, per inch of length
λ_g = air gap permeance for circuit consisting of 2 adjacent damper bars
λ_s = damper slot permeance
λ_e = permeance of flux path from end of core to end bell
ρ = resistivity in microhms per cubic inch
θ = angle measured from pole center line

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The "Biway" System of

Electric Platforms for Mass Transit

This paper describes the "biway" system of mass transit by continuously moving electrically operated platforms which is cited as being suitable for use in the congested sections of large cities. It is planned to have 2 adjacent moving platforms, one of which operates continuously at a speed of about 15 miles per hour, the other of which varies between standstill and the speed of the continuously moving platform to enable passengers to transfer between the stationary and moving platforms. The biway offers convenience in that it may be boarded at any point on the system and will give a nonstop ride to within a short distance of the destination, greater speed than existing transit methods for short distances, seating capacity up to 60,000 passengers per hour past a given point, and economy of operation by the use of regeneration. Figures given in the paper show that the biway may be less expensive than subways and give better service.

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THE PROBLEM of providing adequate means of transit in the congested business districts of large cities has not yet been solved, and is daily becoming more difficult and important. Every new building that is taller than the one it replaces makes the problem more difficult of solution. If the cities of the future are to be made up of skyscrapers, it is impossible to escape the conclusion that there will have to be more and wider streets or the present streets will have to be double or triple decked unless a radical change in the present methods of short haul transit is made. Certainly the present methods are neither adequate nor satisfactory.

Under normal conditions, a street car, bus, or

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taxicab can make an average speed of from 5 to 7 miles per hour through the business section of a large city, but the addition of a few more people or vehicles on the street, or a light shower, nearly blocks the traffic. At no time are the elevated or subway trains satisfactory for short hauls, because of the distance between stations and the time intervals between trains.

The prime requisite for an adequate means of rapid transit in a large city is a private right of way. This is, of course, impossible at street levels as cities are now constructed. Such semiprivate routes as Riverside Drive in New York City are a great boon for de luxe travel, but are practically useless for mass transit. The private right of way for mass transit must be easily accessible from the streets or buildings. It must have capacity to handle the crowds that are present during the rush hours, and do it without crowding. Its speed should be affected neither by the number of passengers nor the weather.

A great many solutions for this problem have been proposed, other than subways and more subways, of which the favorite has been some form of nonstop or continuous transit scheme. The advantage of a nonstop run has been recognized for a long time. It was evidently well understood when Ebenezer Hawkins of Islip, N. Y., took out a patent on December 9, 1874, covering a means for giving intermediate towns the advantage of a high speed nonstop train running through them. He proposed to provide for these towns by means of a light train which would accelerate from a local station on a track adjacent to the one on which the nonstop train was approaching, run beside this train for a short distance at the same speed and, with the 2 trains hooked together, interchange passengers and baggage, unhook, and stop at the next station. Of course, it was a fantastic idea, and probably never was tried, but it contained the germ of a scheme for continuous mass transit.

Continuous Transit by Moving Sidewalks

Many years ago, some one proposed the idea of a continuously moving sidewalk on which pedestrians could ride, and by walking at the same time, could increase their rate of travel. Many serious attempts have been made to utilize this idea for mass transit. The first moving platform used for carrying passengers was installed at the World's Fair in Chicago in 1893. It had 2 continuous belts of platform running side by side at constant speeds, one at 3 miles per hour, the other at 6 miles per hour. The latter was provided with seats. Passengers stepped from a stationary platform to the slow speed, and from that to the high speed one. This platform was about 4,500 feet long, built on a pier running out into Lake Michigan. It was well patronized during the Fair.

The next time moving platforms for carrying passengers were used was in 1896 at an industrial exposition in Berlin where it was used to connect the exposition grounds with a nearby amusement park. It was similar in operation to the one at Chicago and was also quite successful. Again at the Paris Exposition in 1900 the moving platform appeared, this time as a component part of the transportation system. It was 10,900 feet long, and, located on a viaduct, 23 feet above the ground, served admirably to give the passengers a bird's-eye view of the exposition, as well as to transport them. This installation also had 2 platforms running respectively at 3 and 6 miles per hour. It operated successfully throughout the exposition, and carried over 7,000,000 passengers.

Continuous-Motion Variable-Speed System

A scheme very different from moving platforms was proposed by B. R. Adkins and W. Y. Lewis (*Scientific American*, April 6, 1907). This scheme provided for a number of separate 4-wheeled cars which would be bunched close together at stations, where there would be a continuous stream of these cars moving at a speed of 3 miles per hour. As soon as each car passed the station, it would be accelerated to about 21 miles per hour, which would separate the cars, leaving about 6 car lengths between adjacent cars, until the next station was reached, when the speed would be again reduced to 3 miles per hour. The article stated: "The method of

Fig. 1. Depiction of the biway in operation

driving the cars at this variable rate is very simple. On each side of the track, extending along the entire length of the line, is a pair of screws or rather shafts, in each of which a spiral groove is cut. One of these is formed with a right-hand spiral, and the other with a left-hand spiral. These opposed spiral grooves receive the opposite ends of the forward axle of each car so that when the shafts are turned in opposite directions, they feed or 'screw' the cars forward. The desired acceleration or retardation of the cars is produced by varying the pitch of the grooves."

One can visualize many difficulties with the screws, particularly since it would be practically impossible to have such a drive on curves and the cars would consequently have to coast through them. The capacity of the system would be comparatively small and the average speed would be low, but the

scheme had the advantage of continuous loading and unloading at every station on the line, but always to or from a train moving at a speed of 3 miles per hour.

Putnam's Moving Platforms

Between 1920 and 1925, Henry S. Putnam of New York developed a system involving the use of 3 continuous constant-speed platforms running at 3, 6, and 9 miles per hour, respectively. Aside from a novel scheme for driving them and the use of 3 platforms to get a higher speed, the scheme of operation was practically the same as that of his predecessors. A demonstration plant was built at Jersey City, N. J., in the form of a loop 200 feet long and 100 feet wide, with a radius of 50 feet at each end. The 3 and 6 mile per hour platforms were 27 inches wide, and the 9 mile per hour platform was 57 inches wide with double seats spaced 32 inches apart. This gave a real working model.

Putnam had 2 methods for operating the demonstration platforms. The 9 mile per hour platform was driven by the inductive method, using a kind of glorified induction motor with an infinite radius of rotor. The primary of the motor was divided into short sections distributed along the middle of the track, while the secondary was carried under the platform and extended its entire length. It gave a constant speed with no gears or other rotating parts, but was very inefficient. The 3 and 6 mile per hour platforms were driven by rack and pinion, with the rack under the platform extending the entire length, and driven by pinions on countershafts driven, in turn, by motors through chains and sprockets.

The demonstration plant was thoroughly tested and inspected by many people. Largely as a result of this, a report of the Transit Commission of the State of New York was made on an installation for 42d Street, New York, from the Hudson River to the East River. This report went into the subject in great detail and covered everything concerned. It was, on the whole, very favorable to the moving platform scheme, but the project never went through.

There are 2 objections to this system that undoubtedly helped to prevent its adoption:

1. The necessity for passengers to step from one moving platform to another moving at a speed of 3 miles above or below its own speed. There undoubtedly would be many people unable or unwilling to do this, which would be a great handicap to the system. It would be equivalent to a moving stairway running at 3 times its usual speed.

2. The limited speed, for while the system would have large capacity, its average speed of 9 miles per hour or less with 3 platforms, is not high enough to be attractive.

Taylor's Variable Speed Moving Platform

To overcome these obstacles was apparently the object of the next attempt to secure continuous transit, which was made by Herman E. Taylor, supervisor of traffic of the Detroit (Mich.) Street Railways, who apparently began to work on it soon after the Putnam demonstration plant was built. By combining the continuous moving platform idea with the thought that was in the mind of Ebenezer Hawkins, and a drive scheme similar to the screw drive of Adkins and Lewis, he developed a very ingenious system. He proposed having 2 endless moving platforms with one of them running at a fairly high constant speed (20 miles per hour was suggested), and the other running at a speed varying from about 1 mile per hour up to the speed of the first.

The second platform was to be used to transfer passengers between the stationary and the high-speed platforms, and was to be driven so as to go through regular cycles of running at about 1 mile per hour, accelerating, running at the same speed as the high-speed platform, and then decelerating to 1 mile per hour to complete the cycle.

This scheme offered not only a high speed nonstop ride with only 2 moving platforms, but it made transferring passengers from one to the other both safe and easy by transferring them when the difference in speed was very small. It was an excellent system that was undertaken, but there are 2 serious obstacles to its commercial success:

1. Difficulties in connection with the screw drive which would appear to be almost insurmountable, and

2. The amount of power required to operate it, partly because of the inefficiency of the drive, and partly because of the large losses from accelerating and stopping the transfer platform. These losses together with the inefficiency of the screw drive and the peak loads would make the cost of power prohibitive.

The "Biway" System

The "biway" is the latest consideration in the way of continuous or nonstop mass transit for local service in congested traffic areas. The general idea of it is similar to that of the Taylor system, but there

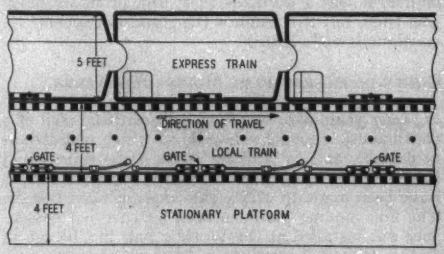

Fig. 2. Floor plan for biway system

are differences both in the results and in the means of obtaining them that are believed to make it a more practicable and economical system.

It consists of 2 endless electric platforms on parallel tracks with a stationary platform extending the entire length beside them. (See figures 1, 2, and 3.) One of the platforms—the express—moves continuously at a selected average speed (not a constant speed) with variations above and below that speed depending on several conditions that will be explained later. (See figure 4.) The other moving

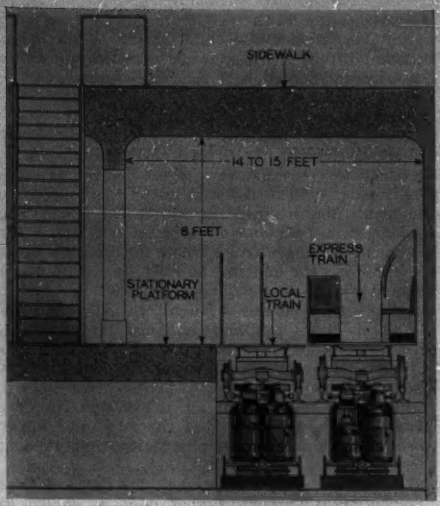

Fig. 3. Cross section of biway system

platform—the local—lying between the express and the stationary platforms, every 42 seconds goes through a regular cycle of standing still, accelerating, synchronizing with the express at its minimum speed, running at that speed for a certain number of seconds, then slowing down to a standstill to complete the cycle.

Figure 4 gives the combined speed-time curves of both platforms, showing the variations in speed of both throughout the cycle. It shows that with an average speed of 15 miles per hour, the express platform varies in speed between 16.5 and 12.5 miles per hour, while the local platform starts from rest, accelerates to 12.5 miles per hour, reaches that speed at the same time as the express, runs at approximately the same speed for 10 seconds, and then decelerates to a standstill while the express accelerates to its maximum speed. This cycle is repeated every 42 seconds as shown on the speed-time curves.

There are several reasons for the variable speed express:

1. It permits a lower maximum speed for the local, which decreases the amount of power required to accelerate it, and, with the same rates of acceleration and deceleration and the same average express speed in both cases, saves from 3 to 5 seconds in the duration of a cycle of operation over that of a constant speed express.

2. It affords a means of securing a practically constant load on the power line. This is effected by interchanging the kinetic energy of the moving platforms when speeds are changing.

3. It increases the efficiency of operation by saving energy that would otherwise have to be lost in stopping the local platform.

The amount of variation in speed of the express is dependent on the relative weights of the 2 moving platforms. The rate of change will be adjusted so as to maintain a uniform flow of power from the external circuit. These results will be obtained by a system of regeneration by which the local draws power from the express when accelerating and returns power to the express when decelerating. Incidentally, this eliminates all forms of mechanical brakes from the equipment. Emergency stops will be made by using the motors for dynamic braking.

As may be seen, the function of the express is to give every passenger a nonstop ride from where he enters the biway until he reaches his destination. The express stops only once a day. The local stops 85 times every hour. Its chief function is to transfer passengers from the stationary platform to the express, and *vice versa*. Of course, passengers may ride the entire distance on the local if they want to, but it will be noted that there is standing room only with posts or outside railing to hold on to, on the local, while the express is provided with seats, there being about 4,000 per mile, giving 60,000 seats per hour past a given point.

Wherever possible, the biway should be located under the sidewalks of the busiest streets, with easy access to it both from the sidewalks and from the principal buildings adjacent to it. Turnstiles or doors should be not more than 100 yards apart unless the biway has to be located at a low level at some points to avoid a subway or other obstruction.

The advantages of this system to the passenger are obvious: The frequent entrances; the short interval between stops; floors of stationary and moving platforms all on the same level; stepping from one platform to another either when both are at a standstill or when both are moving at the same speed; smooth and slow rates of acceleration and stopping; comparatively noiseless operation; the absence of crowding as the result of the better distribution of passengers; the practical certainty of a seat for everyone at all times; and a nonstop ride from wherever one happens to be on the line to within 200 or 300 feet of the exit one wishes to use. All these features will appeal to the passenger because they will save his time or add to his comfort and safety.

The entire line will be well lighted and much of it arcaded where it can be located under the sidewalks. Conspicuous signs give the names of buildings or streets with advice as to when the passenger should transfer to the local in order to come closest to his desired destination. The advice to transfer will be shown about 840 feet from his desired destination, and the passenger will transfer at the next opportunity. If that stops him too far short of his street, he can ride another cycle on the local which will take him about 400 feet farther. In this way, he can come very close to the desired spot.

Figure 5 shows the average speed and distance traveled in terms of cycles. Distances are plotted with one cycle only on the local, 2 cycles on the local, and all on the local. At a speed of 15 miles per hour, the express will travel 924 feet per cycle while the local travels 390 feet. The curve in figure 5 shows that one can go 5,000 feet in 6 cycles (or 4.2 minutes) giving an average speed of 13.5 miles per hour. In 12 cycles, one would travel 10,560 feet at an average speed of about 14.3 miles per hour. Both of these rates are conditioned on riding one cycle on the local and the rest on the express. It follows that the more

cycles one travels on the express, the nearer his average speed approaches 15 miles per hour. While this is not a high speed, it will compare very favorably with subway or elevated local train speeds. The greater accessibility and greater frequency of stopping will save much walking and much time ordinarily spent waiting for trains.

Figures 1, 2, and 3 give a fair picture of the general construction. As indicated on figure 2, the electrically operated platforms are divided up into short sections which will be from 8 to 12 feet long, depending on the minimum radius of curvature on the line. Each section will have only 2 wheels, which will be mounted on a fixed axle at one end of the section. The other end is carried on the axle of the next section, so that the platform is an articulated structure. In order to provide a continuous floor, whether on tangent or curved track, the ends of the sections are arcuately shaped as shown in figure 2.

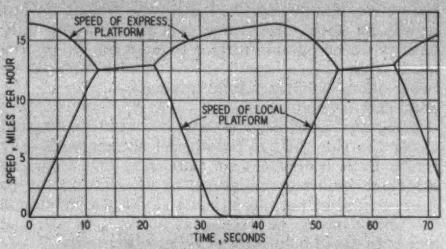

Fig. 4. Speed-time curves for the biway system

The wheels on the axles are mounted on separate roller bearings and perform no functions other than carrying the load and keeping the train on the track. The wheels may be either solid steel or some form of resilient construction. If steel tires are used, it will be desirable for the sake of reducing noise and wear to grease the track rails.

The platform section will be of a very simple and light construction which will lend itself readily to mass production as there will be from 400 to 660 sections per mile in each platform.

The Drive. The method of driving the platforms is rather novel, although the idea is an old one. It is purely an adhesion drive, but the motors are stationary beneath the tracks and the rail is carried under the platform. Figure 3 is a diagrammatic cross section of the biway showing the wheels, fixed axles, and the driving rail which, in the form of a T section like an elevator guide rail, is carried underneath the middle of the axle. The sketch also shows the driving wheels or rollers and the vertical-shaft motors that furnish the motive power. The drivers are in pairs with the flange or stem of the driving rail running between them. The necessary pressure on the drivers is obtained by compressed air. This acts on large roller bearings on the driving shafts just under the drivers, so as to pull the drivers together. The motors, mounted on trunnions to permit a slight lateral variation of the driving rail, are carried on a base frame supplied with small wheels. When in the normal position, the base frame is raised well above the floor and bolted to a solid foundation and the motors are also anchored at the top by tension rods against the reaction of the drivers.

The T section used for the driving rail is a very important element in the platform. It really forms its backbone. It is shown in figure 6 with the coupling castings welded to it with one of them including the means for securing the rail to the axle. The coupling brings the ends of adjacent rails into exact alignment on tangent track where the driving motors are located. The ends of the rails are cut off at an angle of 45 degrees for obvious reasons. The entire drawbar force is carried through this rail. In fact, if the wheels, axles, rail, and couplings were fitted together, they could be driven around the track without any floor or superstructure, whatever. This lends itself to a very simple construction since it permits easy replacement of a rail and coupling from the inspection pit, or of the floor and upper works of a section in case of a serious repair being necessary.

The driving rail is supported by the axle and clamped to it through rubber pads as shown in figure 6. This is to prevent the vibration from the driving rollers and the motor gears from being communicated to the floor of the platform.

The coupling has a universal joint of the ball and socket type. Means are provided in this coupling for taking up slack in the platform and also to allow a small amount of flexibility in it.

Driving Motors. The mechanical arrangement of the driving motors with respect to each other and to the driving rails of the 2 platforms is shown in figure 7, and the main circuit schematic diagram for the motors is shown in figure. 8. It may be noted that a set of motors for a driving station consists of 3 pairs of motors marked $M1$, MG, and $M2$, respectively. The 2 motors of each kind are connected permanently in series. The $M1$ and MG motors are geared to the driving shafts of the express platform, one of each to a shaft on either side of the driving rail. The $M2$ motors are geared to the driving shafts of the local platform. All of the motors are compound wound with shunt windings separately excited, and the series windings connected as usual in series with the armature.

While the $M1$ motors are amply able to drive the express platform, the addition of the MG motor makes it possible to have voltage control for $M2$ for accelerating and also provides means for interchanging stored energy between the 2 platforms.

The $M1$ motors are the only motors connected to the outside power line. Geared to the driving shafts for the express platform, they run continuously at a speed proportional to the speed of the express, and at a load varying only with the total weight of passengers. The MG motors are geared to the same driving shafts for the express platform, one MG motor being geared to each shaft. The $M2$ motors are duplicates of the MG and are geared to the driving shafts of the local platform.

The diagram in figure 8 shows that the MG and

$M2$ motors are permanently connected together electrically, but are disconnected when the local is standing still. All the power taken by the local platform is generated by the MG motors and put into the $M2$ motors. The MG and $M2$ motors act alternately as motors and generators; when one is acting as a generator, the other acts as a motor. They interchange current one way or the other all through the cycle except during the time the local is standing still. The $M2$ motors have a strong field practically all the time they are in operation. The field of MG varies all the way from 0 to its maximum strength, depending on the voltage required or supplied by $M2$.

Control. The control system for the biway is entirely automatic and when once started will continue to put the moving platforms through the regular cycles of operation until power is cut off. Each set of motors will have its own control apparatus which will be operated in synchronism with all other stations. The speeds of the motors, and therefore

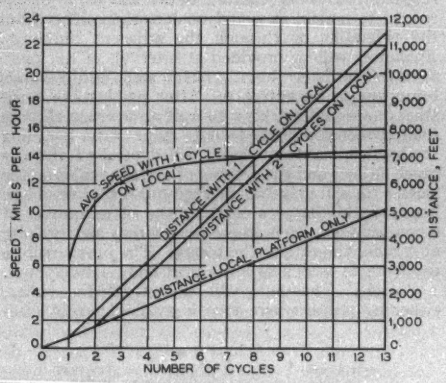

Fig. 5. Speed and distance curves for the biway system

Time of cycle taken as 42 seconds, average speed of express as 15 miles per hour

of the platforms, are controlled entirely by means of field rheostats. A combination of sequence drums and field rheostats is operated by a synchronous motor with power furnished from a generator at the central control station, so that all of the control sets are operated in synchronism and everything is controlled on a time basis. The generator supplying current for the synchronous motor is under the control of the central control station operator, who can change its speed and consequently the length of a cycle by simply changing the speed of its driving motor.

Similarly, the chief operator by a proper control of the supply voltage, can change the speeds of the platforms. By combining these 2 schemes of changing the length of cycle and the speed, he can secure almost any result desired within the capacity of the motors. This may prove to be a valuable asset in meeting various traffic conditions.

In addition to controlling the motors, the synchronous motor-operated sequence drums will open the gates and operate suitable signals to inform the passengers of the proper time to transfer.

Brakes and Train Signals. With the biway system, neither mechanical brakes nor train signals will be necessary because with continous platforms there can be no collisions and every section of the platform must run at the same speed as every other section. As previously stated, the deceleration of an electric platform is accomplished by using the motors on that platform as generators. In the ordinary cycle, the power generated by one electric platform is used to accelerate the other platform. If it is desired to stop both of them, power is cut off the $M1$ motors and the MG and $M2$ motors act as generators and stop the platform by dynamic braking, the power generated being absorbed by resistors.

The elimination of all mechanical brakes in this way eliminates a great deal of noise, all brake shoe dust, and saves the energy usually lost in stopping trains.

Power Consumption. It is significant that the only power taken from the external line is that required to overcome train resistance and to supply the losses in motors, drive, and control. Although the efficiency of regeneration is not high, regeneration effects a considerable saving in the total energy consumption. It is estimated that the energy consumed by this system will be in the neighborhood of 35 watt-hours per ton mile for both platforms, or from 300 to 450 kw per mile, depending on the load. This is very light when compared with street cars or subway trains. A fully-loaded 10-car train in the 8th Avenue Subway, New York, carries a maximum of 2,800 passengers, of whom only 540 are seated, and re-

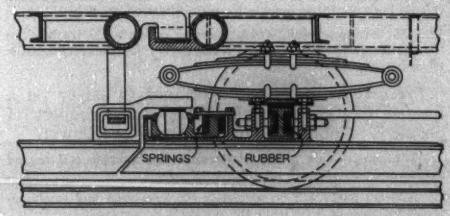

Fig. 6. Section through coupling and running gear of moving platform

quires over 4,200 kw to accelerate it. The power consumption of the biway with a given load will increase as the rates of acceleration and deceleration and the number of cycles per hour increase. The rates recommended are from 1 to 1.25 miles per hour per second, which will be very easy for standing passengers on the local platform, and is fast enough since it does not affect the speed of the express platform. The only disadvantage of the low rate of acceleration is that it increases the length of a cycle

and the distance covered by the express in one cycle. This can be varied over a wide range to suit local conditions.

The low power consumption and the high load factor make it possible to operate the biway during periods of light load with very little expense. It could probably be operated 20 hours per day with an average load of not more than 350 kw per mile.

Safety. Naturally the first consideration in the design of a system for city transit is for the safety of the passengers. This attribute the biway possesses to a high degree for the following reasons:

1. The maximum speed is low, scarcely more than a third of that of the subway or 40 per cent of the maximum speed of the ordinary street car.

2. The floors of the moving and stationary platforms are all on one level.

3. There is no interference or danger from other traffic as there is with street cars and busses.

4. Crowding is prevented:
   a. By receiving the passengers all along the route instead of forcing them all to enter at a few stations,
   b. By the greater frequency of stops, nearly 3 times the maximum frequency of subway trains, which prevents crowds from collecting.

5. The voltage control system used absolutely prevents jerking the train and the rates of acceleration and deceleration are very low.

6. Passing from one platform to another is done when there is practically no difference in speed between them.

7. There will be a minimum of interference in interchanging passengers because the gates will open from $^1/_3$ to $^1/_3$ the entire length of platforms, and provide ample space.

8. The gates will be opened and closed automatically to prevent passengers from transferring when there is a material difference in speed.

9. The sections of platform will be short enough to prevent any serious gaps between platforms on curves.

10. Guards will be placed at frequent intervals along the route to render assistance to any in need.

11. Emergency stop buttons will be located so as to make it possible to stop both platforms quickly from any point on the line.

12. There is no possibility of a passenger falling to the tracks since the platforms cover the entire space except for the very narrow track between them.

Reliability. Next in importance to safety on a line of this character handling large numbers of people is reliability. This is secured as follows:

1. The construction of the platforms will be simple and rugged with every part having a large factor of safety.

2. Wearing parts will be accessible for inspection and easily replaceable, most of them while the system is in operation.

3. Driving motors are stationary, located under the tracks, and can be taken out and replaced easily while the biway is in operation.

4. Control apparatus for a set of motors may also be repaired or replaced without interfering with operation.

5. Sufficient driving stations will be provided so that some of them will always be idle. Stations will be about 500 feet apart.

6. Inspection pits under the tracks will be provided at all driving stations.

7. Gate operating mechanism will be above the floor so it can be repaired or replaced while the platforms are in motion.

8. Couplings may be inspected and lubricated from above the floor.

9. The slow speeds at which the platforms are run will not only contribute to long life of parts, but will make it easy to detect deterioration that might lead to a breakdown.

Capacity. The ultimate capacity of the biway is enormous. As previously stated, there will be 4,000 seats per mile of express, or at 15 miles per hour, 60,000 seats past a given point per hour in one direction. There will be comfortable standing room for as many more. Based on the same floor space per passenger as the subway cars the express could carry 11,000 passengers per mile, or 165,000 per hour past a given point. The local can easily carry 5,500 standing passengers per mile without interfering seriously with transferring. This would make 35,000 more past a given point per hour, or a total ultimate capacity of 200,000 passengers per hour. This appears so far beyond the maximum requirements as to make it scarcely worth considering. Since much of the riding on the biway would be for short distances, the total number of passengers carried would be much greater than the number carried past a given point. There can be no question as to the capacity of the biway.

Convenience. The question of convenience plays a very important part in any transit system. In this respect, the biway located under the sidewalks is second to none. It would be accessible either from the sidewalks or through the adjacent buildings. Entrances will be provided at intervals of not more than 100 yards, so that a very few steps would always bring one to an entrance. After passing the turnstile, one would not have to wait an average of more than 16 seconds for the local to stop. After boarding the local, his average speed will depend on the distance he goes and the number of cycles he rides on the local. He will make an average speed that would be impracticable on a car making the same number of stops per mile, even when accelerating and braking at 4 times the rate of the biway. The biway will be comfortable as well as convenient and relatively fast.

Heating. The biway will be heated in the winter, either by steam where that is available, or by electricity. The entrances will be protected by doors to prevent loss of heat, but since the passengers will be dressed for the street, it will not be necessary to have a temperature above 60 degrees Fahrenheit, and probably 50 degrees would be ample.

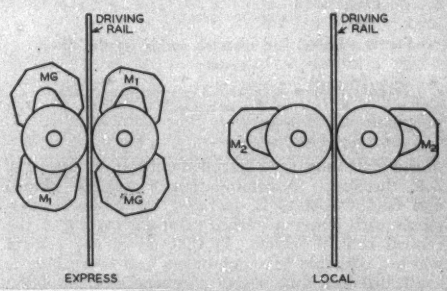

Fig. 7. Arrangement of one set of driving motors

Costs. The cost of a biway system is dependent largely on local conditions which govern the costs of

real estate, excavations, etc., which will be the largest factor in the first cost.

The biway for one direction will require about the same size of tunnel as a single track subway, but will be wider and not so high. On that basis, estimates made from actual costs of subways indicate

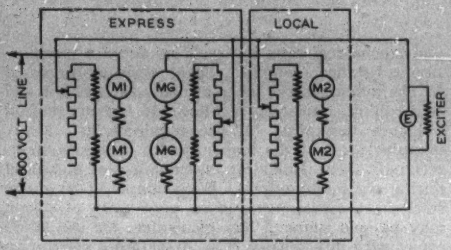

Fig. 8. Diagram of electrical connections for driving motors of the moving platforms

that the total cost of biway ready for operation will lie between $3,500,000 and $4,500,000 per mile, or $10,500,000 to $13,500,000 for a 3 mile loop. At six per cent, the annual charges will be from $630,000 to $810,000.

The annual operating costs are estimated to be approximately $615,000 for a 3 mile loop. It will require about 34,000 passengers daily at 5 cents each to pay this. 45,000 passengers daily will pay the interest charges, so that only 79,000 passengers daily would be required for interest and cost of operation.

Operating Economies. A comparison of the biway with the New York Eighth Avenue Subway will serve to point out the difference in costs. As stated, the biway will require a tunnel with about the same cross section as a single track of the present subway. It would cost more to finish and light it. The tracks would cost somewhat more for permanent resilient supports, which are desirable, and for the double track which, however, would not have heavier than 45 pound rails, while the subway would have at least 90 pound rails.

The biway express would weigh about 440 tons per mile; the local about 325 tons, or a total of 765 tons per mile. This weight is equal to that of 18 subway cars. This number of cars can seat 972 passengers. One mile of biway would seat 4,000. Eighteen cars can carry a maximum of 5,040 passengers. One mile of biway could carry conservatively a maximum of 12,000. It would, therefore, require at least 40 subway cars to equal in capacity one mile of biway. Forty cars weigh 1,700 tons as against 765 tons for the biway.

Forty cars have motor capacity of 380 horsepower per car or a total of 15,200 horsepower. One mile of biway will require less than $^1/_4$ this horsepower in motor capacity, including spare motors on the line. Even this is out of all proportion to the power taken from the line, on account of having extra motors and larger sizes for regenerating. The motors will be located in 10 driving stations with 6 motors per station. The mounting and driving mechanisms of the motors for the biway will probably cost as much as the motors themselves, and the construction of the driving stations will add still more so that the difference in cost of motive power will probably not be very great.

There will be a great difference between the cost of 40 subway cars without propulsion equipment, and one mile of biway. The latter will be a mass production proposition of very simple parts, and, considering that the weight will not exceed $^2/_3$ of that of the subway cars and trucks, should not cost more than half as much.

When it comes to power consumption, the difference will be still greater. It must be understood that it is utterly impossible for the subway cars to make 13.5 stops per mile and maintain a schedule speed of 12 to 14.5 miles per hour as the biway can do (see figure 5). Even with 2 $^1/_4$ stops per mile, the subway trains can maintain a speed of only 14 miles per hour with 73 watt-hours per ton mile—double the watt-hours per ton mile required by the biway. A street car making 9 stops per mile with a schedule speed of 14 miles per hour will require about 325 watt-hours per ton mile—about 4.5 times the amount taken by the subway with the same speed and $^1/_4$ the stops per mile. With only 3$^1/_4$ stops per mile, the subway cars would require about 3 times the watt-hours per ton mile that the biway would. Thus even with reduced service in the subway during the light hours of traffic, and the biway running at normal speed, the biway would not use more than half as much power as the subway. If it is desired to reduce the cost of operation of the biway during the night hours, the speed may be reduced to 8 or 10 miles per hour, and would probably give better service then than the subway with fewer trains.

Altogether it appears that the biway will cost less to construct and install than the subways and will give much better service.

The Field for the Biway

Undoubtedly the initial field for the biway lies in the crowded districts of large cities where it should be used for local transit and for distributing passengers from outlying districts. A set of interconnecting loops through the busy section would enable a passenger to reach any part of the section quickly and easily. There are strong possibilities that it might supersede the present local trains of the 4-track subways. A test in actual service is necessary to prove its suitability for the service and its possibilities for extensions to longer lines. Such a test can be undertaken only by a properly financed transit utility or by a muncipality, since the installation would involve the right of way, interferences, and a cost of construction far beyond what could be financed by a manufacturer of the equipment itself. When such a test has been made, the costs of operation, power, and maintenance will be determined and all questions as to safety, reliability, and general practicability will be answered. Certainly, if cities continue to grow, a system having the characteristics and attributes of the biway will soon be an absolute necessity.

Silicon Steel in Communication Equipment

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Steel containing small amounts of silicon has come into wide use as a magnetic core material. In this paper the different grades of silicon steel, and other magnetic materials such as the nickel-iron alloys, are discussed with particular reference to the selection of the most satisfactory alloy for the various applications in communication equipment, which includes transformers for audio frequencies, small rotating apparatus and relays.

OF THE 10 elements which form nearly 99 per cent of the earth's crust only oxygen is more abundant than silicon, the availability of which makes it inexpensive as compared to other alloy elements. It is doubtful if iron or steel has ever been produced commercially without at least a trace of silicon. In the proper proportions it indirectly increases the initial permeability and decreases losses, but with a reduction in saturation induction slightly greater than the percentage of silicon added.

The early work of Hopkinson, Parshall, and Hadfield dealt with the study of the magnetic and electrical properties of silicon alloys and directed attention to the possible application of such alloys and magnetic structures.[3] The first silicon alloy sheet was produced shortly after 1900 by several German firms for the Physikalisch-Technische-Reichsanstalt. As was expected, because of its higher specific resistance, eddy current losses were reduced, hysteresis losses were also lower, and permeability in low fields was higher than for ordinary iron. The records of the General Electric Company indicate that it was 1905 before silicon steels were regularly used in transformers. Development has continued and improvements are still being made. In figure 1 is shown the decrease in core loss of commercial silicon steels during the period 1905 to 1933.

Silicon Steels

There are available commercially in the United States 6 grades of electrical sheet steels whose normal properties are given in table I and in figures 2 and 3.

It is common practice to purchase steels containing one per cent or more of silicon on the basis of magnetic and mechanical tests but with no definite specification as to silicon content. Sheet steels are processed by the manufacturer by treatments such as hot and cold rolling, annealing, pickling, etc., in any desired sequence depending on the requirements. Many manufacturers of the higher grades of silicon steels reclassify them depending on the losses as measured during the manufacture. For example, a 29 gauge steel sheet containing a given percentage of silicon may be sold under a loss guarantee, for use at 60 cycles with flux density $B = 10{,}000$ lines per square centimeter, of 0.72, 0.66, or 0.60 watts per pound. Maximum permeabilities are available from 5,000 for standard iron to 8,000 for the ordinary transformer irons and 20,000 for the best silicon transformer irons.

In order to select the proper grade of material for a particular application, a number of factors must be considered. For example, standard and armature grades of steel have rather high losses and are subject to aging, or gradual change in magnetic properties at operating temperatures, while steels of higher silicon content do not age. Steels with low silicon content are difficult to mill anneal because of sticking during the process, and further, the low resistivity is objectionable except at low frequencies. Thus standard iron and armature iron are undesirable where efficiency is important; however, these may be used to advantage where low cost is essential, the service is intermittent, or the apparatus requires a high saturation limit and uses low frequency. Unlike standard iron, armature iron is sold by the mills on a guaranteed loss basis, and this, together with the expense of the better annealing, makes an appreciable difference in price.

Electrical sheet containing approximately 1 per cent silicon, is the cheapest reliable grade of mill-annealed steel and so is widely used for low frequency and low cost machines where efficiency is not highly valued. Its mechanical properties are very similar to standard iron although it has slightly more surface scale. It is suitable for use in rotating apparatus.

Motor grade, about $2^1/_2$ per cent silicon, is thoroughly reliable mechanically as well as magnetically. It is particularly suitable for use in medium sized rotating apparatus and in certain classes of transformers and reactors. It normally has an appreciable surface scale which may be satisfactory as insulation in small apparatus. It can be spot welded.

Dynamo grade, which contains $3^1/_2$ per cent silicon, is considered satisfactory mechanically for general use in rotating apparatus but with higher silicon content brittleness makes such use hazardous in the rotating parts. On account of the normal heavy

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3. For numbered references see list at end of paper.

scale of this steel annealing in a neutral atmosphere is necessary to prevent oxidation, and it is often better to purchase this material pickled. Punching of the mill-annealed dynamo steel hardens the edges sufficiently to prevent tearing when used in transformers having a forced fit core where motor grade normally is too soft.

For large transformers, where size and losses are limiting factors, transformer grade with 4 per cent or more of silicon will give uniformly low losses and annealing can be done after punching in a forced fit core design without fear of tearing. Transformer grades of steel are used particularly for apparatus where low losses without particular regard to mechanical properties are necessary. Transformer steel which has been selected for lower than normal losses is additionally classified as audio grade.

These grades of material are further classified as to thickness, the most commonly used gauges being 24, 26, and 29. For power use 29 gauge is about as thin a sheet as is practicable from consideration of manufacturing, resulting loss, and cost. For frequencies from 2,000 to 10,000 cycles 36 gauge and for radio frequencies 3 mil stock is used. Space factor punching and assembling costs, expense of dies, extra rolling, and increasing core losses limit the thinness of steel for a given application. However, it has been found that unless the frequency exceeds 2,000 cycles, the 29 gauge is, in general, the most economical.

Besides selecting the grade and thickness of steel to be used, the designer is faced with some interesting problems in selecting treatment for the steel. For lowest cost, annealing at the mill, punching, and assembling without any factory treatment is the appropriate procedure. For high frequencies, low flux densities, and small tooth widths and air gaps it is important to anneal the material after punching in the factory. Special technique is required in annealing to minimize warping to secure the least possible surface scale, and to obtain the lowest possible hysteresis losses. Surface scale on silicon steel is very objectionable, not only because it causes rapid die wear, poor space factor, and loose particles, but because it materially increases the core losses at high induction. Best results are obtained by annealing in hydrogen and subsequent pickling, but this process is too expensive for general use.[13]

It is important to secure minimum burrs on the punched edges and it is occasionally desirable to lightly grind off these burrs before assembly. Insulation of the punchings is more necessary at high frequencies and in large apparatus, but it can usually be dispensed with on the silicon steels used in small radio and audio apparatus.

Other Magnetic Materials

There are a number of special and experimental alloys which should be mentioned to make any consideration of magnetic materials used in communication equipment complete. For radio frequency use there has been developed a powdered iron which is molded in a binding material which insulates each particle. At present this material is used to make cores for intermediate frequency transformers used in some radio receivers and its possibilities appear quite favorable, particularly from the standpoint of reducing the size of these transformers. A similar material has also been successfully used for the cores of telephone loading coils.

Where lower losses and higher permeabilities are required than can be obtained in silicon alloys, the nickel-iron alloys, or permalloys, are very useful. A 45–50 per cent nickel alloy is used in certain classes of audio transformers, and in other devices where a high saturation limit is not required. This material of 29 gauge can be obtained commercially with losses under 0.35 watts per pound at 60 cycles with B = 10,000. Commercial maximum permeabilities are in the order of 45,000 to 60,000. However, the cost of this material is from 6 to 10 times that of the best grades of transformer steel and of necessity it must be factory annealed after punching. However, the mechanical properties are much better than those of the highest grade silicon steel so manufacturing losses are not as great.

A permalloy which contains approximately 80 per cent nickel has about $1^1/_2$ times the permeability of the 45–50 per cent nickel alloy but the cost is twice that of the latter. Both of these alloys have the disadvantage that magnetic properties change adversely due to mechanical shock or stress, a characteristic which must be given due consideration. Permalloy has been used very successfully for loading extremely long cables such as transatlantic telegraph cables.

Table I—Properties of Electrical Steels

	Grade					
	Standard	Armature	Electrical	Motor	Dynamo	Transformer
Normal silicon, per cent	0	0.5	1.0	2.5	3.5	4.0r
Watts loss per pound at 60 cycles for 29 gauge as purchased, B = 10,000	2.1	1.65	1.35	1.10	0.95	0.70
Flux density in lines per square inch at 100 ampere turns per inch	105,000	105,000	105,000	100,000	100,000	96,000
Number of 180 degree bends over 5 millimeter radius to cause fracture, 29 gauge	20*	20*	21	16	8	2
Ultimate strength in pounds per square inch	42,000	45,000	47,000	60,000	70,000	80,000
Yield point in pounds per square inch	28,000	27,000	27,000	47,000	57,000	69,000
Elongation in 4 inches, per cent	21	19	17	12	4	3**
Resistivity approx. microhms per centimeter cube	14	18	25	43	51	62

* These figures are for 26 gauge (0.019 inch). The values for these materials are quite variable.
** Elongation in 2 inches, per cent.

Application of Silicon Steel

The selection of the grade of magnetic material best suited to the component parts of communication equipment depends primarily on the limitations im-

posed, such as size and weight, losses, voltage regulation, and cost.

Power transformers operate at only one frequency, such as 25, 50, or 60 cycles, although there are special cases where 360, 500, or 800 cycles are used. For

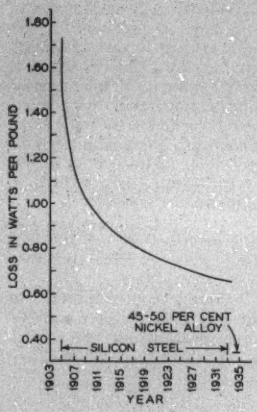

Fig. 1. Improvement in quality of silicon steel as indicated by reduction of core loss

Loss for 29 gauge steel at 60 cycles with flux density of 10,000 lines per square centimeter

the 3 higher frequencies 29 gauge transformer steel is generally used since it has the required high resistivity which limits losses to a satisfactory value. However, for the lower frequencies each limitation must be considered separately.

On high class transmitting equipment the limiting factors are usually voltage regulation and losses. Thus the higher silicon content steels are desirable since for a given loss they can be operated at higher densities, thereby allowing a reduction in core cross section and reducing winding resistance and leakage reactance.

Power transformers or other special apparatus used on ships and airplanes invariably must be made as small and light as possible and hence require the use of a lower loss material such as transformer steel (audio grade). Those used in broadcast receiving equipment, however, are usually built in larger quantities and cost is a more important item. The grade of steel to be used depends more on the relative importance of each limiting factor and also on the manufacturer's plant equipment. Consequently, the 24 gauge motor grade, both the 24 and 26 gauge dynamo grade, and the 29 gauge transformer grade either mill annealed or factory annealed may be used as requirements dictate.

In general, the same factors that control the design of power transformers apply in the design of reactors but have different relative weights in the selection of the material, depending on the function of the reactor. The low frequency filter reactor, for example, operates at an extremely low alternating flux density so the core losses are relatively unimportant. However, the inductance of the reactor must be high to furnish a high impedance to the fluctuating current of a rectifier while the resistance must be low in order to obtain good d-c regulation. Since inductance is directly proportional to the effective permeability of the magnetic path, the permeability is an important factor in the design. The air gap which is introduced in the magnetic circuit to prevent saturation of the core with d-c flux reduces the effective permeability. Consequently, although there is an appreciable difference in the permeabilities of the various commercial silicon steels, there is a relatively small difference in the effective permeability between the motor grade and a higher grade when an air gap is placed in the magnetic circuit. As a result the use of the higher grade of steel is not justified from an economic viewpoint although limits on size and weight may justify its use.

Tank circuit oscillator reactors for use in audio oscillator circuits are distinctly an a-c type of reactor which operate at a given relatively high frequency. If the frequency is 2,000 cycles or above, the eddy current losses in the steel become excessive unless an exceptionally thin lamination of high resistivity material is used. It is, therefore, usually necessary to use a 36 gauge transformer steel in the core.

Audio reactors, like filter reactors, carry direct current but differ from the filter and tank circuit reactors in that they operate over a wide range of frequencies instead of operating at a fixed frequency, the limits depending on the range of the apparatus in which they are used. The audio reactor should have a uniformly high impedance over its entire frequency range and consequently the distributed capacity of its windings as well as its inductance must be given consideration, since the combined impedance of these 2 factors is the net impedance. As the inductance, which varies with the square of the number of turns, should be very high and since the distributed capacity, which in general increases with the number of turns and the size of the coil, should be very low, it is necessary to compromise on the number of turns and use a high permeability steel. Usually the requirements listed make it necessary to use a 29 gauge transformer steel (audio grade) in audio reactors although in special low cost apparatus, with a narrow frequency range, either motor grade or dynamo grade may meet the requirements.

Selection of Core for Audio Frequency Transformers

The audio frequency transformer has little in common with the power transformer. The power transformer operates from a voltage source of good regulation which permits a design having relatively high losses. The audio transformer, on the contrary, operates from a voltage source of poor regulation, varying widely in amplitude, and covering a wide frequency range (nominally 30 to 10,000 cycles). As a result the flux densities vary from negligible values at 10,000 cycles to approximately 4,000 lines per square centimeter at 30 cycles. Under these conditions it is desired that the transformer have a constant ratio over the operating frequency range. While such performance is obviously impossible it can be approached by providing sufficient primary

impedance, selecting the turn ratio to properly reflect the load and by correctly balancing the leakage reactance and distributed capacity in the secondary winding.

In order not to unnecessarily load the voltage source the transformer open circuit primary impedance must be equal to or greater than the impedance of the voltage source and losses in the transformer must be kept low. Since the permeability of magnetic materials decreases with the flux density (below the point of maximum permeability) this impedance should be determined at the lowest operating signal voltage and frequency. The primary impedance of the interstage or input transformers, operating with no d-c flux in the core, varies with the square of the primary turns making it desirable to use a large number of turns. The high frequency requirements, however, demand that the distributed capacity and leakage reactance of the secondary windings be kept low so that series resonance between them will not occur in the operating frequency range. Since the secondary leakage reactance varies with the square of the secondary turns and the turn ratio is fixed by the respective circuit impedances, there are 2 conflicting demands: one for a large number of turns, and the other for a small number of turns. The primary impedance also varies with the permeability and with cross section of the core, making it possible to obtain the required primary impedance by the use of a high permeability core of the proper cross section.

From the foregoing it may be seen that the characteristics of the materials used are of vital importance and that the higher the permeability of the steel, especially at lower densities, the better it is for interstage and input transformer design requirements.

If the output transformer operates from a single tube, the direct current usually passes through the primary winding and it is necessary to insert an air gap in the core to prevent saturation by the d-c flux. The output transformer is normally a step down transformer which makes it possible to use a large number of primary turns without introducing difficulties with high leakage reactance. Since the distributed capacity of the secondary winding with so few turns is negligible no consideration need be given to balance between leakage inductance and distributed capacity. Consequently, as far as core material is concerned, the same factors that influence the filter reactor design must be considered for the output transformer which carries direct current in its primary winding. The push-pull output type of transformer design can be considered as an a-c reactor operating over a wide frequency range.

In all audio transformers the operating core densi-

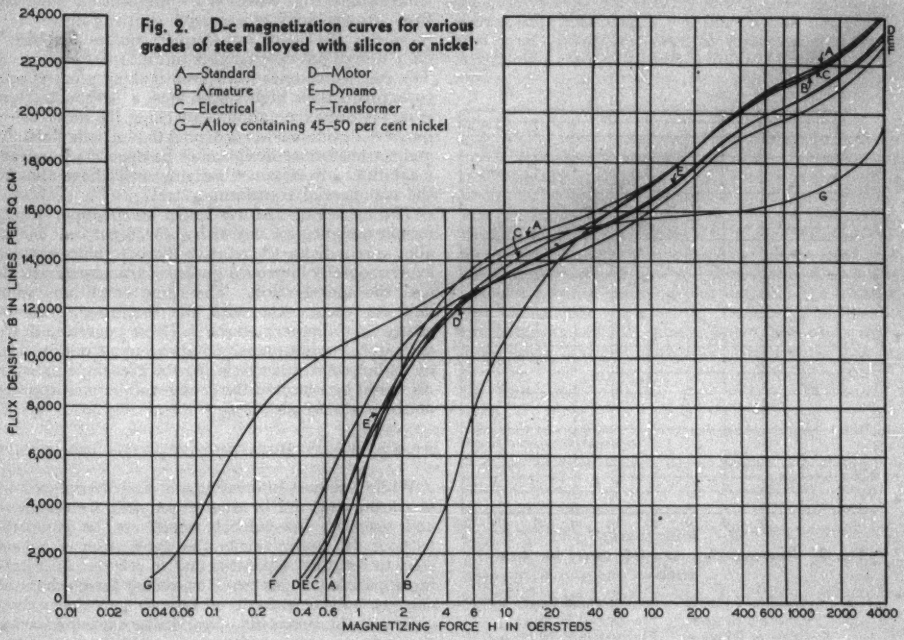

Fig. 2. D-c magnetization curves for various grades of steel alloyed with silicon or nickel

ties are kept very low and this condition combined with thin laminations and a high resistivity steel to restrict the eddy current losses at high frequencies adequately provides for the low loss requirements.

The silicon steel which best meets the requirements of high permeability and high resistivity is the transformer grade. In practice, transformer steel (audio grade) is used except in low cost receiving equipment output transformers having an air gap in the magnetic circuit. In these latter transformers to keep the cost low either motor or dynamo grade is used, but at a sacrifice in quality.

Application of Nickel-Iron Alloys

As previously indicated, a compromise between the requirements of high primary impedance and low leakage reactance and distributed capacity must be made. The primary turns are thus limited for any given design, and if a transformer steel core is used it is necessary to have a relatively large core cross section to obtain sufficient primary inductance.

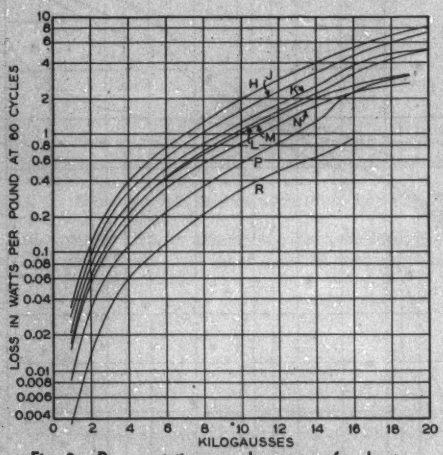

Fig. 3. Representative core loss curves for sheet steels

H—Standard, 24 gauge
J—Armature, 24 gauge
K—Electrical, 26 gauge
L—Motor, 24 gauge
M—Motor, 26 gauge
N—Dynamo, 29 gauge
P—Transformer, 29 gauge
R—Alloy containing 45–50 per cent nickel, 28 gauge

If an attempt is made to reduce the over-all physical size of the transformer by reducing the cross section the turns must be increased and it then becomes necessary to sectionalize the coils to keep the leakage reactance and distributed capacity low. The result however, is a tendency to further increase the size of the transformer rather than decrease it because of the poorer winding space factor. To obtain a size reduction it is, therefore, apparent that a core material of much higher permeability is needed to permit the use of relatively few primary turns.

With such a very high permeability steel the core section area could be reduced, and with the resulting smaller core, lower distributed capacity and leakage inductance could be obtained because both depend on the physical size of the coil. Consequently, the higher the permeability of the steel can be made the better it is for the audio transformer design, providing, of course, that the losses are also proportionally lower.

An alloy containing from 45 to 50 per cent nickel meets the requirements of both low loss and high permeability at low densities and for that reason is being used extensively although its high cost tends to limit its use. This seems to indicate that it should be used only where small size is required but actually under certain conditions of design of the larger audio transformers the additional complication resulting from the necessity of excessive splitting up of coils in silicon steel core transformers makes the nickel alloy design not only smaller but also less expensive. The steel companies have been making great efforts to improve their high silicon steel. Although there is no present expectation of reaching the nickel alloy quality, developments indicate that a new field for audio transformer design may be opened up as permeabilities are obtained ranging well above that of the commercial transformer steel.

The curves of figure 4 taken on an input transformer designed for use with a 45–50 per cent nickel alloy core indicate the relative characteristics of some experimentally improved grades of transformer steels and the nickel alloy. The same conditions were held for each curve with the single exception of changing the core material. These curves indicate very well the comparative improvement obtained in an audio transformer by using the experimental iron. As would be expected the greatest difference appears at the lower frequencies.

Application to Rotating Apparatus and Relays

While the most interesting and varied applications of silicon steel are in connection with transformers and reactors, the subject would not be complete without discussing briefly the application of silicon steel to rotating apparatus and to relays. In rotating apparatus, an air gap is necessary for mechanical reasons, and as a result of this air gap the permeability of the iron is not of particular consequence for the same reasons as discussed under low frequency filter reactors. However, the flux density in a rotating machine is relatively high; therefore, the core losses are important, and for this reason it is desirable to use a high grade of steel.

In practically all rotating apparatus for communication work built in fractional horsepower motor frames, the motor grade steel is found preferable. The thicknesses used vary from 24 gauge for the usual power frequencies down to 29 gauge for frequencies up to 2,000 cycles, and 36 gauge for still higher frequencies.

The chief consideration in selecting the steel for these small machines is to balance the efficiency

against the cost, as heating due to iron losses is seldom important. The flux densities used are kept well below saturation to minimize the excitation ampere turns consumed in the steel. The densities are reduced for the higher frequencies to keep down the total losses.

The larger rotating machines used in communication work, such as battery charging generators, high voltage d-c generators for radio broadcasting power supply, etc., present no unusual features, so far as their steel is concerned. An interesting special case, however, is that of the 15,000 to 30,000 cycle Alexanderson alternators built about 20 years ago for some of the first transoceanic radio stations, for which a special 1.5 mil standard iron was used in strip form.

The magnetic design of relays and contactors presents an entirely different problem from that of other apparatus, as the important thing here is to have low magnetic retentivity, so that the device will not be held in a closed position by residual magnetism when the circuit is opened. Many special grades of steel of low retentivity have been developed but careful annealing is required to make this property permanent. Hardening of contactor steels, resulting from the hammering of repeated operation, tends to increase the retentivity of the steel, and so makes a wide margin of safety necessary in new designs.

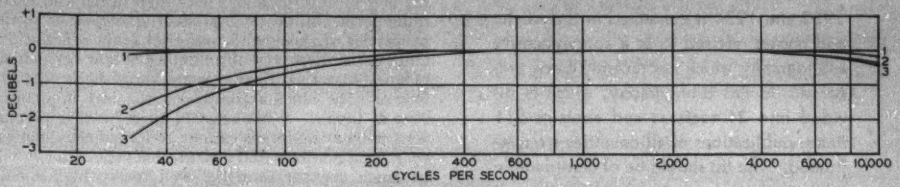

Fig. 4. Curves showing the effect of different materials on the frequency response of an audio transformer

1—Alloy containing 45–50 per cent nickel 2—Experimental iron 3—Transformer steel, audio grade

Outlook for the Future

The present trend in the development of magnetic steels is toward the use of a great variety of special alloys for new applications. Thermomagnetic steels, which lose their magnetism sharply at a certain temperature, are increasingly employed for thermal control relays and for temperature compensation purposes. Other steel alloys with aluminum, nickel, and cobalt are being developed for use as permanent magnets. These magnets make possible the design of more compact synchronous motors and small high frequency generators formerly provided with exciting coils.

Experimental work in laboratories as well as data published by the steel manufacturers indicate that future developments may be expected to yield further improvements comparable with those already obtained. The experimental steel to which we have previously referred may become a competitor of the 45–50 per cent nickel alloy and may even surpass it when used where high electrical resistivity is important. The cost will, no doubt, be very much less than that of nickel alloys. The promising success obtained by the Smith process[1a] and developments described by Goss[1] in producing cold rolled strip may be the forerunner of a still better quality and more economical method of manufacture. The one development upon which there seems to be little or no progress is that of producing a commercial material which saturates at a higher density with a low exciting current. One must not forget standard iron as more economical materials are demanded, since development work on it indicates the possibilities of replacing the lower grades of silicon steel with this cheaper material. A great variety of other alloys are being experimented with, in the hope of developing new varieties of steels with improved characteristics of loss, permeability, and other magnetic properties, and marked progress has been made.

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Research Work in Magnetics—1933—34

A review of the research work which has been done in the field of magnetics during 1933 and 1934 is contained in the articles and papers referred to in a comprehensive bibliography which has recently been prepared. In this bibliography, which is divided into 31 sections and contains 211 items, publications of all countries are considered. The list should be of considerable value to those interested in magnetics. It is preceded by an introduction which outlines briefly the trends and the developments in magnetics at the present time.

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THE causes of ferromagnetic phenomena are largely a mystery and the laws governing them are mostly empirical. This is a challenge to the physicist and engineer, which results in an enormous amount of experimental and theoretical work. Moreover, these magnetic phenomena must be correlated with the new theories of physics such as quantum mechanics, wave mechanics, and electron spin, if these theories are to be proved valid. The large number of references to theoretical investigations and to a study of phenomena chiefly of theoretical interest, such as the Barkhausen effect, Heusler alloys, properties of thin films, gyromagnetic effects, and the like, indicate the interest in this subject.

Much valuable progress has been made recently toward unified practice all over the world with reference to magnetic definitions and symbols, due to the activities of the International Electrotechnical Commission and associated bodies.

Further experimental data have become available on the a-c ferromagnetic properties of materials as a function of superposed direct current. This is of value to designers of audio frequency transformers and to rotating machine designers.

When a knowledge of the magnetic properties of single crystals became available a few years ago, it proved very valuable in furthering an understanding of the properties of ordinary polycrystalline materials. This knowledge when applied to the effects of mechanical working and heat treatment promises to be of considerable commercial importance.

The magnetic properties of ferromagnetic materials at moderate inductions are profoundly affected by mechanical stress. Much useful work in the field of magnetostriction has been done recently, both from a theoretical and practical standpoint.

Recent developments of commercial magnetic materials have followed several major directions: (1) new core materials suitable for radio frequencies; (2) new nickel-iron alloys with high initial and maximum permeabilities; (3) production and study of the properties of sheet with preferred grain orientation; and (4) the discovery of a number of new permanent magnet materials having remarkably high coercive forces. The chief activities on the last item have been in Japan. While most of these newest permanent magnet materials cannot be forged they mark a very great advance and at least one type of alloy will be much cheaper than the well-known high cobalt steels.

Nearly everyone working in the field of magnetics seems to feel called upon to develop new methods of test. Some of these are desirable because of new materials having properties outside of the range of previously existing materials and some are desired in order to increase the speed and accuracy of measurement or both. In the first class the newly developed permanent magnet materials have required the construction of new permeammeters which will supply higher magnetizing forces without undue heating. For the measurement of the a-c magnetic properties of laminated materials one of the most interesting new devices is the "ferrometer" developed by the Siemens-Halske Company. This measures permeability and losses by means of d-c instruments supplied through vibrating mechanical rectifiers. It also traces hysteresis loops.

The bibliography which follows covers, in general, the published articles on research work in magnetics appearing in 1933 and 1934. In its preparation, very considerable use was made of *Science Abstracts* for these 2 years. In general, diamagnetic and paramagnetic materials have been omitted.

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62. S. Kaya, *Zeits. f. Physik*, v. 84, No. 11–12, 1933, p. 705–16. Presents mathematical formulas for the remanence of single crystals based on experimental results.

63. J. Koenigsberger, *Phys. Zeits.*, v. 33, 1932, p. 763–7. Discusses the spontaneous magnetization and thermoremanence in ferromagnetic single crystals.

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67. C. W. Heaps, *Phys. Rev.*, v. 42, 1932, p. 108–18. Presents data on the effect of strain on magnetostriction and the magnetization of nickel wire.

68. N. Akulov and E. Kondorsky, *Zeits. f. Physik*, v. 78, No. 11–12, 1932, p. 801–7. Give a theoretical discussion of the magnetostriction of single crystals.

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83. O. v. Auwers, *Ann. d. Physik*, v. 17, No. 1, 1933, p. 83–106. Presents experimental data on the influence of the intensity of magnetization upon the modulus of elasticity and damping of natural vibrations of ferromagnetic materials.

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IX—Magnetic Fields

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100. G. Fanselau, *Terr. Mag.*, v. 38, 1933, p. 277–82. Presents tables for use in terrestrial magnetic field measurements.

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102. I. N. Zavarine, A.I.M.E. *Trans.*, v. 113, 1934, p. 190–201. Gives data on the magnetic transformations in carbon steels during quenching.

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109. C. W. Heaps, *Phys. Rev.*, v. 45, 1934, p. 320–3. Deals with experimental results on discontinuities of resistance associated with the Barkhausen effect, his specimens being a nickel wire under bending stress.

110. R. E. Reinhart, *Phys. Rev.*, v. 45, 1934, p. 420–4; and v. 46, p. 483–6. Has investigated large Barkhausen discontinuities and their propagation in nickel-iron alloys under conditions of circular field, longitudinal field, torsion, and tension.

111. K. J. Sixtus and L. Tonks, part I, *Phys. Rev.*, v. 37, 1931, p. 930–58; part II, v. 42, 1932, p. 419–35; part III, v. 43, 1933, p. 70–80; part IV, v. 43,

1933, p. 931–40; and v. 39, 1932, p. 357–8 and 375–6. Have written a series of papers dealing with the propagation of large Barkhausen discontinuities.

112. F. Hunter, *Zeits. f. techn. Physik*, v. 13, No. 11, 1932, p. 516–31; and v. 13, No. 12, p. 618. Has 2 papers dealing with large magnetic discontinuities of the Barkhausen type.

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114. O. Tesche, *Phys. Zeits*, v. 34, 1933, p. 879. Gives experimental data on the Barkausen effect below and above the Curie point for samples of iron, nickel, and cobalt, and various kinds of steel.

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115. R. F. Edgar, A.I.E.E. Trans., v. 52, Sept.-Dec. 1933, p. 721–5; disc. 725–6; and Elec. Engg., v. 53, Feb. 1934, p. 318–22. Describes methods of testing and gives experimental data on the loss characteristics of silicon steel with combined a-c and d-c excitation.

116. S. Procopiu, *Comptes Rendus*, v. 196, 1933, p. 1976–9. Gives an expression for the magnetization and susceptibility of iron under the condition of a superposed a-c field on a constant field.

117. S. S. Sidhu, *Indian Jl. Phys.*, v. 8, 1934, p. 451–67. Develops new formulas for the hysteresis loss with superposed direct-current for commercial silicon steel and nickel-iron alloys. These are derived from experimental data.

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120. M. Kersten, *Zeits. f. techn. Physik*, v. 15, No. 7, 1934, p. 249–57. Discusses new magnetic powder materials called "isoperms."

121. O. Dahl and J. Pfaffenberger, *Zeits. f. techn. Physik*, v. 15, No. 3, 1934, p. 99–106. Compare the magnetic properties of "isoperms" with soft iron and nickel-iron alloys, with reference to their use in telegraphy.

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123. W. Arkadiew, *E.N.T.*, v. 10, 1933, p. 220–2. Gives a mathematical treatment dealing with curves and calculations of permeability and hysteresis loss in thin laminas.

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125. M. Kersten, *Wiss. Veröff. a. d. Siemens-Konzern*, v. 13, No. 3, 1934, p. 1–9. Discusses the effect of copper on the shape of the magnetization curve of cold-rolled iron-nickel-copper alloys.

126. B. Hague, *E.u.M.*, v. 51, 1933, p. 208–11. Discusses the magnetic properties of "hipernik," "permalloy," and "mumetal," and their application to modern current transformers.

127. F. Stablein, *Zeits. f. techn. Physik*, v. 13, No. 11, 1932, p. 532–4. Describes apparatus and gives experimental results on the measurement of the coercive force of iron-nickel alloys and data on the effect of the addition of silicon.

128. K. W. Grigorow, *Phys. Zeits. d. Sowjetunion*, v. 3, No. 4, 1933, p. 418–20. Offers data on magnetic properties of electrolytically deposited films of iron and the effect of heat treatment on these properties.

129. W. E. Ruder, Am. Soc. for Metals *Trans.*, v. 22, 1934, p. 1120–31. Discusses the influence of grain size on magnetic properties and includes some data on the hysteresis loss in single crystals and the effect of grain orientation on magnetic properties.

130. New development in Electrical Strip Steels Characterized by Fine Grain Structure Approaching the Properties of Single Crystals, N. P. Goss. *Advance Paper No. 30*, presented at the October 1–5, 1934 meeting of the American Society for Metals. Announces a new magnetic sheet having exceptionally good magnetic properties in the direction parallel to rolling.

XIV—Permanent Magnet Materials

131. K. Honda, H. Masumoto, and Y. Shirakawa, Tohoku Univ. *Sci. Reports*, v. 23, 1934, p. 365–73. In English, *Report No. 325* of the Res. Inst. for Iron, Steel and Other Metals. Give a summary of the composition and magnetic properties of recently developed permanent magnet steels, including data on a new steel having very high coercive force and called "new K. S. magnet steel."

132. *A.T.M.*, v. 3, T. 56, 1934. A discussion is given of the properties of Mishima permanent magnet steel (a Ni-Al-Fe alloy) as compared with the older, better known permanent magnet steels.

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134. R. L. Dowdell, Am. Soc. for Metals *Trans.*, v. 22, 1934, p. 19–30. Presents an investigation of the treatment of steel for permanent magnets.

XV—Lifting Magnets

135. E. Jasse, *E.u.M.*, v. 50, 1932, p. 617–20. Describes an analytical investigation of lifting magnets, neglecting leakage.

136. E. Jasse, *E.u.M.*, v. 51, 1933, p. 8–10. Describes an analytical investigation of lifting magnets including leakage.

XVI—High Frequency Magnetic Properties

137. K. Kreielsheimer, *Ann. d. Physik*, v. 17, No. 3, 1933, p. 293–332. Gives data on the magnetic permeability of iron wires in the wave length region of 46 to 1,000 meters for H values from 0 to 12 oersteds, using a bridge method.

138. W. Arkadiew, *Zeits. f. Physik*, v. 79, No. 7–8, 1932, p. 558–61. Reviews the results of a number of investigations on the anomalous behavior of permeability at high frequencies.

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141. R. Sanger, *Helv. Phys. Acta*, v. 7, No. 5, 1934, p. 478–80. Discusses the dependence of permeability of iron, nickel, and cobalt wires on frequency, showing a decrease of permeability at very high frequencies of the order of 10 to 100 centimeter wave lengths.

142. F. M. Colebrook, Dept. Sci. and Indus. Res. Pub., *Special Report No. 14*, 1934. Gives a very complete survey of commercial materials for use at radio frequencies, and includes a very good bibliography.

143. P. K. Taylor, I.R.E. *Proc.*, v. 22, 1934, p. 886–96. Discusses the action of high frequency a-c magnetic fields on suspended magnetic rings and offers a method of measuring the intensity of high frequency magnetic fields as a function of torque.

XVII—Magnetic Skin Effect

144. E. Hinze, *Ann. d. Physik*, v. 19, No. 2, 1934, p. 143–54. Considers the theory of skin effect in ferromagnetic circular cylinders under the influence of weak alternating fields, dealing with both permeability and hysteresis losses.

XVIII—Magnetic Oxides

145. L. A. Welo and O. Baudisch, *Phil. Mag.*, v. 17, 1934, p. 753–68. Discuss the ferromagnetism in gamma ferric oxide and include some data on the effect of temperature.

146. H. Forestier and G. Guiot-Guillain, *Comptes Rendus*, v. 199, 1934, p. 720–3. Give data on the magnetic properties of various ferric oxides including the effect of heating at various temperatures and for different lengths of time.

XIX—Heusler Alloys

147. O. Heusler, *Zeits. f. Metallkunde*, v. 25, 1933, p. 274–7; disc. p. 277–8. Deals with the crystal structure and ferromagnetism of Mn-Al-Cu alloys.

148. O. Heusler, *Ann. d. Physik*, v. 19, No. 2, 1934, p. 155–201. Deals with the crystal structure and ferromagnetism of Mn-Al-Cu alloys, including the magnetic characteristics considered as a function of heat treatment, temperature, composition, and field strength.

149. A. J. Bradley and J. W. Rodgers, Roy. Soc. *Proc.*, v. 144, 1934, p. 340–59. Present a study of the ferromagnetic properties of Heusler alloys as a function of structure for a given chemical composition.

150. S. Valentiner and G. Becker, *Zeits. f. Physik*, v. 83, No. 5–6, 1933, p. 371–403. Present studies of the magnetic properties of Heusler alloys as a function of composition, temperature, and aging treatment.

XX—Magnetic Properties of Minerals

151. J. G. Koenigsberger, *Beitr. z. angew. Geophys.*, v. 4, No. 3, 1934, p. 385–94. Discusses the remanent magnetism of ferromagnetic minerals as a function of geologic age.

152. G. Grenet, *Comptes Rendus*, v. 197, 1933, p. 874–5. Describes an apparatus for measuring the magnetic properties of rocks.

153. G. Grenet, *Comptes Rendus*, v. 197, 1933, p. 746–8. Discusses the theory of ferromagnetic powders and the magnetic susceptibility of rocks.

XXI—Magnetic Properties of Thin Films

154. S. Procopiu and T. Farcas, *Comptes Rendus*, v. 198, 1934, p. 1983–5. Give experimental results and a theoretical discussion of the Curie point as a function of the thickness of electrolytically deposited nickel films with an explanation of the possible cause of variations.

155. S. Procopiu, *Jl. de Physique et le Radium*, v. 5, 1934, p. 199–206. Deals with coercive force values of thin films of iron with superposed a-c field, considering the effect of frequency and gives formulas for the phenomenon.

156. K. Richter, *Kolloid Zeits.*, v. 61, 1932, p. 205–18. Discusses the electrical conductivity and other physical properties of thin metallic films as well as magnetic properties.

XXII—Magnetic Aging

157. An Example of Magnetic Aging, J. Muir. *Jl.* of the Royal Tech. College (Glasgow), v. 3, part 2, January 1934. Gives experimental data on the permeability aging of soft steel at fairly high magnetizing forces.

XXIII—Magnetic Properties in Weak Fields

158. H. Wittke, *Ann. d. Physik*, v. 18, No. 6, 1933, p. 679–700. Gives experimental results and a discussion of strongly reversible phenomena in the magnetization of ferromagnetic bodies in very low alternating fields.

159. H. Wittke, *Ann. d. Physik*, v. 20, No. 1, 1934, p. 106–12. Presents further experimental results on quasistatic magnetic cycles in weak fields, explaining the results as being due to magnetic "after effect."

XXIV—Magnetic Testing of Materials

160. E. Thellier, *Comptes Rendus*, v. 197, 1933, p. 232–4. Describes a double astatic magnetometer.

161. H. N. Otis, *Rev. Sci. Instruments*, v. 4, 1933, p. 681–3. Describes a torsion magnetometer for testing thin ferromagnetic specimens.

162. L. W. McKeehan, *Rev. Sci. Instruments*, v. 5, 1934, p. 265–8. Describes a modification of the pendulum magnetometer making it suitable for the study of small ferromagnetic specimens.

163. J. Sugiura, Electrotech. Lab., Tokyo, Japan, *Research No. 354*, 1933. Describes a new permeameter claimed to have high accuracy, designed particularly for use with high magnetizing forces.

164. R. L. Sanford and E. G. Bennett, Bureau of Standards *Jl. of Research*, v. 10, 1933, p. 567–73. Describe a new apparatus for general magnetic testing at high magnetizing forces from 100 to 1,000 oersteds. The apparatus does not heat the specimen.

165. P. C. Hermann, *Zeits. f. techn. Physik*, v. 14, No. 1, 1933, p. 39–44. Describes a new method for making magnetic measurements on thin disks of metal. Comparisons are made with other methods of test.

166. P. C. Hermann, *Zeits. f. techn. Physik*, v. 13, No. 11, 1932, p. 541–9. Discusses a new apparatus for making magnetic tests on thin strips of material using both direct and alternating current.

167. C. Dannatt, *Jl. Sci. Instruments*, v. 10, 1933, p. 276–85. Describes a new method of making magnetic loss tests on single strip specimens. Discusses the errors due to harmonics.

168. H. Kühlewein, *Zeits. f. techn. Physik*, v. 14, No. 8, 1933, p. 314–16. Gives 2 methods for the investigation of the magnetic properties of high permeability material in the form of laminated rings. By means of the second test, the Curie point may be determined.

169. R. Jouaust, Soc. Franc. Elec. *Bul.*, v. 3, 1933, p. 885–90. Discusses the accuracy of the Epstein method of measuring core losses.

170. B. R. Isaacs, *Electrician*, v. 109, 1932, p. 679–81. Describes a method of testing an iron sample magnetically and deals with the construction of the magnetic circuit.

171. G. Keinath, *Physik*, v. 1, No. 1, 1933, p. 21–40. Gives a survey of modern instruments and methods available for magnetic and electrical measurements.

172. B. Hague, Congres Intl. d'Electricite, Paris, Sec. 3, *Rapport No. 7*, 1932. Offers a review of the available methods for measuring the distribution of the magnetic field in electrical machinery and other apparatus.

173. A. P. M. Fleming, *Jl.* I.E.E., London, v. 73, 1933, p. 591–5. Reviews the subject of electrical measurements and their relation to the technical progress of industry, including data on modern methods of testing magnetic materials.

174. W. Thal, *A.T.M.*, v. 3, 1934, T. 78–9. Discusses the accuracy of various methods of determining the magnetic properties of magnetic materials and includes some information on the effect of inhomogeneities on the accuracy of measurement.

175. S. Procopiu and N. Florescu, *Jl. de Physique et le Radium*, v. 4, 1933, p. 251–61. Deal with the demagnetization of iron, steel, and nickel wires of various diameters and for a wide range of frequencies from 50 to 1,000,000 cylces per second.

176. A. W. Smith, *Jl. Sci. Instruments*, v. 3, 1932, p. 626–31. Discusses a reversing and short-circuiting switch for use in making hysteresis measurements.

177. R. P. Johnson and W. B. Nottingham, *Rev. Sci. Instruments*, v. 5, 1934, p. 191–2. Describe a suspension for instruments which provides a constant level and protection from small vibrations.

178. H. Neumann, *A.T.M.*, v. 3, 1934, T. 67–8. Discusses a number of methods of measuring magnetic potential by means of search coils.

179. J. L. Snoek, *Physica*, v. 1, 1934, p. 649–54. Calculates the demagnetization factors for thin cylinders of small dimension ratio and checks the calculations by test.

180. E. A. Neumann and J. Pfaffenberger, *Arch. f. Elektrotech.*, v. 27, 1933, p. 287–94. Discuss a method of making iron loss measurements on small ring samples using a synchronous rectifier and meter for flux measurements and a wattmeter for determining the losses. This method makes possible the use of small samples.

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185. E. W. Golding, *Electrician*, v. 111, 1933, p. 503–5. Discusses the Grassot fluxmeter and its advantages over the ballistic galvanometer for magnetic measurements.

XXV—Magnetic Fields—Determination of Strength

186. H. Auer, *Ann. d. Physik*, v. 18, No. 6, 1933, p. 613–25. Describes an absolute method of making magnetic field measurements.

187. H. Buchner, *Phys. Zeits.*, v. 35, 1934, p. 409–10. Describes a method of measuring the magnetic field strengths using a small aluminum cylinder controlled by a spring.

188. H. S. Jones, *Rev. Sci. Instruments*, v. 5, 1934, p. 211–14. Discusses a method of measuring the intensity of magnetic fields by means of a small spring-suspended coil, carrying a variable current which is a measure of the field strength.

189. S. E. Forbush, *Terr. Mag.*, v. 39, 1934, p. 135–43. Discusses devices for measuring the changes in the horizontal intensity of the earth's magnetic field.

190. L. F. Bates, Phys. Soc. *Proc.*, v. 45, 1933, p. 180–92; disc. p. 193. Describes a new method for measuring the vertical and horizontal components of the earth's magnetic field using a "mumetal" cylinder carrying a fine wire winding.

XXVI—Magnetic Anisotropy

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XXIX—Magnetic Analysis

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XXXI—Miscellaneous

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Self Excitation of a Frequency Converter

After a general discussion of the phenomenon of self excitation of a-c machines, a specific case of 3 phase self excitation of a Scherbius machine is treated. Such a machine is used in the regulating set of a variable-ratio frequency converter for inherently constant power transfer, the operating features of which are described. Under certain conditions this converter may be subject to the danger of self excitation. These conditions are discussed in detail and means are indicated to prevent self excitation during the normal operation of this converter.

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THE object of this paper is a discussion of the probability and the danger of self excitation of a Scherbius 3 phase commutator machine as employed in a variable-ratio frequency converter, with inherently constant power transfer. This and other types of variable-ratio frequency converters are used as a tie between 2 power systems whenever the power transfer has to be independent of the frequencies of the systems. They consist of a synchronous machine connected to one system and an induction machine connected to the other system; a regulating set is used in conjunction with the induction machine. The regulating set ordinarily is composed of a stator or rotor-fed a-c commutator machine together with its exciting and regulating equipment to change the electromotive force of the commutator machine properly in phase and magnitude. Various schemes of using the commutator machine to control the frequency converter are used, but the one to which particular attention is given in this paper is designed so that the power transfer within the operating range is inherently constant, a Scherbius machine being used for control.

The principal conclusions which may be drawn as a result of the study presented in this paper are as follows:

1. The Scherbius machine used in a variable-ratio frequency converter for inherently constant power transfer as proposed by Seiz may be subject to 3 phase self excitation.

2. Because of the relatively low self-excited rotor frequency and the correspondingly high rotor currents self excitation must be prevented.

3. The danger of self excitation decreases among other things with a reduction of the induced electromotive forces in the field circuits of the exciter of the Scherbius machine, increasing short-circuiting effect of the network, increasing ohmic component of the load impedance, and increasing leakage inductance of the Scherbius machine.

4. A self-excited field in the Scherbius machine may, in principle, rotate in either direction. There are, however, usually external conditions which cause 1 of the 2 to be preferred.

5. If the frequency changer ampere turns are relatively high, the sense of rotation is primarily determined by the direction of power flow during normal operation. The sense is such that the frequency ampere turns have a component in phase with the slip ring ampere turns.

6. If the frequency changer ampere turns are small, the field rotates in such a direction that the rotor of the induction machine covers part of the losses of the rotor circuit. This is dependent upon the self-excited stator frequency being below the network frequency. Self excitation will, therefor, preferably be supersynchronous (sense of rotation of rotor field during self excitation equal to that during normal supersynchronous operation).

7. The self-excited Scherbius machine may operate as a generator or as a motor if it only provides the magnetizing power for the self-excited circuits. The larger part of the active power during self excitation is drawn from or delivered to the shaft of the induction machine. The remainder is supplied or absorbed by the network and the Scherbius machine.

The various phases of the problem for self excitation of a frequency converter for inherently con-

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stant power transfer will be treated in this paper in the following order:

1. Self excitation of commutator, particularly Scherbius, machines.
2. A variable-ratio frequency converter with inherently constant power transfer.
3. The problem of self excitation of this converter.

Self Excitation of Commutator Machines in General

An electric machine is called self excited if a voltage, assumed to exist across its terminals, supplies to its field circuits a magnetizing power sufficient to maintain this voltage. If the field does not vary with time, the magnetizing power is equal to the ohmic losses of the field circuits. An example of such a machine is the self-excited d-c generator. Should it be desired, however, that self excitation occur with alternating current, both the active and the reactive magnetizing power have to be supplied by the self-excited machine. As the reactive power causes the field current to lag behind its supply voltage, means have to be provided to compensate this phase difference. Unless this is done, a-c self excitation will not occur. Thus, a-c self excitation of the normal d-c generator is impossible because a given terminal voltage would not produce a current of the proper phase to sustain this voltage. Only by inserting into the field circuit capacitance great enough to compensate the inductive voltage drop at a given frequency could a-c self excitation be rendered possible. (For reasons not directly connected with this such a machine would have to be built with laminated iron and a compensating winding in the stator.) This is an obvious result if it is remembered that a-c self excitation is equivalent to the generation of undamped oscillations. Without the help of capacitance or its equivalent, the field of a single phase commutator machine running at constant speed could not periodically lose and regain its energy because no other energy store for the magnetic energy is available.

In the case of a 2-phase or 3-phase commutator machine, a-c self excitation is not dependent upon capacitance. Ruedenberg[1] has shown that the oscillations of a self-excited 3-phase shunt commutator machine consist of a periodic transfer of the magnetic energy from one phase to another. A similar example is the self-excited Scherbius machine, as described by Hull,[2] to which reference will be made later in this paper.

Once the conditions for self excitation are satisfied, it usually starts due to some impulse, *e. g.*, electrical or mechanical transients or residual magnetism. Voltage and current will then rise until the saturation of the magnetic paths prevents a further increase. For this reason self excitation is undesirable, often even very dangerous whenever a machine is not primarily intended to be a self-excited generator.

Self Excitation of a Scherbius Machine

After this general discussion the conditions for self excitation of a Scherbius machine will be treated. This will be preceded by a short description of the machine itself.

The stator of the Scherbius machine has salient main poles, 120 electrical degrees apart, with auxiliary poles in between. In addition it is provided with a compensating winding to counteract exactly the ampere turns of the rotor winding. Its rotor resembles that of a d-c machine, but differs from it by a winding pitch and a distance between brushes of 120 instead of 180 electrical degrees. The rotor electromotive force is induced by rotation only.

In his paper on a self-excited Scherbius machine Hull[2] has shown that such a machine is capable of

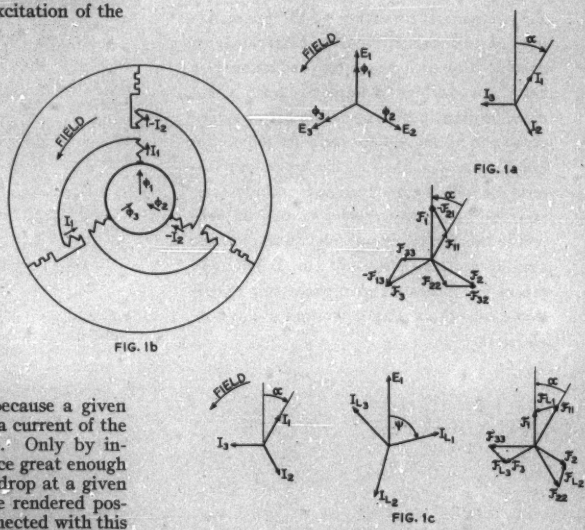


Fig. 1. Three phase diagrams of a Scherbius machine

a—Three phase diagrams of electromotive force (flux), field current, and ampere turns

b—Schematic circuit diagram of a shunt excited Scherbius machine during 3 phase self excitation

c—Three phase diagrams of field and load currents and ampere turns of a shunt-excited counter-compounded and inductively loaded Scherbius machine during 3 phase self excitation

1. For all numbered references, see list at end of paper.

operating as a self-excited 3-phase generator if, besides a sufficiently low field resistance, the ampere turns of a given pole *lead* the field current, flowing through the brushes under this pole, by the same angle α by which this field current *lags* the electromotive force induced under this pole. Expressed in other words the lagging in time of the field current has to be compensated by a leading in space of the axis of the field windings. By these means a self-excited field in the Scherbius machine is forced to rotate in space. As an illustration figure 1*a* shows the 3 phase diagrams of flux ϕ, electromotive force E, field current I and ampere turns $\mathfrak{F}$ of a self-excited Scherbius machine. Figure 1*b* gives a schematic diagram of its rotor and field circuits and the magnitude of flux and field currents for the instance when the flux through pole 1 is at its maximum. The above-mentioned phase angle α is assumed to be 30 degrees. In order to bring the total ampere turns of pole 1 in phase with the flux ϕ_1, it is necessary to excite pole 1 not only by the field current I_1 (I_1 and ampere turns $\mathfrak{F}_{11}$ *lagging* E_1 and ϕ_1 by 30 degrees) but also by current I_2 producing the ampere turns $-\mathfrak{F}_{21}$. If the number of turns of these 2 windings is equal, $\mathfrak{F}_1$ will *lead* $\mathfrak{F}_{11}$ by 30 degrees, i. e., $\mathfrak{F}_1$ and ϕ_1 are in phase.

If the angle α is reduced to zero, i. e., each pole is excited only by a field current flowing through brushes under this pole, only d-c self excitation is possible because for no other but zero frequency could I_1 and E_1, i. e., $\mathfrak{F}_{11}$ and ϕ_1 be in phase. It is, however, obvious that even with only one shunt winding per pole, 3 phase self excitation is possible as long as another current of the proper frequency and phase flows through a second winding on this pole. If it should be sufficient that self excitation occurs only under load, it is always possible to send the load current through a proper compound or anti-compound winding and compensate for the lagging of the ampere turns $\mathfrak{F}_{11}$. As an example of such an arrangement figure 1*c* shows the 3 phase diagrams of the field currents I, inductive load currents I_L and ampere-turns $\mathfrak{F}$ of the Scherbius machine if each pole is excited only by currents flowing through the brushes under this particular pole. As will be seen later, these are the fundamental conditions of self excitation of the Scherbius machine as used in a frequency converter to be described.

It is of interest to conclude from figure 1*c* that for a given compound winding self excitation is only possible if the phase angle between the load current and the electromotive force of the Scherbius machine remains within a certain range. Outside of this range self excitation cannot occur. For instance, for an inductive load it is only possible with an anti-compound winding.

A Variable-Ratio Frequency Converter With Inherently Constant Power Transfer

Before describing the principle and the main operating features of this converter (the possibility of self excitation of which will be discussed later in this paper) a short account of variable ratio frequency converters in general will be given. They are used as a flexible tie between 2 power systems to transfer—within the operating range of the converter—an arbitrary, often constant amount of power independently of the frequencies of the 2 systems.

The converters consist of a synchronous machine connected to one system and an induction machine with its regulating set connected to the other system. With few exceptions the regulating set is composed of a stator or rotor-fed a-c commutator machine and its exciting and regulating equipment.

The commutator machine introduces into the rotor circuit of the induction machine an electromotive force which together with its rotor electromotive force covers the voltage drop of the desired rotor current. By properly changing the electromotive force of the commutator machine any rotor current for any slip—within the operating range of the set—can be obtained.

The manner, now, in which this electromotive force is changed with varying slip, i. e., in which the field of the commutator machine is controlled gives rise to a large variety of connection diagrams of variable ratio frequency converters. Two main groups may be distinguished. In the first group the field is controlled by an automatic load regulator, which changes the field voltage of the main commutator machine in magnitude and phase, *e. g.*, by varying independently the currents through 2 field windings, perpendicular to each other, of a small synchronous machine or by shifting the brushes of a frequency changer, also called ohmic drop exciter. (The frequency changer consists of a d-c rotor revolving inside of a closed magnetic path with slip rings tapped to the armature and connected to the 3 phase supply. On the commutator slide sets of brushes, *e. g.*, 2, the brushes of each set being 120 degrees apart. The desired voltage is obtained by shifting the 2 sets against each other and jointly with respect to the frame of the machine.) This type of control is in exclusive use in the United States and has been described in several papers.[3,4,5,6]

The excitation of the commutator machine in the second group is designed in such a way that the power transfer within the operating range is inherently constant. The first converter of this kind, with a Scherbius machine as the main commutator machine, is due to Seiz.[7,8] The principle, however, is not restricted to stator fed machines and even for these a variety of circuit diagrams has been proposed.[9,10,11]

The basic idea of the Seiz circuit is to neutralize completely the slip ring voltage of the induction machine for any operating slip by one electromotive force component of the commutator machine, i. e., to prevent any rotor current from flowing and then, by a second component, to introduce the necessary voltage for the desired rotor current.

A typical circuit diagram of this converter is shown in figure 2. In this figure, 1 and 2 are the synchronous and induction machines connected to their respective systems; 3 the commutator machine, and 4 the frequency changer with its transformer 5; 6 and 7 are resistances; and 8 an exciter driven by the motor 9. This exciter is a small Scherbius machine with a powerful counter-compound winding of such a magnitude that the resultant ampere turns of the

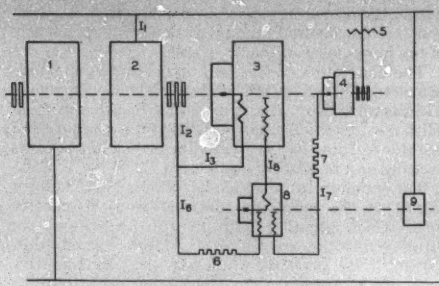


Fig. 2. Connection diagram of a frequency converter for constant power with exciter

1—Synchronous machine
2—Induction machine
3—Commutator machine
4—Frequency changer
5—Auxiliary transformer
6—Resistance in the slip ring excitation circuit
7—Resistance in the frequency changer excitation circuit
8—Exciter
9—Motor of the exciter

I_1—Stator current of the induction machine
I_2—Rotor current of the induction machine
I_3—Armature current of the commutator machine
I_4—Slip ring excitation current
I_7—Frequency changer excitation current
I_8—Field current of the commutator machine

exciter are only a fraction of the anti-compound and field ampere turns. It acts as current amplifier and serves the reduction of the field losses, but is not essential for the understanding of the operation of the converter.

The 2 electromotive force components of the commutator machine mentioned above are produced by the field circuits shown in figure 2 as resistances 6 and 7. Both circuits are essentially ohmic. The currents in the resistances and the corresponding rotational voltages of the commutator machine are therefore approximately proportional to and in phase with the exciting voltages, i. e., the slip ring and frequency changer voltage, respectively. The first electromotive force component of the commutator machine, neutralizing the slip ring voltage of the induction machine, is produced by the circuit connected to these slip rings (slip ring circuit). The other component is proportional to the current in the circuit connected to the frequency changer (frequency changer circuit). In order to make the rotor current essentially independent of secondary influences, like brush drop, speed, and slight saturation of the commutator machine or leakage reactances in the rotor circuit, the commutator machine has a counter-compound winding.

The power transfer of the converter is changed by known methods, *e. g.*, shifting of the brushes of the frequency changer. For a given position of these brushes the power transfer of the converter is completely defined.

In order to facilitate the later discussion, the voltage, current, and ampere turns diagrams of the converter are given in figure 3 for subsynchronous generator operation of the induction machine. The rotation of the field in these diagrams is counterclockwise, the ratio of the number of turns of the stator and rotor windings is unity, all reactances are calculated for the primary frequency f_1 and iron losses are neglected: the stator electromotive force $\boldsymbol{E}_1$ (figure 3*a*), lagging the flux ϕ by 90 degrees, minus the voltage drop $I_1(R_1 + jX_1)$ gives the primary terminal voltage $\boldsymbol{V}_1$. The primary and secondary currents $\boldsymbol{I}_1$ and $\boldsymbol{I}_2$ (figure 3*b*) result in the magnetizing current I_0, assumed to be in phase with the flux ϕ. In figure 3*c* the rotor electromotive force $\boldsymbol{E}_2 \cdot s$, lagging 90 degrees behind ϕ, minus the voltage drops in the rotor circuits of the induction and commutator machines $\boldsymbol{I}_2\ (R_2 + jX_2 \cdot s) + \boldsymbol{I}_3(R_3 + jX_3 \cdot s)$ plus the voltage $\boldsymbol{E}_{3c}$, induced in the anti-compound winding of the commutator machine, are compensated by its electromotive force $\boldsymbol{E}_3$. (The voltage $\boldsymbol{E}_{3c}$ lags the stray electromotive force $-\ j\boldsymbol{I}_3 X_3 \cdot s$ by the same angle as that by which the resultant ampere turns $\mathfrak{F}_3$ (figure 3*e*) lag the anti-compound ampere turns $\mathfrak{F}_{3c}$. $\boldsymbol{E}_{3c}$ is proportional to the flux of the commutator machine and the rotor frequency f_2, i. e., roughly proportionally to f_2^2.) In figure 3*d* the current $\boldsymbol{I}_3$ of the commutator machine leads the rotor current $\boldsymbol{I}_2$ because $\boldsymbol{I}_3$ is the sum of the partially inductive current $\boldsymbol{I}_2$ and the essentially ohmic field current $\boldsymbol{I}_5$. The ampere turns $\mathfrak{F}_3$ in figure 3*e* are in phase with $\boldsymbol{E}_3$ (and ϕ_3) and the resultant of the field ampere turns $\mathfrak{F}_4$ and the compound ampere turns $\mathfrak{F}_{3c}$ (in phase opposition to $\boldsymbol{I}_3$).

The remaining diagrams, figures 3*f* to 3*i* refer to the exciter. The electromotive force $\boldsymbol{E}_4$ (figure 3*f*), induced by the flux ϕ_3 in the field winding of the commutator machine and lagging ϕ_3 by 90 degrees, minus the voltage drops in this winding and the exciter $\boldsymbol{I}_8\ (R_4 + jX_4 \cdot s + R_8 + jX_8 \cdot s)$ is equal and opposite to the rotational electromotive force $\boldsymbol{E}_8$ of the exciter. $\boldsymbol{E}_8$, as $\boldsymbol{E}_{3c}$, is roughly proportional to the square of the rotor frequency. (The electromotive force induced in the anti-compound winding of the exciter is neglected.) The ampere turns to produce $\boldsymbol{E}_8$ are $\mathfrak{F}_8$ (figure 3*g*). They are in phase with $\boldsymbol{E}_8$ and the sum of $\mathfrak{F}_6$, $\mathfrak{F}_7$ and $\mathfrak{F}_{8c}$. $\mathfrak{F}_6$ is the ampere turns produced by the field circuit connected to the slip rings of the induction machine (slip ring field) to compensate the slip ring voltage and $\mathfrak{F}_7$ by that connected to the commutator of the frequency changer (frequency changer field) to cause the desired rotor current to flow. $\mathfrak{F}_{8c}$ is the anticompound ampere turns of the exciter; it is almost equal and opposite to the sum of $\mathfrak{F}_6$ and $\mathfrak{F}_7$. (It is of interest to point out that, because of the strong anticompounding of the commutator machine and the exciter, the ampere turns $\mathfrak{F}_6$ and $\mathfrak{F}_7$ of the latter correspond—roughly at least—to the ampere turns $\mathfrak{F}_3$ and $-\mathfrak{F}_{3c}$ of the former.) Figures 3*h* and 3*i* finally give the voltages in the 2 exciter field circuits. They are the simple diagrams of a slightly inductive circuit with the modification that the electromotive forces $\boldsymbol{E}_6$ and $\boldsymbol{E}_7$, induced by the main flux ϕ_8 of the exciter in the respective field windings, lead the negative inductive voltage drops of the field currents $\boldsymbol{I}_6$ and $\boldsymbol{I}_7$ by the same angle as that by which the resultant ampere turns $\mathfrak{F}_8$ lead the ampere turns $\mathfrak{F}_6$ and $\mathfrak{F}_7$. The electromotive forces $\boldsymbol{E}_6$ and $\boldsymbol{E}_7$ are proportional to $E_8 \cdot f_2$,

i. e., they increase roughly with the third power of the rotor frequency.

From these diagrams it may be seen that for direct coupling of the commutator and induction machines and constant primary voltage and frequency there are a number of factors which prevent the rotor current, i. e., the active and reactive power of the induction machine from being entirely independent of the slip. The more important ones are the induced electromotive forces $-jI_2X_2 \cdot s$, $-jI_2X_3 \cdot s$, E_{3c}, $E_4 - jI_8(X_4 + X_8) \cdot s$, $E_6 - jI_6X_6 \cdot s$ and $E_7 - jI_7X_7 \cdot s$, the dependence of E_3 upon the speed of the commutator machine for constant ϕ_3 and finally the saturation of the commutator machine.

These influences have been discussed in detail in other papers.[8,12] Suffice it here to state that their combined influence (saturation excepted) causes, for subsynchronous speed, the generator power of the induction machine to increase and the motor power to decrease, for supersynchronous speed the generator power to decrease and the motor power to increase and for subsynchronous and supersynchronous speeds the reactive volt-amperes to increase in the sense of overexcitation. In the same papers it was shown that by means of auxiliary circuits it is possible to very considerably reduce or almost compensate the effect of these disturbances. If the auxiliary circuits are omitted and still a close control of the power transfer is demanded, automatic load regulators are required to act as corrective devices.

The Problem of Self Excitation of This Converter

As an introduction a short qualitative account will be given. This is facilitated by 2 facts. First, the exciter 8 in figure 2 is essentially only a current amplifier. Its existence can therefore be neglected. Second, as calculations of typical cases have shown, the self-excited frequency—if self excitation be possible—is usually of such a magnitude that the network of the induction machine is virtually a short circuit for the self-excited voltages. The load of the self-excited Scherbius machine is therefore essentially inductive (as will be seen, roughly, the short circuit impedance of the induction machine and the network) and because of the low self-excited primary voltage of the induction machine, which is also the supply voltage of the frequency changer, the ampere turns produced by the frequency changer circuit may be neglected. The Scherbius machine is thus, as an approximation, inductively loaded, anticompounded and shunt-excited. As it was shown in the first part of this paper that such an arrangement is capable of 3 phase self excitation, it can be concluded that self excitation of the Seiz converter is possible in principle. Whether it actually will occur, depends upon the sum of all available ampere turns being equal or larger than the required ampere turns.

If self excitation does occur, the rotor current of the Scherbius machine will increase to a multiple of its rated current because of the relatively low load impedance. Dependable operation of the converter is therefore only possible if the danger of self excitation during normal operation is definitely eliminated. Means to do this may be derived from an analysis of the different ampere turns contributing to self excitation.

A convenient way of doing so is to retain for the actual converter the picture of a shunt excited, inductively loaded commutator machine. The ampere turns of the commutator machine and the exciter may then be combined and represented for constant flux of the Scherbius machine as components of its resultant ampere turns. As some of these vectors depend upon the load current, it is first necessary to determine the load impedance.

It was already pointed out that the self-excited rotor frequency is usually a multiple of the normal rotor frequency (around 5 to 10 cycles per second). The self-excited stator frequency differs therefore

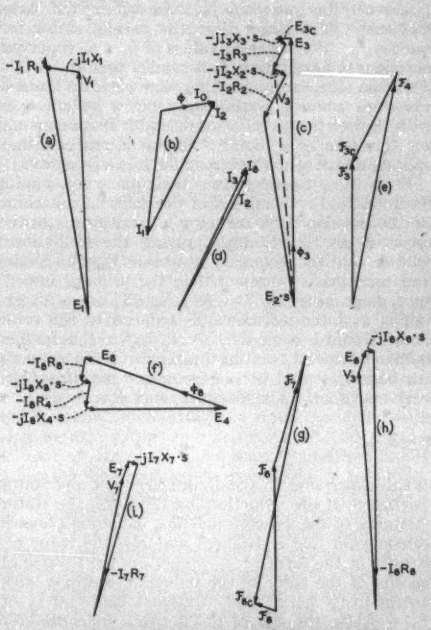


Fig. 3. Voltage, current, and magnetomotive force diagram of a frequency converter for constant power with exciter

a—Voltage diagram of the stator of the induction machine
b—Magnetomotive force diagram of the induction machine
c—Voltage diagram of the rotor circuit of the induction machine
d—Current diagram of the rotor circuit of the induction machine
e—Magnetomotive force diagram of the commutator machine
f—Voltage diagram of the field circuit of the commutator machine
g—Magnetomotive force diagram of the exciter
h—Voltage diagram of the slip ring excitation circuit of the exciter
i—Voltage diagram of the frequency changer excitation circuit of the exciter

enough from the normal stator frequency to make the network act nearly like a short circuit to the self-excited stator voltage. The load of the Scherbius machine is therefore roughly equal to the sum of the short circuit impedances of the induction machine and the network. Their imaginary part can with sufficient accuracy be considered to be proportional to the frequency, i. e., the load inductance is constant. For the real part such a simple relation does not exist; a more detailed discussion is therefore necessary.

A self-excited field in the Scherbius machine may rotate in either direction unless for specific reason one direction is preferred or the only possible one. If the field rotates in the same direction as a field during normal subsynchronous operation of the induction machine (subsynchronous self excitation with positive rotor frequency f_{2s}), the self-excited stator frequency f_{1s} is larger than the normal stator frequency f_1. For negative values of f_{2s}, i. e., supersynchronous self excitation, f_{1s} is smaller than f_1. In the first case all rotating machines connected to the network are running considerably below synchronism with respect to the self-excited stator frequency and act therefore as a motor. In the second case they operate above synchronism and act as a generator.

From these considerations a simple expression for the total load resistance R of the Scherbius machine can be developed by reducing all resistances to the rotor circuit by suitably applying the well-known relation that the secondary resistance R_2 of an induction machine is represented in the primary impedance diagram as $R_2/S = R_2 f_1/f_2$. Thus, as an example, a stator resistance R_1 reduced to the rotor circuit would become $R_1/s' = R_1 \cdot f_2/f_1$. It is further assumed that all rotating machines of the network can be represented by one induction machine (network machine). The load resistance R is then

$$R \approx R_2 + \frac{R_1 + R_{N1}}{s_s} + \frac{R_{N2}}{s_s \cdot s_N} \qquad (1)$$

In this expression R_2 and R_1 are the rotor and stator resistances of the induction machine, R_{N1} the stator resistance of the network machine including possible transmission line resistances and R_{N2} the rotor resistance of the former; $s_s = f_{1s}/f_{2s}$ is the inverse of the slip of the rotor of the induction machine with respect to its self-excited rotational field and $s_N \approx (f_{1s} - f_1)/f_{1s}$ the slip of the network machine—for simplicity assumed to run in synchronism with f_1—with respect to the self-excited stator frequency f_{1s}. As s_s and s_N are positive for subsynchronous self excitation and negative for a supersynchronous one, R is in the first case larger than in the second case. For large values of R_{N1} and negative values of s_s and s_N it might even become negative, though this is unusual.

Determining Self Excitation From the Ampere Turns Diagram

It is now possible to draw the above-mentioned ampere turns diagram of the commutator machine by combining the properly changed vectors of figure 3. This diagram is shown in figure 4 for the Scherbius machine generating. Because the effect of subsynchronous or supersynchronous self excitation is taken into account by the load resistance R, such a diagram holds qualitatively for both senses of rotation of the self-excited field of the commutator machine.

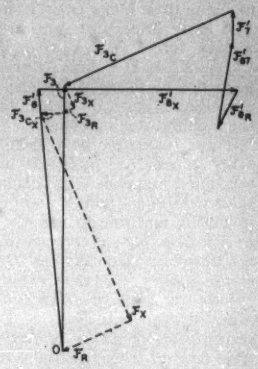


Fig. 4. Ampere turns diagram of a Scherbius machine with exciter during self excitation

The ampere turns of the exciter are represented as equivalent ampere turns of the commutator machine

The dotted lines give the voltages of the armature and load circuit of the commutator machine expressed as ampere turns of the commutator machine

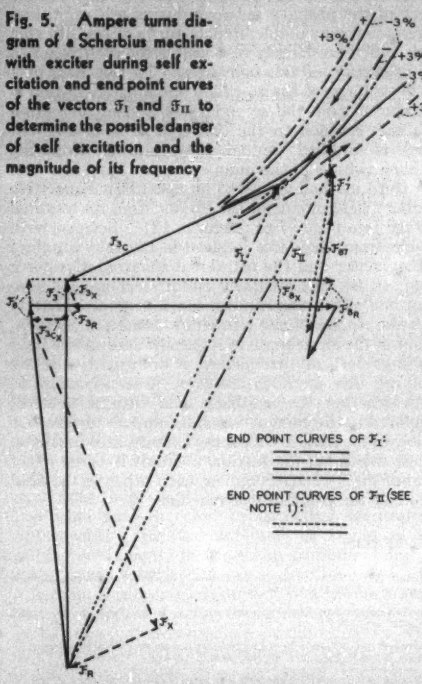
The voltages in the armature and load circuit of the commutator machine are reduced as shown in figure 4 by multiplication with the quotient of the resultant ampere turns $\mathfrak{F}_3$ and the electromotive force E_3 of the commutator machine. The sum of $-\mathfrak{F}_R - \mathfrak{F}_x$ is equivalent to the slip ring voltage. The ampere turns of the exciter have to be reduced in such a way that the ampere turns of the slip ring field are equal to the ampere turns representing the slip ring voltage plus a small correction which is necessary to take into account the effect of the ohmic drop in the field circuit of the commutator machine. For convenience these ampere turns of the exciter are divided into 3 groups. The first group is the ampere turns $\mathfrak{F}_6'$ and $\mathfrak{F}_7'$ proportional to the excitation voltages proper, i. e., the slip ring and frequency changer voltages. The second group is the 2 components of the resultant ampere turns of the exciter, one proportional to the total ohmic drop of the field current of the commutator machine $\mathfrak{F}_{8R}'$, the other one, $\mathfrak{F}_{8x}'$, proportional to the induced electromotive force in the field winding of this machine (the inductive voltage drop of the field current is neglected). The third group is the ampere turns $\mathfrak{F}_{67}'$ caused by the voltages induced in the 2 field windings of the exciter by its main flux (the leakage flux is neglected). This group is perpendicular to this flux, which is in phase with $-\mathfrak{F}_{8x}' - \mathfrak{F}_{8R}'$.

It can easily be shown that for constant flux of the commutator machine the following relations between the different vectors and the self-excited rotor frequency and the speed of the commutator machine hold. $\mathfrak{F}_{8X}'$ and $\mathfrak{F}_{3cX}$ are proportional to the frequency. $\mathfrak{F}_{67}'$ is, for a given ratio of flux to resultant ampere turns of the exciter, approximately proportional to

$\mathfrak{F}_{3X}'$ and the frequency; it increases, therefore, roughly with the square of the frequency. $\mathfrak{F}_7'$ and $\mathfrak{F}_{3c}$ decrease with increasing frequency and the lag of the latter is increased. By varying the speed of the commutator machine, $\mathfrak{F}_3$ and $\mathfrak{F}_{3X}'$ are not affected and $\mathfrak{F}_{67}'$ is only slightly affected. All other full drawn vectors are strictly or approximately proportional to this speed.

The danger of self excitation can now conveniently be discussed by dividing the vectors of figure 4 into 2 groups, each group vector starting from point O. $\mathfrak{F}_I$ is the difference $\mathfrak{F}_3 - \mathfrak{F}_{3c}$ and can be considered as the ampere turns necessary to produce the assumed voltage and current. $\mathfrak{F}_{II}$, being the sum of all other components, gives the ampere turns which the field circuits of the commutator machine and the exciter produce. Self excitation is only possible if $\mathfrak{F}_{II}$ is at least equal to $\mathfrak{F}_I$. The question whether self excitation is possible or not can therefore be answered by plotting the endpoint curves of the vectors $\mathfrak{F}_I$ and $\mathfrak{F}_{II}$ (see figure 5) for different speeds of the commutator machine within the operating range of the converter and for several self-excited frequencies. If such a diagram shows $\mathfrak{F}_{II}$ to be smaller than $\mathfrak{F}_I$ for a certain frequency for which the end points of $\mathfrak{F}_I$ and $\mathfrak{F}_{II}$ are approximately in line parallel to $\mathfrak{F}_3$, self excitation will not occur.

Fig. 5. Ampere turns diagram of a Scherbius machine with exciter during self excitation and end point curves of the vectors $\mathfrak{F}_I$ and $\mathfrak{F}_{II}$ to determine the possible danger of self excitation and the magnitude of its frequency



The solid vectors are for +3 per cent slip, the dotted vectors for −3 per cent slip

The + and − signs at the end point curves of $\mathfrak{F}_I$ stand for subsynchronous (+) and supersynchronous (−) self excitation

+3 per cent and −3 per cent designate the operating slip of the induction machine for which the end point curves are drawn

The arrows point in the direction of increasing self-excited rotor frequency

Note 1—For simplification the end point curves of $\mathfrak{F}_{II}$ are drawn identical for subsynchronous and supersynchronous self excitation

From this diagram a few interesting conclusions can be drawn. The most important ones are as follows:

The danger of self excitation increases with decreasing short circuiting effect of the network, decreasing ohmic component of the load, increasing speed of the commutator machine, and increasing flux and number of turns of the field windings of the exciter.

The self-excited rotor frequency increases with decreasing load inductance and increasing counter-compounding of the commutator machine and decreasing ratio of the resultant to the counter-compound ampere turns of the exciter.

Because of the number of variables it is not feasible to state numerically which converter would be self-excited and which not. It is, however, usually possible by properly applying the above conclusions to definitely eliminate the danger of self excitation in specific cases.

Some Factors Affecting Self Excitation

Of special interest is the increasing probability of self excitation with decreasing load resistance in the light of a previous statement that this resistance can become negative. As a machine loaded by a negative resistance is operating as a motor, the conclusion must be drawn that this Scherbius machine can be self excited and at the same time operate as a motor as long as the reactive load component is inductive. This is the more surprising as the load resistance of the commutator machine was negative when the losses in the network were particularly high. This apparent contradiction is easily cleared up when it is remembered that for supersynchronous operation of the induction machine and generator action of its stator the rotational field delivers to its rotor an amount of power equal to the stator power times the slip. If the stator and therefore the rotor power are large enough, all losses in the rotor circuit can be covered and in addition a certain amount of mechanical power given off. (For a similar discussion see reference 13.) All this power is supplied from the shaft of the induction machine and the Scherbius machine has indeed to supply only the magnetizing power in order to make self excitation possible.

Of similar interest is the other extreme when the network delivers a large amount of power to the stator of the induction machine. Because of the supersynchronous self excitation f_{2s}/f_{1s} times this stator power is supplied from the rotor to the rotational field of the induction machine. Both powers appear as mechanical output at the shaft of the in-

duction machine. This leads to the apparently paradoxical result that the generator output of the Scherbius machine rises with increasing generator output of its "load."

In this connection it should be pointed out that for a strong short-circuiting effect of the network, i. e., negligible frequency changer ampere turns, supersynchronous self excitation is more probable than subsynchronous self excitation. This is so because the load resistance R according to equation 1 (previously given) is smaller for supersynchronous self excitation on account of the negative values of s_s and s_N.

The physical reason for this difference of R is that the rotor of the induction machine with its stator generating is motoring for subsynchronous self excitation, and generating for supersynchronous self excitation. In the second case it is therefore reducing the losses to be covered by the Scherbius machine.

If the frequency changer ampere turns during self excitation are relatively large the sense of rotation of the self-excited rotor field is determined by the phase angle between the frequency changer and slip ring ampere turns, i. e., by the direction of the power transfer during normal operation. This sense will be such that the frequency changer ampere turns have a component in phase with the slip ring ampere turns. It can be easily shown that with the induction machine motoring during normal operation the self excitation will tend to be supersynchronous, with the induction machine generating subsynchronous.

If the induction machine be accidentally disconnected from its network, the load impedance of the Scherbius machine becomes high, about equal to the no-load reactance of the induction machine and the full frequency changer ampere turns are available. This will almost certainly produce self excitation. The rotor frequency under these conditions is rather low and the main fluxes of both the commutator and induction machine will probably rise to a very high saturation.

If the circuit breaker at the distant end of a transmission line should trip, the no-load impedance of the induction machine will be shunted by the capacity of the transmission line. This will increase the load inductance of the Scherbius machine and therefore decrease the self-excited rotor frequency. As before, self excitation is almost certain. It is, however, not so dangerous as it seems because it does not occur during normal operation. Secondly, normal operation could not be resumed before—among other things—the frequency changer circuit is adjusted to zero power transfer. As changes in the field circuits of the commutator machine have to be made anyway, it is not unreasonable to provide means which will produce these changes automatically in case of service interruption in order to stop immediately the self excitation of the disconnected converter.

Special Means of Compensating for Self Excitation

Under certain conditions it is possible that within an economical design the danger of self excitation cannot be entirely eliminated. In such cases it is necessary to introduce means by which the available excitation for the self-excited voltage is automatically decreased from its value for the normal frequency. According to Seiz this can be achieved by connecting a small unloaded induction machine with a large ratio of no-load to short-circuit impedance to a suitable point of the exciter circuits. Due to its low speed and special design it will always revolve virtually in synchronism with the normal rotor frequency and therefore be nearly a short circuit for any self-excited voltage of a frequency usually encountered.

Another method is to utilize the short-circuiting effect of the primary network during self excitation to reduce the available ampere turns of the slip ring field, which are largely responsible for the danger of self excitation of this converter. To this end, part of the voltage of the so-called slip ring excitation is introduced from the secondary of a small induction machine, coupled to the converter, the primary of which is supplied through a transformer from the primary voltage of the main induction machine.[13]

A third method is to feed an essentially capacitive auxiliary field circuit of the exciter from its terminal voltage (see page 27 of reference 12). Because both the electromotive force induced in the field windings of the exciter and the rotational electromotive force produced by this auxiliary circuit increase for constant flux of the commutator machine approximately with the square of the frequency, complete compensation of the electromotive forces induced in the field windings for any frequency is indicated. Before applying this method, however, it is necessary to check whether the auxiliary field current is small compared to the current which its ampere turns cause to flow in the field circuit of the commutator machine. Unless this is so, the auxiliary circuit is of no effect because the 2 currents oppose each other in the field circuit of the commutator machine.

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Improvements in Communication Transformers

The rapidly advancing art of electrical communication and the increasingly wide variety of its applications have required marked improvements in the transformers used in communication circuits. These improvements, achieved partly through advances in design and partly through improvements in the constituent materials, are discussed in this paper.

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THE rapid development of the art of electrical communication in the last decade has necessitated marked improvements in the transformers used in it. New applications for these transformers and the extension of old ones have imposed new and far severer performance requirements. The primary applications of communication transformers are in the telephone plant, in the various voice and carrier transmission circuits, and in a multitude of incidental services. They have also wide uses in radio broadcasting transmitters and receivers, in the amplifiers of sound motion picture equipment, in the radio equipment for aircraft, and in a variety of other circuits.

Although communication and power transformers have a common origin, the communication transformer now has evolved as a precision device which has only a general resemblance to the usual power transformer. Some voice frequency transformers, such as those used in aircraft, weigh but 2 or 3 ounces, yet transmit speech substantially undistorted. Some used in program circuits transmit with negligibly small phase or amplitude distortion all frequencies from 20 to 16,000 cycles per second. Transformers also have been developed for transmitting narrow bands of frequencies and having associated with the normal transformer performance valuable frequency discriminating properties. A discussion of improvements in these narrow band transformers is outside the scope of this paper, which will be confined to those transmitting wide frequency bands, that is, those for which the ratio of upper to lower limiting frequencies is at least 10 to 1.

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1. For all numbered references, see list at end of paper.

The design of the modern communication transformer is based upon extensions of the familiar theory of transformers covered in numerous texts. However, this type of transformer is a more complex device, with its multiplicity of requirements and its transmission over a wide frequency range. Its proper representation accordingly requires a more elaborate equivalent network than the customary Π or *T* network. With the use of such a network, the performance of the transformer may be correlated mathematically with its constants in accordance with network theory.

Improvements in Low Frequency Transmission

The great improvements in communication transformers, particularly at audio frequencies, are largely attributable to the invention and application of the permalloys as magnetic core materials. For convenience, the term "permalloy" has been applied to a group of nickel-iron alloys containing between 30 and 95 per cent nickel which have been developed by Bell Telephone Laboratories.[1,2,3] In addition to other desirable magnetic properties, some of these permalloys[4] when properly heat treated yield exceptionally highly initial permeabilities. As a result of the use of these special alloys, telephone transformers may be designed to have less loss and distortion over wider frequency ranges than has been possible in transformers designed without the benefit of use of such materials.

Figure 1 illustrates the excellence of performance resulting from the use of a special permalloy consisting of approximately 4 per cent chromium, 78 per cent nickel, and the remainder iron, in a trans-

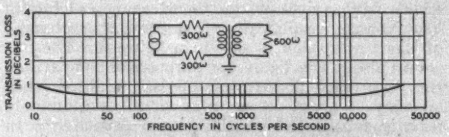

Fig. 1. Transmission-frequency characteristic of a transformer utilizing a permalloy core and designed to connect a telephone transmission line to a program repeater. Transmission loss shown is the loss relative to an ideal transformer of the same ratio

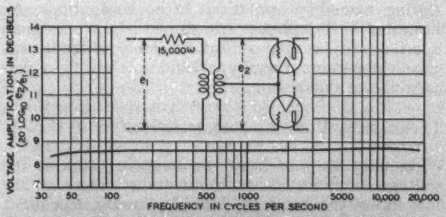

Fig. 2. Voltage amplification-frequency characteristic of an interstage transformer for a high quality program amplifier

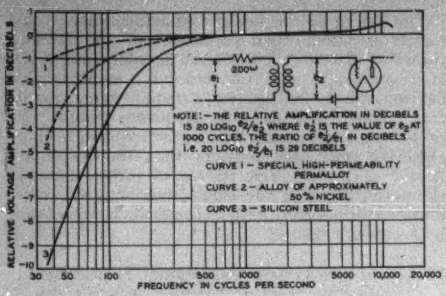

Fig. 3. Curves showing the relative effect of different core materials on the voltage amplification-frequency characteristic of a small transformer designed for portable recording apparatus. The composition of the special permalloy is approximately 4 per cent chromium, 78 per cent nickel, and the remainder iron

former designed to connect a telephone transmission line to a program repeater. Figure 2 shows the voltage amplification characteristic of an interstage transformer for a high quality amplifier. As is well known,[5] superimposed direct currents generally decrease the effective a-c permeability of ferromagnetic materials. Therefore, to retain the full benefit of the permalloy core, an auxiliary circuit was used with this transformer for supplying the plate current to the preceding tube. Another illustration is a transformer designed for use as an input transformer (that is, one designed to operate into the grid circuit of a vacuum tube) for portable recording equipment where light weight is an important consideration. The voltage amplification-frequency characteristic of this transformer is shown in figure 3. There is shown also in this figure, for purposes of comparison, the very much poorer characteristic realized when an alloy of about 50 per cent nickel as commonly used is substituted for the special permalloy. In addition, there is shown the effect of using silicon steel as core material, which was the practice in older transformers.

An important limitation of high permeability alloys is their sensitivity to mechanical strain which may seriously impair their magnetic characteristics. Considerable care must be exercised to avoid strain during assembly operations after laminations are annealed. Telephone transformers are designed specially to provide a firm assembly without mechanical strain, thereby retaining the high permeabilities available.

Increase in Voltage Amplification

As may be seen from the foregoing curves, the voltage amplification of input transformers at the low end of the frequency band is directly dependent on the permeability of the magnetic core material. At the highest frequencies the voltage amplification of the above input transformers is controlled by leakage and capacitances, the latter including grid circuit capacitances as well as the transformer distributed capacitances. Over a wide range in the central part of the frequency band these effects are negligible and the transformer performs much as an ideal transformer of the same ratio. By proper proportioning of the leakage and capacitance effects, the shape of the characteristic may be controlled to a certain measure at will. For example, a rising voltage amplification-frequency characteristic can be obtained if desired to correct for a falling characteristic of other parts of the amplifier.

In certain types of circuits the voltage amplification of input transformers is at a high premium, such as in the amplification of low energy signals when a-c power is used for the tubes. Under these conditions the tubes tend to introduce appreciable noise. A high voltage amplification in the input transformer serves to raise the signal voltage at the grid terminals so as to override the tube noises. Figure 4 shows that a high amplification, in this instance 10,000 to 1 in impedance level from a 30 ohm source, may be realized without undue restriction in either the low or the high frequency transmission.

Since transformers of this type are located at points of very low energy levels, special pains must be taken to avoid interference from stray magnetic and electrostatic fields. To prevent hum from nearby power apparatus, transformers are enclosed in cases or shields of high permeability material. The interference voltages induced in these transformers are some 30 or 40 decibels less than in older unshielded types of transformers. For higher frequency interference, effective shielding is obtained by cases made of high conductivity material such as copper or aluminum.

Reduction in Size and Weight

The demand for lightweight equipment for aircraft communication and for portable apparatus for testing and recording has resulted in the development of communication transformers of unusually small size and weight. The smaller sizes weigh only $3^1/_2$ ounces and occupy a space of but 3 cubic inches. One of these used in aircraft receiving sets is illustrated in figure 5 contrasted with an earlier transformer also for lightweight service. The transmission loss-frequency characteristics are shown in figure 6. The corresponding characteristic of an input transformer for similar service is shown in figure 7.

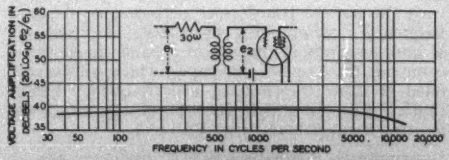

Fig. 4. Voltage amplification-frequency characteristic of an input transformer having an impedance ratio of 10,000 to 1

Extension of Range to Higher Frequencies

The effective permeabilities of alloys of high initial permeabilities drop rather rapidly with frequency, a property which lessens the value of such alloys in transformers for carrier and higher frequencies. This effect, which is attributable primarily to eddy currents, can be greatly decreased, of course, by the use of thinner laminations. The use of these alloys, however, is limited by the rapidly increasing cost of reducing the lamination thickness and the less efficient use of the volume available for the core. This dropping off of effective permeability with frequency is not so important in audio frequency transformers, since there the core characteristics limit the transmission only at low frequencies where the effective permeability is high.

At higher frequencies the voltage amplification is severely limited also by the grid circuit and transformer capacitances. It has been found advantageous to add correcting elements, such as inductances and capacitances, to increase the gain ordinarily available. These added elements and the equivalent elements in the transformer are designed together as configurations similar to low-pass filter sections terminated midshunt in the grid circuit capacitance. Figure 8 illustrates the performance of a transformer designed for certain high frequency transmission experiments. The performance of this transformer in the frequency range of 30–500,000 cycles per second is similar to that of earlier types in the range of 30–60,000 cycles per second.

In most telephone applications the design of input transformers is complicated greatly by circuit functional requirements in addition to those of direct transmission. For example, as discussed in a succeeding section of this paper, phase distortion requirements demand self-impedances far higher than those required by transmission loss considerations, thermal[6] noise requirements demand lower dissipations, and impedance requirements limit the voltage amplification obtainable. For feed-back type amplifiers[7] the input transformers in addition to the forward amplification must meet transmission and phase requirements in the regenerative path. These special requirements apply not only for the transmitted frequency band but also at frequencies remote from this band in order to insure stability of the amplifier.

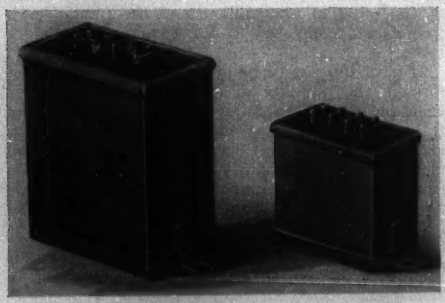

Fig. 5. Output transformer A (right) utilizing a permalloy core transmits frequencies from 40 to 3,000 cycles with greater over-all efficiency than the larger output transformer B (left) utilizing a core of silicon steel (see figure 6)

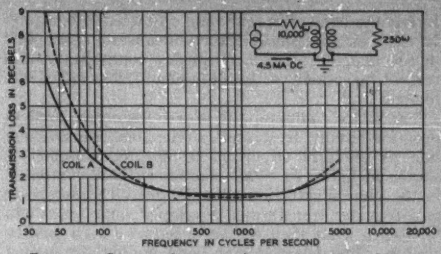

Fig. 6. Curves showing the transmission loss-frequency characteristics of (A) the small output transformer and (B) the larger output transformer shown in figure 5

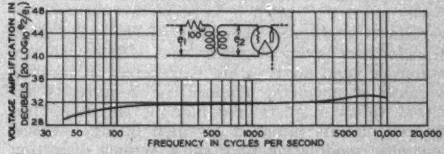

Fig. 7. Voltage amplification-frequency characteristic of an input transformer similar in size to the smaller output transformer shown in figure 5

Reduction in Phase Distortion

Since transformers are reactive devices, they introduce phase shift in the circuits in which they are used. If the phase shift introduced be a linear function of the frequency it will not produce any distortion in the shape of the transmitted wave. However, departures from linearity change the wave shape, and this form of distortion is referred to as phase or delay distortion. The delay at any frequency is a measure of this departure from linearity, and is dependent upon the frequency derivative of the phase shift at that frequency. Differences in delay of the various frequency components of the signal wave which transformers tend to produce result in distortion that may be especially serious in circuits intended for program transmission.

For wide band transformers the delay caused by the shunting effect of the mutual impedance usually predominates. In fact for audio transformers the delay at higher frequencies is relatively so small that the delay distortion is practically equal to the mutual impedance delay at the lowest transmitted frequency. Delay distortion is also of importance in trans-

formers to be used in television and telephotography. In these circuits phase distortion causes a space shift in the image of certain frequency components with respect to others with consequent blurring of the image.

The delay characteristic of a transformer used in program circuits to connect a telephone transmission line to the grid circuit of a repeater amplifier is shown in figure 9. This characteristic is compared in the same illustration with the delay characteristic of a repeater transformer developed some years ago for use in what then was regarded as a high quality circuit. The delay characteristic of a high frequency transformer is shown in figure 10.

Reduction in Audio Frequency Modulation

The present exacting requirements for transformer performance have made it necessary to lessen greatly certain second-order distortion effects inherent in transformers having magnetic cores. Nearly all core materials tend to generate extraneous frequencies because of magnetic nonlinearity—a property referred to as magnetic modulation. In audio frequency circuits intended for high quality service, magnetic modulation may cause serious distortion in that harmonics of the lower frequencies appear higher in the audible range. The energy present at the lower frequencies is usually so much greater than that over the rest of the band that the modulation products may approach the order of magnitude of the signal components at higher frequencies.

This form of distortion in no way is revealed by the ordinary transmission loss characteristic; in fact, a transformer having a very flat loss characteristic over a wide frequency range may nevertheless be definitely objectionable from a modulation standpoint. In present audio frequency transformers, the total modulation products are some 40 to 80 decibels down from the energy of frequencies around 35 cycles per second producing them. This represents an improvement of about 30 decibels over older types.

Another second order effect resembling modulation is microphonic noise caused by magnetostriction phenomena, that is, changes in magnetization accompanying the physical deformation of the magnetic material. For instance, slight jarring of input transformers used in very high gain amplifiers (100 decibels or more) may induce in this manner disturbing noise voltages. Freedom from magnetostriction is a unique characteristic of permalloys containing approximately 80 per cent nickel, and

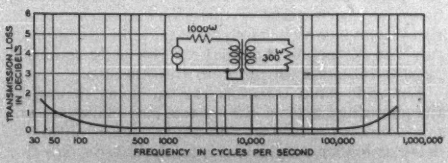

Fig. 8. Transmission loss-frequency characteristic of a transformer designed to transmit high frequencies in addition to audio frequencies

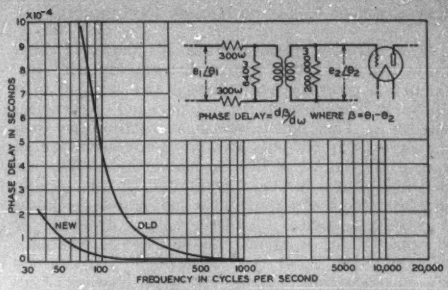

Fig. 9. Phase delay-frequency characteristic of an input transformer used in recent program repeaters, compared with that of an input transformer used in an older repeater

their use accounts for the superiority of telephone transformers from this standpoint.

Reduction in Carrier Frequency Modulation

Magnetic modulation is even more serious at carrier frequencies where a transformer may transmit many channels, frequently at widely different levels. The modulation from the higher level channels may produce very objectionable interference in other channels. Carrier transformers now have been improved to such an extent that highly sensitive testing circuits are required to detect and measure the modulation products contributed by them. Representative values of these modulation products expressed as current ratios to the fundamentals are of the order of one millionth of the fundamental frequencies, compared to one thousandth in older types.

It is of interest to point out that in such transformers the presence of magnetic material, other than the special permalloys, in the vicinity of the transformer must be avoided with great care. For example, a small steel screw near the field of the transformer will seriously impair its performance from a modulation standpoint. Common practice is to use brass parts for the assembly and to confine the field of the transformer by completely enclosing it in a copper or aluminum case. The transformer then may be mounted by any convenient means without affecting its performance.

Improvements in Shielding and Balance

In the very nature of the service that it renders, the telephone plant involves many independent communication circuits in fairly close proximity. The minimizing of interference between these independent communication circuits has constituted a major problem in telephone engineering. Where such interference occurs between like circuits, that is, between 2 voice circuits or between 2 carrier circuits of overlapping frequency bands, the interference commonly is referred to as cross talk, as distinguished from the

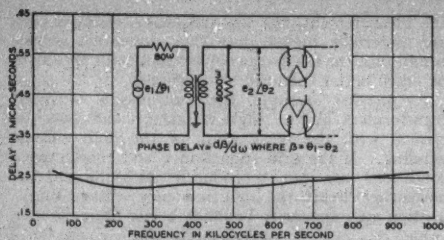

Fig. 10. Phase delay-frequency characteristic of an input transformer designed to transmit radio frequencies

interference from other types of circuits such as power and telegraph circuits.

In order to avoid cross talk and other interference, balanced* circuits are used almost exclusively in the telephone plant. For simplicity, some of the terminal apparatus connected with these circuits is constructed unbalanced, so that it is necessary to interpose transformers between the lines and the office equipment, these transformers providing a barrier to the propagation of the relatively large longitudinal currents from the line circuits. (Longitudinal currents, in contrast with the usual circulating currents, are currents that flow equally and in the same direction in both sides of the line.) In order to insure that the voltage impressed on the office equipment is attributable to the voltage between the wires of the line circuit and not to that between the wires and ground, it is necessary that the transformers be balanced very carefully; and for certain types of circuits, shields must be interposed so that the direct capacitance between the line winding and office winding is reduced to a very small value.

With a greater emphasis on carrier frequency transmission, a higher degree of balance is required between certain transformer windings, and highly effective shielding is frequently necessary. It is necessary also that the line windings be balanced very closely with respect to capacitances to the shield and case. The unbalance effects in carrier transformers now have been reduced to values in the order of 1 or 2 microamperes in circulating current per volt between the line windings and ground at 30,000 cycles per second, which compares with values of 50 microamperes or more for older transformers. At the same time the electrostatic shielding between the windings has been reduced to 1 or 2 micromicrofarads instead of 30 or 40 as before. The shields are arranged to intercept the dielectric flux lines tending to connect the primary and secondary windings, so that the direct capacitance between the 2 windings is attributable only to stray flux which by-passes the shield. One of the windings usually is enclosed completely in lead or copper foil with overlapping edges insulated to prevent a short-circuited turn. Still further improvements are obtained by covering the leads with grounded metal braiding, and in special cases by enclosing the terminals of the shielded winding in a separate shielded compartment. In certain transformers designed for high precision testing equipment, the direct capacitance between windings has been reduced to values less than 0.001 micromicrofarad.

In connection with phantom circuits, severer cross talk requirements have necessitated more precise balances in the associated voice frequency transformers. In these transformers the turns are so arranged that the various distributed capacitances, flux linkages, and d-c resistances are disposed symmetrically with respect to ground. It has been found in practice that this symmetry is realized most readily by close coupling between the various parts of the windings. By improvements in design, the cross talk between phantom and side circuits has been reduced to values in the order of 20 millionths in current ratio compared to values 5 times as large formerly tolerated.

Reduction in Impedance Distortion

As a further consequence of the extension of carrier systems, it has become necessary to match the impedance presented by transformers, when terminated in the succeeding circuits, to particular values over the frequency range. For example, the transposition schemes used on open wire lines are such as to minimize cross talk primarily for carrier signals propagated in one direction in any line. If the transformer terminating such a line does not present an impedance under load equal to the characteristic impedance of the line, a portion of the wave is propagated in the reverse direction, that is reflected, causing cross talk into adjacent circuits. This reflection effect increases with the vector difference in the impedances of the transformer and the line, the latter impedance approaching a pure resistance as the frequency increases.

The impedance of transformers has become increasingly important where such transformers terminate filters that require a nearly constant resistance termination to maintain proper attenuation characteristics. Another example is in transformers ter-

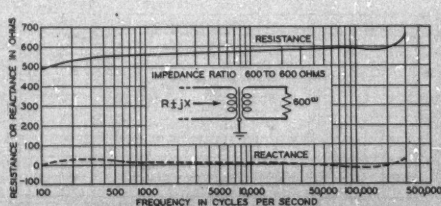

Fig. 11. Impedance-frequency characteristic of a transformer designed to operate between 600 ohm terminations and to transmit high frequencies in addition to audio frequencies

* The new coaxial cable circuits under development are an interesting exception. In this type of cable a grounded outer conductor completely encloses the central conductor, and shielding rather than balance is relied upon to protect the circuit from interference. The shielding depends upon the size, thickness, permeability, and conductivity of the outer conductor and the frequency of the disturbance. If the frequency band used in the transmission over coaxial circuits is chosen properly, the circuit may be made substantially immune to effects from outside fields.

minating screen grid tubes where the plate impedances are relatively very high. Here the energy abstracted from the plate circuit and transmitted by the transformer is directly dependent upon the resistance component of the impedance of the transformer when terminated in its load.

Better impedance characteristics of transformers for these various applications have been obtained by increasing the mutual impedance and decreasing the leakage and capacitance effects. This procedure is made difficult by the necessity for meeting at the same time other and newer requirements, as, for example, modulation limits. Correcting elements consisting of capacitances and inductances usually are added and are proportioned with the transformer elements in accordance with network theory. Typical impedance characteristics of such transformers are shown in figures 11 and 12.

Input transformers operating into the grid circuits of vacuum tubes inherently have impedances that depart widely from the nearly pure resistances usually desired, because of the reactive termination provided by the grid circuit. This makes it necessary to add resistances to serve in place of the usual load resistance. The required dissipation may be provided in many ways in the input transformer, which consideration allows much wider latitude in the design than in the ordinary transformer; there the major part of the dissipation for low transmission loss necessarily must occur in the load. A typical impedance characteristic of such an input transformer is shown in figure 13.

Testing Precautions

As a necessary concomitant to improvements in transformers, more precise testing circuits have been developed for accurately determining transformer performance. In estimating the performance of the transformer from its characteristic, care must be taken to make sure that the service conditions were reproduced carefully in the measuring circuit. In particular, certain precautions must be observed in the measurement in order to avoid obtaining a misleading characteristic. For example, the permeability of magnetic core materials tends to rise rapidly from its initial value with increasing voltages. If in the measurement, the low frequency voltages used are materially higher than they are under service conditions, the low frequency response will appear to be much better than the true response.

As another example, the transmission of input transformers at the high frequency end may be critical with the termination of the high voltage winding. If the grid capacitance and conductance conditions are not reproduced faithfully in the measuring circuit, the high frequency voltage amplification may appear to be much better than the true value.

In addition to more precise transmission measuring circuits, various other special circuits have been developed for measuring transformers, such as modulation, impedance, and cross talk measuring circuits. The design of these circuits is of necessity a specialized art.

In the foregoing, various types of improvements in communication transformers have been discussed. Wherever applicable, several such improvements have been incorporated in an individual design. The improved performance of transformers as described has been an essential step in the development of the communication art.

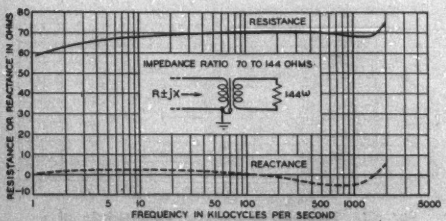

Fig. 12. Impedance-frequency characteristic of a transformer designed to operate between resistance terminations of 70 ohms and 144 ohms

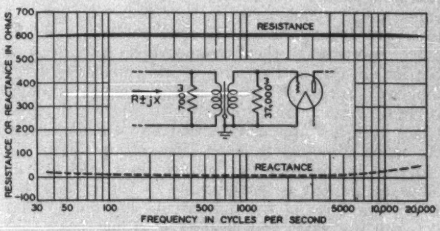

Fig. 13. Impedance-frequency characteristic of an input transformer used to operate from a telephone transmission line into a high quality program repeater. Impedance ratio is 600 to 15,000 ohms

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I.E.C. Adopts MKS System of Units

At its plenary meeting of June 1935 at Scheveningen-Bruxelles, the International Electrotechnical Commission unanimously adopted the meter-kilogram-second (mks) or Giorgi system of units, 15 of the 25 constituent countries being represented. In this paper the principal historical antecedents of this action by the I.E.C. are outlined, and its principal import to electrical engineering is indicated. Since the preparation of this paper there have been further important developments in connection with the adoption of this system; reports of these developments, as translated from the original French texts, are given in appendixes I and II.

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As is well known, the International Electrotechnical Commission is an international organization maintained by 25 countries. It was called into existence under the leadership of R. E. Crompton, in response to a recommendation of the International Electrical Congress of St. Louis (Mo.) in 1904. It was organized in 1906 with its secretariat in London, and C. LeMaistre has been its general secretary since that time. It comprises 24 advisory committees, each dealing with a particular electrotechnical subject, and it has held plenary meetings in London, Paris, Brussels, The Hague, Berlin, Cologne, Turin, Zurich, Bellagio-Rome, Geneva, Denmark, Scandinavia, and New York. It has accomplished much international electrotechnical work during its 29 years of activity.

At its plenary meeting, in June 1935, at Scheveningen-Bruxelles, the I.E.C. unanimously adopted the Giorgi System of meter-kilogram-second (mks) units, 15 countries being represented by the delegates present. Every electrical engineer should make himself acquainted with the significance of this decision. In effect, it replaces the 3 systems at present in use (namely, the absolute electromagnetic cgs system, the absolute electrostatic cgs system, and the practical series) by one practical system.

The fundamental units are so chosen that the present practical series or system becomes at once an absolute system. This brings about a great simplification in the teaching of units and in practical calculations.

For the present, the question of rationalization has been left for future consideration. As the permeability and permittivity of space are no longer unity, it would be an easy matter to fix their values so as to rationalize all calculations; that is to say, to arrange matters so that the multiplier 4π comes into those formulas only where it would be expected to enter.

Not since the International Congress of Electricians, at Paris[7] in 1881, has there been made a decision of similar international significance. It is the purpose of this paper to outline the principal historical antecedents of this I.E.C. action, to indicate its main import to electrical engineering, and to suggest a few of the implications it may involve. The account here given is, however, necessarily subsidiary to the official minutes of the meeting, which should be consulted by interested readers.

History of CGS and Practical Units

As early as 1848, resistance boxes had been produced in Germany, calibrated to correspond to the linear resistance of particular sizes of telegraph wire. Gauss and Weber, about 1850, showed how to make certain electric and magnetic measurements in absolute measure, adopting for this purpose the millimeter-milligram-second system (mms). In 1860, Werner Siemens introduced his mercury unit of resistance; i. e., a glass tube of one square millimeter cross sectional area and one meter long, filled with pure mercury, at zero degrees centigrade.

The British Association for the Advancement of Science (commonly abbreviated to B.A.), at its meeting in Manchester, of 1861, established a committee to report upon "standards of electrical resistance." This B.A. committee became famous for its pioneer work. It made annual reports[1] until 1867. It recommended the adoption of an absolute fundamental system of scientific units, and after trying the foot-grain-second system (fgs) advocated the meter-gram-second system (mgs). It computed theoretically, and worked out practically, approximate electric standards, especially that of electrical resistance, for which Latimer Clark suggested the name *ohm*. Because the mgs absolute electromag-

A paper recommended for publication by the A.I.E.E. committee on electrophysics, and scheduled for discussion at the A.I.E.E. winter convention, New York, N. Y., Jan. 28–31, 1936. Manuscript submitted Sept. 30, 1935; released for publication Nov. 1, 1935.

Scheduled for republication by the Institution of Electrical Engineers, London.

7. For all numbered references see list at end of paper.

netic unit of resistance was found to be an extremely small quantity in reference to practical needs, this committee recommended that the practical unit of resistance (or *ohm*) should be 10^7 of these units, since 10 such *ohms* would be roughly equal to the resistance of one mile of an ordinary size of telegraph wire. Telegraph engineering was at that date almost the only existing application of electrical science. The demand for electrical units came from telegraph engineers. Again, since the mgs electromagnetic unit of electromotive force was extremely small from a telegraph-engineering standpoint, another large decimal multiple, 10^8, was recommended for the practical unit, with the name *volt*, since about 100,000 such mgs units were roughly equal to the electromotive force of one Daniell voltaic cell. The decimal factors 10^7 and 10^8 were purely arbitrary and adventitious, to meet the needs and convenience of these particular applications; but once the *volt* and *ohm* were adopted, a new strong influence came into effect, namely, systematic connection between the practical units, such, for example, that the *volt* acting in a circuit of one *ohm*, should deliver one practical unit of current. This would mean that the rest of the practical units were no longer arbitrary, but assigned themselves in accordance with the laws of physics, in one-to-one unit relations. Thus the literature shows that the original value of the *farad*, as the B.A. practical unit of capacitance, was equal to what now is called the *microfarad*, taken as an arbitrary convenient magnitude for telegraph practice; but this was changed[2] later to the present magnitude of the *farad*, because of considerations of systematic relations.

The second B.A. committee was appointed in 1868, "for the selection and nomenclature of dynamical and electrical units." It proceeded to discuss and compare the relative advantages of the cgs, mgs, fgs, and mms systems, for the purposes of a comprehensive fundamental system adapted for use in all branches of science. Its first report—an important document—was published[3] in 1873. It decided, after much debate, in favor of the cgs system. A principal reason for this choice was that the cgs system was the only one of the 4 considered that gave the unit of density equal to that of pure water at standard temperature and pressure (one gram per cubic centimeter). The practical units with standards already in use among practitioners—*ohm*, *volt*, and *farad*—were converted from the mgs multipliers 10^7, 10^8, and 10^{-7}, to the corresponding cgs multipliers 10^9, 10^8, and 10^{-9}, as they exist today. The report also advocated 3 names for as many cgs units, namely, the *dyne* for unit force, the *erg* for unit work, and the *erg per second* for unit power. These names also remain in use.

Although the cgs system and its appended practical units gained recognition among scientists and electrotechnicians, no international action was taken on them until the First Electrical Congress at Paris, in 1881. This memorable congress[7] adopted the cgs electromagnetic units as fundamental, and 5 practical units decimally derived therefrom: the *ohm*, *volt*, *ampere*, *coulomb*, and *farad*. Steps were taken to produce a standard *ohm* as a mercury column resistor of one square millimeter cross section at standard temperature and pressure. The 5 practical units formed a series in one-to-one relation. The cgs system thus became the great fundamental absolute system for universal measurements in all branches of physical science.

Since 1881, 4 more units have been added to the practical electrical series: the *joule*, *watt*, *henry*, and *weber*, in 1889, 1889, 1893, and 1933, respectively, the first 3 at international electrical congresses, and the fourth by the I.E.C. at Paris (confirmed this year at Brussels).

Glossary of Abbreviations

I.E.C.	International Electrotechnical Commission
B.A.	British Association for the Advancement of Science
I.P.U.	International Union of Pure and Applied Physics
S.U.N. committee	Committee on symbols, units, and nomenclature of the I.P.U.
N.P.L.	National Physical Laboratory (British)
E.M.M.U. committee	Electric and magnetic magnitudes and units committee of the I.E.C.
I.C.W.M.	International Committee of Weights and Measures
C.C.E.	Comité Consultatif d'Electricité of the I.C.W.M.
mks	meter-kilogram-second (system)
cgs	centimeter-gram-second (system)
fgs	foot-grain-second (system)
mgs	meter-gram-second (system)
mms	millimeter-milligram-second (system)
qes	(earth-quadrant)-(eleventh-gram)-second (system)
cg-ss	centimeter-(gram-seven)-second (system)

Comprehensive Practical Unit Systems

Clerk Maxwell, who placed the classical cgs systems (electric and magnetic) on a firm mathematical basis, pointed out,[6] in 1881, that the practical series of electromagnetic units virtually formed a complete electromagnetic system, in which the unit of length was the earth-quadrant (10^9 centimeters), the unit of mass 10^{-11} gram (eleventh-gram), and the unit of time the mean solar second. The numerical value of space permeability in this qes system of Maxwell was $\mu_0 = 1$, the same as in the cgs magnetic system. This conception of the practical series as part of a magnetic system was interesting, but merely a proposition in the theory of units. Neither Maxwell nor any other theorist ever seriously proposed that the qes system should be adopted in practical scientific work, because the fundamental units of length and mass were so awkward. For instance, with unit electric current strength as one *ampere*, the unit of current density would be the *ampere per square earth quadrant!* Maxwell's discovery remained, therefore, an academic curiosity.

G. Giorgi of Rome pointed out,[12] in 1901, that if the value of space permeability μ_0 were taken not as unity but as 10^{-7} unrationalized, or as $4\pi \times 10^{-7}$ rationalized, the practical series fell into an electromagnetic system like the qes system, and parallel to the magnetic cgs system, with unit length equal to the international meter (10^2 centimeters), unit mass equal to the kilogram, and unit time the mean solar second. Giorgi presented a paper on this new

mks system to the International Electrical Congress[15] of St. Louis, in 1904. A colleague of his, Ascoli, presented another paper[14] to the St. Louis congress, pointing out that there existed an indefinitely long series of such systems, all containing the practical series of units, such that if the system length unit were 10^l centimeters and its mass unit 10^m grams: then the equation of condition was $2l + m = 7$. In Giorgi's mks system, $l = 2$ and $m = 3$: while in Maxwell's qes system, $l = 9$ and $m = -11$. In this indefinite series of possible systems, all embracing the internationally adopted practical units, only Maxwell's qes system kept $\mu_0 = 1$, and only Giorgi's mks system comprised the international standards of length and mass maintained by the International Bureau of Weights and Measures at Sèvres, in the Park of St. Cloud, near Paris. Moreover, only Giorgi's mks system offered units of length and mass that were satisfactory practically.

The Giorgi mks system slowly advanced in favor all over the world. It was endorsed by several physicists in Europe. In the United States, G. A. Campbell came forward[24] heartily in support of the "definitive system," which differs from the Giorgi system only in details of definition. The only seriously advanced objection to it, setting aside the complaint that the Giorgi system fundamental equations are dissymmetrical from the standpoint of theoretical physics, seems to have been that its unit of density is the kilogram per cubic meter, which is 1,000 times smaller than that of pure water under standard specifications. Since the recent discoveries, however, of deuterium and of "heavy water," the argument for unit-density water has lost some force. To have the density of distilled water unity is, of course, an asset to a system of units; but its loss is not disastrous. The great bulk of water on the earth is ocean water, with a density distinctly greater that that of one gram per cubic centimeter; moreover, tables of specific gravity with that of pure water taken as unity are the same in the mks system as in the cgs system, and for engineering purposes specific gravities are likely to be more useful than absolute densities.

In or about the year 1916, proposals appeared to adopt another comprehensive system, sometimes[21] called "international system," based upon the centimeter as length unit, the gram-seven or 10^7 grams (10 metric tons) as mass unit, and the mean solar second as the unit of time (cg-ss system). Here $l = 0$ and $m = 7$. Several proponents have been named for this system, among them Blondel, Dellinger, Bennett, Karapetoff, and Mie. In the cg-ss system, the numerical value of space permeability μ_0 would be 10^{-9} unrationalized, and $4\pi \times 10^{-9}$ rationalized. Various papers and at least one book[22] have been printed on this system, which claimed many of the advantages of the Giorgi system. Its principal disadvantage, however, was the awkwardly large size of its unit of mass.

Magnetic Units

In reference to the history of practical magnetic units, it may suffice here to point out that as early as 1889, the Second Electrical Congress of Paris discussed the adoption of units for magnetic flux and flux density in the practical system, with personal names for both; but no action was taken in the matter at that time. Similar suggestions were made at the Third International Electrical Congress, of Frankfort, in 1891, but again without action being taken. At the Fourth International Electrical Congress, of Chicago, in 1893, certain proposals of the A.I.E.E., to adopt magnetic units in the practical series for magnetomotive force, flux, flux density, and reluctance, were considered; but the chamber of delegates recommended[9] that magnetic units should be restricted to the cgs system, and without specific names.

At the Fifth International Electrical Congress, of 1900, in Paris, names were requested for cgs magnetic units. There was considerable difference of opinion, and debate. Finally, the congress adopted the names *maxwell* for the cgs unit of magnetic flux, and *gauss* for the cgs unit of magnetizing force H. There was also some accidental misunderstanding of the action taken, some of the delegates present having supposed that the name *gauss* had been adopted for flux density B. No further international action on magnetic units took place thereafter, until the matter was taken up in 1927 by the I.E.C.

Actions of the I.E.C. and the International Union of Pure and Applied Physics (I.P.U.), in Reference to Magnetic Units. At its Bellagio[25] meeting in 1927, the I.E.C. discussed certain proposals relating to magnetic units. In view of much manifest difference of opinion, a subcommittee was appointed to consider and report upon the subject. The committee, composed of representatives from different countries, endeavored to reach conclusions by correspondence; but this was found to be impracticable because of the marked differences of opinion as to the meaning of terms used in magnetic literature and especially as to the meaning of the unit name *gauss*. These differences affected not only the literature of different countries, but also of different writers in each of several countries. The matter therefore was brought to the attention of the various I.E.C. national committees and placed on the agenda of the next I.E.C. meeting, in Scandinavia (1930).

After considerable discussion in Copenhagen and Stockholm, the committee decided unanimously[28] that, for electrotechnical purposes, the convention should be established that in free space the quantities flux density B and magnetizing force H should be taken as physically different; so that their ratio, the space permeability μ_0, was a physical quantity with dimensions and not a mere numeric. The same convention was applied to the absolute permeability μ of a simple magnetic medium; so that its relative permeability μ/μ_0 was dimensionless, or a mere numeric. The committee then assigned the unit name *gauss* to flux density B, confirmed the name *maxwell* for magnetic flux Φ, and gave the new international name *oersted* to the unit of magnetizing force H, all in the classical cgs system. These recommendations were confirmed unanimously by the I.E.C. plenary convention at Oslo, in July 1930. This Oslo convention gave satisfaction to the great

Table I—Incomplete List of MKS Units and of Corresponding CGS Units

No.	Quantity	Symbol	MKS Unit	CGS Unit	CGS Units in One MKS Unit
Mechanical					
1	Length	L	meter	centimeter	10^2
2	Mass	M	kilogram	gram	10^3
3	Time	T	second	second	1
4	Area	S	square meter	square centimeter	10^4
5	Volume	V	cubic meter (stere)	cubic centimeter	10^6
6	Frequency	f	hertz (cycle per second)	cycle per second	1
7	Density	d	kilogram per meter	gram per cubic centimeter	10^{-6}
8	Specific gravity		numeric	numeric	1
9	Velocity	v	meter per second	centimeter per second	10^2
10	Slowness		second per meter	second per centimeter	10^{-2}
11	Acceleration	a	meter per second per second	centimeter per second per second	10^2
12	Force	F	— (joule per meter)	dyne	10^5
13	Pressure	p	— (joule per cubic meter)	dyne per square centimeter, barye	10
14	Angle	α, β	radian	radian	1
15	Angular velocity	ω	radian per second	radian per second	1
16	Torque	τ	— (joule per radian)	dyne $\perp$ centimeter	10^7
17	Moment of inertia	J	kilogram-square meter	gram-square centimeter	10^7
Energetics					
18	Work or energy	W	joule	erg	10^7
19	Angular work, $\tau\alpha$	W	joule	erg	10^7
20	Volume energy	w	joule per cubic meter	erg per cubic centimeter	10
21	Active power	P	watt	erg per second	10^7
22	Reactive power	jQ	var	erg per second	10^7
23	Vector power, $P = jQ$		watt $\angle$	erg per second	10^7
Thermal					
24	Quantity of heat	Q	kilogram-calorie	gram-calorie	10^4
25	Temperature	θ	degree centigrade or Kelvin	degree centigrade or Kelvin	1
Luminous					
26	Intensity	I	candle	candle	1
27	Luminous flux	ψ	lumen	lumen	1
28	Illumination	E	lux	phot	10^{-4}
29	Brightness	b	candle per square meter	stilb	10^{-4}
30	Focal power		diopter		10^{-2}
Electrical					
31	Electromotive force	E	volt		10^8
32	Potential gradient	$\mathcal{E}$	volt per meter		10^6
33	Resistance	R	ohm		10^9
34	Resistivity	ρ	ohm-meter		10^{11}
35	Conductance	G	siemens, mho		10^{-9}
36	Conductivity	γ	siemens per meter, mho per meter		10^{-11}
37	Reactance	jX	ohm		10^9
38	Impedance, $R = jX$	Z	ohm $\angle$		10^9
39	Quantity	Q	coulomb		10^{-1}
40	Displacement	Q	coulomb		10^{-1}
41	Current	I	ampere		10^{-1}
42	Current density	i	ampere per square meter		10^{-5}
43	Capacitance	C	farad		10^{-9}
44	Specific inductive capacity	ϵ/ϵ_0	numeric	numeric	1
Magnetic					
45	Magnetic flux	Φ	weber	maxwell	10^8
46	Flux density	B	weber per square meter	gauss	10^4
47	Inductance	L	henry		10^9
48	Relative permeability	μ/μ_0	numeric	numeric	1

NOTE: Various units used in acoustical engineering, radio engineering, and mechanical engineering are omitted from this list.

majority of electrotechnicians all over the world; but the satisfaction among physicists has been less complete.

The International Union of Pure and Applied Physics (I.P.U.), at its Brussels meeting of July 1931, appointed, for the first time, a committee on "symbols, units, and nomenclature" (S.U.N.). This important S.U.N. committee has held several meetings of great value to the physical sciences. Its president has been Sir Richard Glazebrook, and its secretary, E. Griffiths, of the National Physical Laboratory (N.P.L.). The I.E.C. requested the I.P.U. for the co-operation of the S.U.N. committee in the matter of magnetic units, and this co-operation very courteously was granted. The S.U.N. committee proceeded to prepare a questionnaire on "electrical units," addressed to physicists and physical societies in different countries, calling attention to certain ambiguities in the definitions of fundamental electric and magnetic quantities entering into the classical cgs system, and inviting opinions as to how these ambiguities might be eliminated, in order to arrive at international agreement. This printed document[40] was issued by the S.U.N. committee in December 1931, and replies thereto were collected and distributed to the I.P.U. committees, as well as to the national committees of the I.E.C.

The electric and magnetic magnitudes and units (E.M.M.U.) committee of the I.E.C. met in London, September 1931, to consider the Oslo recommendations made by the same committee in July 1930. Ten countries were represented by delegates. The president and secretary of the S.U.N. committee attended the meeting, as well as H. Abraham

(general secretary of the I.P.U.), President Enström, and General Secretary LeMaistre of the I.E.C. At this meeting the actions taken at Oslo in regard to cgs magnetic units were endorsed unanimously.

In view of the many physicists assembling in Paris during the week July 5–12, 1932, to attend the 1932 Paris International Electrical Congress, the S.U.N. committee called an informal meeting in Paris on July 9, to discuss the matters contained in its questionnaire, and especially the cgs magnetic units. President Sir Richard Glazebrook was the chairman, and E. Griffiths was the secretary; 19 persons, from 8 countries, attended. The actions taken were informal, in the sense that the voting was by individuals and not by countries. The resolutions adopted, if not unanimous, were by considerable majorities. Among the resolutions was the proposition (6) "B and H are quantities of different nature." The Oslo convention was endorsed, and the I.E.C. actions concerning cgs magnetic units and their names, were confirmed. No specific reference was made to the Giorgi system; but it was voted that: "(1) Any system of units recommended must retain the 8 internationally recognized practical units: *joule, watt, coulomb, ampere, ohm, volt, farad, henry.*" It was voted also that in any practical magnetic system, "the factor $4\pi/10$ should be retained in the definition of magnetomotive force." This implies that the S.U.N. committee opposed rationalizing the practical magnetic system.

At the Brussels meeting of the I.P.U. in July 1931, already mentioned, R. A. Millikan was elected as the incoming president, and it was contemplated holding the next I.P.U. meeting in Chicago, June 1933, contemporaneously with the Chicago exposition of 1933. It was found necessary, however, to postpone the I.P.U. meeting; but a meeting of the American Section of the I.P.U., with a few foreign guests, was held at Chicago instead, June 24, 1933, in Mandel Hall, University of Chicago. R. A. Millikan, president of the I.P.U., opened the meeting. The program was directed to the work of the international S.U.N. committee, and 6 papers were read, with E. C. Crittenden, chairman of the American S.U.N. committee in the chair. The papers[49] related to electric and magnetic units and systems, as prepared by R. T. Glazebrook, H. Abraham, L. Page, G. A. Campbell, H. L. Curtis, and A. E. Kennelly. E. Bennett acted as secretary of the meeting. The attendance at the meeting was about 150, and of these the estimated number voting was 30 to 40. In brief, the following resolutions[49–53] were passed:

1. That the classical cgs system should be left unchanged.

2. That the existing series of practical units may advantageously be extended into a complete absolute practical system, either through the mks system, or through the cg-ss system; of these, the mks system is preferred.

3. That the American S.U.N. committee shall be requested to consider the objections to the use of the absolute ohm and the advantage that might be gained by the use of the international ohm in the practical system.

A meeting of the E.M.M.U. committee of the I.E.C. was held[54] at Paris in October 1933. The *weber* was adopted as the practical unit of magnetic flux Φ, subject to the approval of the various national committees. The names *hertz* and *siemens* likewise were voted, for the names of the practical units of frequency and conductance, respectively. The Oslo convention concerning μ_0 and μ was reconfirmed. Special consideration was given to the resolutions passed by the American Section of the I.P.U. at Chicago in June 1933, on the extension of the practical series of units into a complete system, as referred to in preceding paragraphs. Giorgi, who was present as an Italian representative, gave a brief résumé of the mks system. H. Abraham, general secretary of the I.P.U., who attended the meeting, pointed out certain advantages of the mks system, as also did M. Brylinski, president of the French I.E.C. national committee. The following resolution was adopted unanimously:

"Section B of the advisory committee No. 1 on nomenclature, having heard with great interest the communication from Mr. Giorgi on the mks system, and endorsing the resolution adopted by the American Section of the International Union of Pure and Applied Physics at Chicago, in June 1933, decides to invite the national committees to give their opinion on the extension of the series of practical units at present employed in electrotechnics by its incorporation in a coherent system having as fundamental units of length, mass, and time, the meter, kilogram, and second, and as fourth unit either that of resistance expressed as the precise multiple 10^9 of cgs electromagnetic unit or the corresponding value of the space permeability of a vacuum."

These resolutions were distributed to all the I.E.C. national committees in the regular way, together with the minutes of the meeting, with a request for opinions.

Actions of the I.E.C. at the Latest and Plenary Meeting in Scheveningen-Brussels

In regard to actions on units, the E.M.M.U. committee met at Scheveningen, with representatives from 15 countries. President Enström attended the sessions. Paul Janet, president of advisory committee No. 1, was prevented from being present. He was unanimously elected honorary president of the I.E.C., an honor shared by Elihu Thomson. The principal actions taken at this meeting were briefly as follows:

1. The Oslo convention concerning μ_0 and μ was reconfirmed.

2. The adoption of the *weber* was confirmed as the name of the practical unit of magnetic flux Φ.

3. The replies were read as received from the various national committees concerning the extension of the practical series into a practical system of units, on the mks basis. Practically all the replies were in favor. The question of adopting the mks system then was moved and unanimously approved, except that 2 countries made reserves as to the suitability of retaining the *kilogram* as a basic unit of the system.

There was considerable difference of opinion among the delegates as to the fourth fundamental unit for the system. The *ohm* and the *coulomb* each had been suggested. It was agreed that a fourth unit was needed, because it would be possible, starting with the 3 units, meter, kilogram, and second, to construct an indefinite number of possible associated electromagnetic series, differing from the existing practical series which all desired to maintain. It finally was agreed to defer action on the choice of a fourth fundamental unit until an opportunity had been offered to consult the Comité Consultatif d'Electricité (C.C.E.) of the International Committee of Weights and Measures (I.C.W.M.) at Sèvres, and

also the S.U.N. committee of the I.P.U. In the meantime, it was voted that the new system should be called the "Giorgi System." Opinions also were requested from the various national committees as to the selection of the fourth unit.

4. By way of example, in the formation of derived units in the system, the following were adopted unanimously: (*a*) the volt per meter as unit of electric force; (*b*) the weber per square meter as unit of magnetic flux density B; (*c*) the joule per cubic meter as unit of volume energy.

5. The actions taken at the preceding meeting in Paris, concerning the practical unit names *hertz* and *siemens* were confirmed, as also the desirability of inserting the space permeability symbol μ_0 in all working magnetic formulas where its absence might mislead, thus reconfirming the Oslo convention.

Advantages of the Giorgi System to Students of Electrical Engineering

Table I, which gives a list of mks and cgs units, shows that although the classical cgs system in no way is altered or disturbed by the completion of the practical series into an independent practical system; yet:

1. There is great simplification in elimination of the necessity of learning the decimal ratios 10^8, 10^8, 10^7, 10^{-1}, and 10^{-9}, which connect various units in the 2 systems. The practical units all stand in unity-sequence relation.

2. The mks system is single and requires no accompanying companion electrostatic system. All electrostatic phenomena can be dealt with very easily through the existing electromagnetic practical units.

3. The dimensional formulas of the Giorgi units can be expressed without resorting to fractional exponents, as shown by Giorgi[55] and other writers.

4. It permits the use of either "rationalized" or "unrationalized" formulas, according to the choice of each writer, without disrupting the system on that account.

5. It requires no appreciable change in the existing literature and terminology of electric circuits. It may be said that the electrical engineering literature of the voltaic circuit is already Giorgian. It will not be difficult to transform the literature of the magnetic circuit from cgs to mks units.

6. For almost all practical purposes, the mks system can be studied and used now, without waiting for the formal adoption of the fourth fundamental unit to complete the system's base. Until readers become familiar with the expression of magnetic circuit formulas in mks units, the old cgs magnetic formulas may be retained in the cgs system without confusion.

7. It affords a clear perspective of the distinction between the earlier cgs units and the practical units, in regard to nomenclature and scope. If new cgs units be named, the names may conformably be impersonal. New practical units may conformably receive personal names, especially units 12, 13, and 16 in table I. If desired, a few impersonal names in the mks system might be changed later into personal names.

Comments

Table I shows that the only department of the cgs system in which personal names appear is that concerning the magnetic circuit. This discrepancy results from the resolution of the Chicago congress of 1893 to keep magnetic units out of the practical series. The very large aggregate number of electrotechnicians all over the world thus were impelled to seek for the magnetic circuit names they so earnestly desired, in the cgs system itself. Although this inconsistency is regrettable, it seems likely that with patience and good-will, it may be surmounted later.

Looking back upon the path of the development of units since 1861, when the B.A. made the first move in the direction of practical units, it appears that starting in about 1865 with the *ohm* and the *volt* based upon the cgs system, and with magnitudes selected fortuitously to suit the convenience of electric telegraphy, Ohm's law pointed the way from these 2 nuclei to the coherent magnitude of the *ampere* as the practical unit of current. These, in turn led, through other simple physical laws and their mathematical formulas, to the succeeding members of the practical series. After the *ohm* and *volt*, no further arbitrary choice was left, and the practical series determined itself. Each new member of the series made systematization more imperative and finally led to the completion of the whole series into the Giorgi system. It has been as though the marvelous simplicity of the physical universe in its individual actions, working on the minds of men engaged in physical applications, brought pressure upon them psychologically to imitate in their thoughts and arithmetic the order and system of the vast environment in the physical world. In 1935, the need for the system has reached the stage of international recognition, over a journey of 70 years. Under unfavorable conditions, the time required might have been much greater.

Table I also suggests the importance of co-operation among all scientific organizations, national as well as international, to maintain the systematic quality and classification of all units they employ. In a structure like the mks system there logically can be one and only one unit for each physical quantity.

In regard to the rationalization or nonrationalization of the mks system, discussions on the subject in recent years by the I.E.C. and I.P.U. committees have shown that there is much difference of opinion on the subject. In the E.M.M.U. committee, a small majority has been in favor of rationalization; in the S.U.N. committee, the majority has been more definitely against it. It is clear that any attempt to force a decision one way or the other at the present time would divide the mks adherents

Table II—Electric and Magnetic MKS Units Affected by the Deferred Question of Rationalization

No.	Quantity	Symbol	Name of Rationalized* MKS Unit	Unrationalized Units in One Rationalized Unit
Electrical				
49	Electric flux	ψ	coulomb	
50	Flux density	D	coulomb per square meter	
51	Space permittivity	ϵ_0	farad per meter	
52	Space elastivity	σ_0	meter per farad	
53	Elastance	S	daraf	
Magnetic				
54	Magnetomotive force	$\mathcal{F}$ or M	ampere-turn	4π
55	Magnetizing force	H	ampere-turn per meter	4π
56	Space permeability	μ_0	henry per meter	$1/4\pi$
57	Space reluctivity	ν_0	meter per henry	4π
58	Permeance	$\mathcal{P}$	weber per ampere-turn	$1/4\pi$
59	Reluctance	$\mathcal{R}$	ampere-turn per weber	4π
60	Pole strength	m	weber	$1/4\pi$
61	Magnetic moment (ml)	$\mathcal{M}$	weber-meter	$1/4\pi$
62	Magnetization	$\mathcal{J}$	weber per square meter	$1/4\pi$

* No names have been chosen for unrationalized units.

Table III—Numerical Values of Space Constants in MKS System, Rationalized and Unrationalized

No.	Quantity	Symbol	Rationalized	Unrationalized
	Electrical			
51	Permittivity	ϵ_0	$10^7/4\pi c^2 = 8.854 \times 10^{-12}$	$10^7/c^2 = 1.113 \times 10^{-10}$
52	Elastivity	ϵ_0	$4\pi c^2/10^7 = 1.129 \times 10^{11}$	$c^2/10^7 = 8.988 \times 10^9$
	Magnetic			
56	Permeability	μ_0	$4\pi \times 10^{-7} = 1.257 \times 10^{-6}$	10^{-7}
57	Reluctivity	ν_0	$10^7/4\pi = 0.7958 \times 10^6$	10^7

The value of the transmission velocity c is taken here as 2.998×10^8 meters per second and of c^2 as 8.988×10^{16} (meters per second)^2.

Because of admitted small discrepancies, of a few parts per myriad, between certain existing unit standards and their estimated absolute theoretical values, the future adoption of a fourth fundamental unit to complete the base of the mks system, might alter slightly some of the numerical "constants" in Table III.[16]

into 2 opposing camps, the rationalists and the nonrationalists. It seems desirable, therefore, to avoid the issue and to leave each writer free to follow his own choice, until experience may have crystallized opinion in the different countries. The same question pervades the cgs world today. The classical cgs electric and magnetic systems of Maxwell are unrationalized, while the Heaviside-Lorentz modification is rationalized. The advantages of rationalizing would be that the mks system thus would be made simpler, more logical, and coherent. There is much to be said for having pole strength identical with magnetic flux, so that a pole of one *weber* would give emergence to one *weber* of flux, and a charge of one *coulomb* also give emergence to one *coulomb* of electric flux. Table II shows that there are already enough practical international quantities to give names to all the principal units in the rationalized magnetic circuit, although some of them are cumbersome; whereas it appears to be necessary to adopt a series of new international names, in order to provide for the corresponding needs of the unrationalized circuit. Giorgi himself, in proposing his system (1901–04), rationalized it, as an act of recommendation. On the other hand, the disadvantage of rationalizing the mks system would be to break parallelism, in this direction, with the parent classical cgs system.

As regards the fundamental basis of the mks system, it has been pointed out by several writers that it is a blemish on the system to have (in the *kilo*gram) a basic *prefixed* unit. The mks *meter* is certainly preferable to the cgs *centimeter* in this respect; but the mks *kilogram* is inferior to the cgs *gram*. Theoretically, the basic units of any system should be prefix free. However, the cgs system has given splendid service to the world of science for many years, in spite of the *centimeter*.

Until there has been time to obtain the opinions of the I.C.W.M. and the I.P.U. on the question of choosing the fourth fundamental unit for the mks system, it would be invidious to offer any views on that point. It may be permissible to point out at this time, however, that whatever particular fourth unit may be selected in drawing up the international constitution of the Giorgi system, it is very desirable that each and all of the practical units in the ohm-volt-ampere series shall be identical for both basic and applied physicists. It surely would be a great misfortune to the whole scientific world if in taking up a standard ohm coil, or a standard capacitor, say 20 years hence, it should be necessary to ask whether it was standardized for physicists or electrotechnicians. Some trifling oversight in specifying the fourth fundamental unit might conceivably lead to such a divergence.

Further Developments

Since this paper was written in August 1935, the following important developments have occurred in relation to the Giorgi system:

1. The Consultative Committee on Electricity (C.C.E.) of the International Committee on Weights and Measures (I.C.W.M.) held meetings in Paris-Sèvres September 24–27, 1935, under the chairmanship of Paul Janet, and made an important report on electrical units and standards, covering also the reply to the I.E.C. inquiry concerning the fourth basic unit for the Giorgi system.

2. The I.C.W.M. held meetings in Paris-Sèvres, October 1–8, 1935, adopting this C.C.E. report and authorizing its general publication. It also issued a brief statement for publication concerning its own activities and aims.

3. The S.U.N. committee under Sir Richard Glazebrook has been actively engaged in securing opinions, by correspondence, as to the fourth basic unit in the Giorgi system for reply to the I.E.C. question on that point. The reply is expected to be published shortly.

Translations of the I.C.W.M. statement and of the C.C.E. report (from the original French texts) are given in Appendixes I and II.

Appendix I—Fourth Report of the Consultative Committee on Electricity (Comité Consultatif D'Electricité) to the International Committee of Weights and Measures

(As translated by the author from the original French text released for publication)

After notices sent out by the International Bureau of Weights and Measures, signed by President Paul Janet, the Consultative Committee on Electricity met in Paris, September 24–27, 1935.

At this fourth session of the committee, the following persons were in attendance:

Mr. Paul Janet, president, Membre de l'Institut de France, director of the Laboratoire Central d'Electricité.
Mr. Crittenden of the National Bureau of Standards, Washington.
Mr. Sears of the National Physical Laboratory, Teddington.
Mr. Von Steinwehr of the Physikalisch-Technische Reichsanstalt, Berlin.
Mr. Nagaoka, professor emeritus of the University of Tokyo, representing the Electrotechnical Laboratory of Tokyo.
Mr. Lombardi, director of the Electrotechnical Laboratory of the Royal School of Engineers, Rome.
Mr. Guillaume, director of the International Bureau of Weights and Measures.
Mr. Jouaust of the Laboratoire Central d'Electricité, Paris.

In attendance by invitation were:

Mr. MacLellan, Member of the International Committee of Weights and Measures.
Mr. Vigoureux of the National Physical Laboratory.
Mr. Pérard, subdirector of the Bureau International des Poids et Mesures.
Messrs. Romanowski and Roux of the Bureau International des Poids et Mesures.
Mr Brylinski, president of the French Committee of the I.E.C.
Mr. Kennelly, member of the International Committee of Weights and Measures, prevented from attending by ill health.

On opening the session, President Janet outlined the conditions under which the committee was convened:

The International Committtee, at its last meeting, decided on a recommendation from the Consultative Committee:

"That the Consultative Committee should request the laboratories it represents

to appoint members intended to form a technical subcommittee charged with the duty of making comparisons between their standards of resistance and voltage with all necessary precision, and to assign their values in terms of absolute units."

"That the technical subcommittee should meet at the International Bureau of Weights and Measures in 1935."

"That the decisions of the subcommittee should be examined by the Consultative Committee, before being transmitted to the International Committee."

In conformity with the above decision of the International Committee, Mr. Janet corresponded during the last 3 months of 1934 with the national laboratories represented on the Consultative Committee, requesting each to assign a member to the technical subcommittee, and to propose a date for the meeting of the subcommittee.

The majority of the replies showed that the tasks undertaken in the different laboratories for the determination in absolute units were not far enough advanced to permit of assigning to the regular laboratory standards their values in terms of the absolute system, that under these circumstances the work of the members of the technical subcommittee would be quite ineffective and would be limited to intercomparisons between the standards of the different laboratories, these intercomparisons being effected by conveyance between laboratories; these being either the national physical laboratories, or the International Bureau of Weights and Measures.

Under these conditions, Mr. Janet considered it necessary to postpone the meeting of the technical subcommittee, and to limit operations to a meeting of the Consultative Committee a few days in advance of the International Committee.

The object of the present meeting was therefore to examine the degree of progress in the determination of the absolute units, and the discussion of the precision of the methods employed; so that each member might profit from the experience of his colleagues.

The question of the realization of secondary standards presented itself, especially the nature of the metal to be employed for the construction of secondary standards of the ohm; also the question of the temperature to which they should be referred, might be considered.

In particular, Mr. Janet insisted upon the necessity for fixing at the present session, the date, if possible, for calling the meeting of the technical subcommittee and arranging its program. The fixing of this date was especially called for in a letter received from the Electrotechnical Laboratory of Tokyo.

Mr. Janet pointed out that he had also received information from Mr. Kennelly, that the International Electrotechnical Commission had adopted the mks system, called the Giorgi System, involving the establishment, in addition to the 3 classical fundamental units of length, mass, and time, a fourth fundamental unit, relating to an electrical magnitude, and that the Electrotechnical Commission desired to have the opinion of the Consultative Committee, as to the electrical magnitude which would be desirable to select for this unit.

Mr. Janet considered that, with certain reservations, this question might be placed on the agenda of the Consultative Committee. A report prepared by Mr. Lombardi, a member of the Consultative Committee and also of the International Electrotechnical Commission, might serve as the basis for discussion.

We may now summarize the results attained by the Consultative Committee:

I. Absolute Units

Only 2 laboratories have completed their tasks, namely, the National Bureau of Standards and the National Physical Laboratory, and only one of these investigations has taken the form of a complete publication; i. e., the determination of the ampere, made at the N.B.S. by Messrs. H. and R. Curtis.

The other laboratories (Physikalisch-Technische Reicheanstalt, Electrotechnical Laboratory, Laboratoire Central d'Electricité) have confined themselves to presenting certain notes on the methods employed. The representative of the Electrotechnical Laboratory, Mr. Nagaoka, announced that his establishment would shortly be able to report the result of its measurements. The representatives of the P.T.R. and L.C.E. have been unable to make any similar statement.

(*a*) *Absolute Value of the Unit of Resistance.* The National Bureau of Standards give the following result:

1 international ohm N.B.S. = 1.000 450 absolute ohm

The determination of the absolute ohm had been made at the National Physical Laboratory by 2 methods:

The Lorenz method gave:

1 international ohm N.P.L. = 1.000 50 ± 0.000 02 absolute ohm

By the Campbell method:

1 international ohm N.P.L. = 1.000 47 ± 0.000 02 absolute ohm

In the opinion of the representative of the N.P.L., in view of the precision of the 2 methods, it seemed desirable to take the mean of the 2 above values, and to take as the N.P.L. result:

1 international ohm N.P.L. = 1.000 49 absolute ohm

The above are the only results definitely communicated to the Consultative Committee. The difference of the order of a few millionths between the international N.P.L. ohm and the international N.B.S. ohm, make these results directly comparable.

Moreover, the representative of the Physikalisch-Technische Reichsanstalt observed that certain corrections should be applied to the old measurements of Grueneisen and Giebe, which would lead to the following:

1 international ohm P.T.R. = 1.000 49 absolute ohm

All the above results seem to indicate that one may hope for a knowledge of the ratio of the international ohm to the absolute ohm, when all the laboratories shall have finished their task, to a precision of $\pm 2 \times 10^{-5}$.

(*b*) *Absolute Value of the Unit of Current Strength.* Only 2 laboratories, the N.B.S. and the N.P.L. have finished their researches. The results obtained, expressed in the form used in the reports to the Committee are:

Bureau of Standards

1 international ampere N.B.S. = 0.999 926 absolute ampere

National Physical Laboratory

1 absolute ampere = 1.000 14 international ampere N.P.L.

If account is taken of the difference which exists in the realization of the international ampere in the 2 laboratories, these 2 results differ by 9 hundred-thousandths.

The agreement in the determination of the unit of current strength is thus much less close than in the determination of the unit of resistance.

Discussion of the methods of measurement employed led to an interesting remark from the representative of the P.T.R., on the difficulty of calculating, for the Balance of Lord Rayleigh, the correction due to the volume of the bobbin windings. He observed that in the work of H. and R. Curtis, it was possible to arrive at 2 different values for this correction, according to the method used in measuring the windings.

Reference was made to a recent work of Sir Richard Glazebrook, recently appearing in the *Proceedings* of the Royal Society, *A*, volume 150, 1935, page 487, setting forth the same difficulty.

Mr. Von Steinwehr also mentioned that in order to remedy this difficulty, the Reichsanstalt had given up the method of winding the coils of the Rayleigh balance with wire, in favor of a method of band winding. The necessity of redetermining the radii ratio for these new coils, was one of the reasons for the Reichsanstalt not yet being ready to furnish results.

Mr. Crittenden recognized the importance of Mr. Von Steinwehr's remark, and indicated that at the N.B.S. they had undertaken in their Rayleigh type of electro-dynamometer, the construction of new coils, one made with bands, and the other with but a single layer of wire.

In any case, it would seem that this uncertainty as to a correction does not completely explain the difference between the N.B.S. and the N.P.L.

The committee, while expressing its regrets for the technical difficulties that had hindered the completion of its undertaking, felt glad that the meeting had given rise to a suggestive discussion for all who are engaged in the determination of units to absolute measure.

II. Present Representation of the Units

The value of the international ohm is maintained in the laboratories by means of manganin coils. The resistance of these coils is not constant, but varies slowly as a function of time.

Is it possible to find for the construction of these coils, a metal free from such variations?

A report from the National Physical Laboratory, presented and commented on by Mr. Vigoureux, described the experiments made

in that establishment, for the production of ohm standards in platinum.

Having given the value of the temperature coefficient of resistivity for platinum, these resistances should be used at a practically well determined temperature, that of melting ice.

Mr. Pérard drew the committee's attention to the difficulty which may exist in keeping such resistances precisely at the temperature of melting ice. Mr. Von Steinwehr alluded to the use of the "triple point."

However that may be, many years must elapse before one can be assured of the constancy of these resistances.

The Committee could therefore only felicitate the National Physical Laboratory upon the undertaking of this research.

Questions were asked of the representative of the National Bureau of Standards concerning a new alloy studied in that establishment. Mr. Von Steinwehr remarked that studies had also been made at the P.T.R. on this chromium-gold alloy, and that it had been possible to obtain specimens whose temperature coefficient between 20 and 30 degrees centigrade was almost zero.

But there is still no assurance as to the stability of this alloy, so that it will still be necessary for a long time to come, to construct secondary ohm standards in manganin.

The committee listened also with interest to the account given by Mr. Vigoureux of the method employed at the N.P.L. in the search for standards having a resistance as nearly constant as possible.

A considerable part of the variations manifested by these resistances is attributed to the layer of lacquer which covers them.

At the N.P.L., the manganin wire, rolled under the form which it will occupy on its supporting core, is annealed at 500 degrees, treated with acid, and then placed on its supporting core without being subjected to any mechanical deformation. The layer of lacquer which is intended to protect the wire against the action of the petroleum bath in which it is submerged, is made as thin as possible.

III. Comparison of the Standards From Different Laboratories

Mr. Pérard drew direct attention to the fact that the reference temperature of the units should be standardized. In European countries, this temperature is 20 degrees centigrade; but in the United States and Japan, it is 25 degrees centigrade.

Mr. Pérard requested that this temperature should be fixed, and proposed 20 degrees centigrade.

Mr. Crittenden (United States), and Mr. Nagaoka (Japan), pointed out that in their countries, the temperature was close to 25 degrees centigrade. They indicated the difficulty there would be in keeping the standards at a temperature lower than the ambient temperature. Nevertheless they agreed to the temperature of 20 degrees centigrade for standards intended for international comparison.

This agreement was recorded in a resolution. (See appended Resolution 1, at the end of the report.)

The transport of standards from one laboratory to another, involves certain difficulties.

In a note sent to the committee, the Electrotechnical Laboratory of Tokyo described the boxes which it utilized for the transport of standard cells.

Certain laboratory representatives pointed out, however, the difficulties that customhouse administrations had given them, and asked whether it would not be possible to use the consular bag (*valise diplomatique*) for standards intended for international comparison.

It was decided to ask the president of the International Committee of Weights and Measures to take the steps necessary for having standards intended for international comparison accepted for transport in consular bags (Resolution 2).

Messrs. Pérard, Romanowski, and Roux reported on comparisons made at the International Bureau of Weights and Measures, of standards of resistance and of electromotive force from laboratories represented in the membership of the Committee.

The results were rendered comparable by taking for the mean value of the units, the arithmetical mean of the units in the 6 laboratories, and by indicating the difference between the unit of each laboratory and this mean.

The representative of the Laboratoire Central, Mr. Jouaust, stated that the units of the establishment to which he belonged differed the most, particularly as regards the mean value of the resistance units.

The cause of these divergences of 7 hundred-thousandths had not, of course, escaped him. In view of accidental error, he asserted that the Laboratoire Central intends to modify the value of its standards, so as to bring them into agreement with those of the other 5 laboratories.

By employing only these 5 values, in the establishment of the average, the difference between the resistance units of these laboratories and their average would then appear as follows (at the date of March 15, 1935):

P.T.R.	+ 9.8 millionths
N.B.S.	− 5.5 millionths
N.P.L.	− 3.6 millionths
E.T.L.	−11.2 millionths
U.R.S.S.	+10.6 millionths

The above differences are small; but nevertheless it may be necessary to take them into account in certain cases. In consequence, Mr. Jouaust asked if the different laboratories could not follow the example set by the Laboratoire Central and modify the value of their unit for the purpose of standardization.

This proposition met with some opposition. The values of the units being due to be changed shortly, to be expressed in absolute units, certain members of the committee considered that it would be preferable to await that date before proceeding to the proposed standardization.

Others did not consider themselves authorized to accept any change in a standard of their country, however small.

Nevertheless, the Committee concluded by adopting resolution 4.

IV. Fixing the Date of Meeting for the Technical Subcommittee

President Janet renewed attention to the agreement arrived at on this matter by the Consultative Committee at its last session.

He insisted on the necessity of fixing this date for the subcommittee, pointing out that Japan proposed that this date should be set between June and December 1936. He also asked the committee to specify the duties to be assigned to the subcommittee.

All the members agreed that the 2 parts of the program indicated for the subcommittee still hold, and that the comparisons appearing in its program were only set up for the purpose of immediately fixing the values in absolute units.

The 2 functions of the subcommittee are inseparable.

It was unanimously agreed that it would only be possible to convene the subcommittee after a sufficient lapse of time to enable its members to carry out the comparisons themselves. Only certain ones could be effected. The principal task of the subcommittee will therefore be to discuss the values found and assign weights to them.

The setting of the date for the subcommittee gave rise to some remarks from Mr. Von Steinwehr, who wished to leave the date to the president with power to fix it when he judged the work of the laboratories was sufficiently far advanced. It was finally decided to set the date at the beginning of the year 1937 (Resolution 3).

V. Examination of the Question Raised by the International Electrotechnical Commission Relative to the MKS System

In opening the meeting, President Janet explained the conditions under which the matter was laid before the Consultative Committee.

The Consultative Committee was appointed to inform the International Committee of Weights and Measures on questions relating to standards in the electrical field and in adjacent subjects.

In giving advice to any other organization, it would be going outside the limits assigned to it.

The International Electrotechnical Commission should therefore have addressed its question to the International Committee.

But it is almost self evident that the International Committee would wish to have the opinion of the Consultative Committee. But since the session of the latter preceded that of the International Committee, if the question had been transmitted directly to the International Committee, it would have been impossible to bring it before the Consulting Committee without a rather long delay.

Under these conditions, with the approval of Mr. Volterra, president of the International Committee, Mr. Janet considered himself justified in placing the matter on the agenda of the Consultative Committee, it being understood that any opinion reached would be forwarded to the International Committee, which is alone competent to reply. The president asked the members of the Consultative Committee if they approved of the procedure he suggested.

This procedure was unanimously adopted.

On the other hand, the Consultative Committee forwarded to the International Committee a series of proposals anonymously received,

relating to questions of notation and nomenclature. The Committee then proceeded to an examination of the question presented by the I.E.C.

The question is set forth in a communication from Mr. Lombardi. Moreover, the members of the Committee were in possession of various documents on the subject, emanating from Sir Richard Glazebrook and from Messrs. Kennelly, Campbell, Giorgi, Emde, Wallot, and Bennett.

Mr. Lombardi presented his memoir with comments. From this presentation, it appears that the original form of the mks system, as given by Mr. Giorgi and strongly endorsed by Mr. Campbell, should comprise 4 fundamental units of which only 3, the meter, the kilogram, and the second were originally indicated. The fourth should now be fixed in such a manner as to permit of incorporation into a coherent system the well-known practical units of current, electric quantity, electromotive force, capacitance, resistance, inductance, and magnetic flux. Messrs. Giorgi and Campbell have proposed the international ohm for the fourth unit, in view of the large number of its existing standards; but their proposal could not be entertained by the International Electrotechnical Commission after the decision by the International Commission of Weights and Measures, ratified by the General Conference of 1933, to substitute the absolute system for the international system.

The I.E.C. did not consider that it could adopt the permeability of space unchanged since it has not the essential character of a unit and is not susceptible of being embodied in a standard, but assumes different values in the rationalized and nonrationalized mks system between which no definite choice has yet been made, by international agreement. For this reason the I.E.C. considered that the choice should be limited to the 7 practical units above referred to, which from a theoretical standpoint are equivalent in this regard, and which being dependent on the absolute cgs system are necessarily related to the unity value of space permeability. With reference to the ease of construction and comparison of standards, Mr. Lombardi has shown in his paper some preference for the unit of resistance without losing sight of the fact that certain among the other units might possess similar advantages, and that the creation of a primary standard could only be effected to an approximation quite sufficient for practice without possessing the absolute invariability attributable to the other fundamental units of length, mass, and time selected arbitrarily and represented to some extent conventionally by concrete standards maintained at Breteuil.

Mr. Janet drew the attention of the committee to the opinion of Sir Richard Glazebrook, president of the S.U.N. commission, definitely expressing the opinion that the fourth unit should be the magnetic permeability of vacuum, to which in the mks system would be given the value 10^{-7}; so that the electrical units of the mks system would be the practical units of the absolute system. He also read a letter from Sir Joseph Petavel, stating that the executive committee of the National Physical Laboratory supported this proposal.

Mr. Sears observed that in making a selection of a fourth unit at the request of the I.E.C., the committee accepted by implication the mks system, so far as concerns the electrical units. But the mks system is essentially the same as the cgs system, there being only a difference of powers of 10.

Therefore the committee should not assign any superiority of choice, and should manifest no preference.

By a large majority, the committee decided for a selection of the permeability of space. Mr. Nagaoka, representing Japan, abstained, and Mr. Crittenden stated that his opinion was a personal one.

On the observation by Mr. Lombardi, that the solution indicated by the committee was aside from that sought by the I.E.C., and that the committee should only select from among the 7 units already referred to, the president consulted the committee anew under the following form: If the solution of fixing the value of space permeability were set aside, which electrical unit would you propose to introduce for definition into the mks system?

By the feeble majority of 4 votes against 3 and 1 abstention, the committee declared for the ohm, after a protest from one of the members at the limitation imposed on the opinion asked for, in the form of the question raised by the I.E.C., and finally a draft opinion drawn up by Messrs. Pérard and Jouaust, appearing at the end of the present report, was approved by the committee. (Resolution 5a.)

The day after the above discussion, Mr. Sears read a note which he had drawn up. To a question from one of the members, he explained that the values given in paragraph 5 below only represent an ideal series of derived units from among a number of possibilities, and that this plan should not be taken as definitely assigning the procedure to be followed in the practical development of standards.

He showed by way of example, the possibility of deriving, practically, all of the electrical units from the construction of an inductance.

The proposals of Mr. Sears, which are not in opposition to the preceding decisions of the committee, were much appreciated by the members, who expressed the opinion that Mr. Sears's note, whose text is appended (Resolution 5b) should be transmitted to the International Committee, along with the opinions previously expressed.

VI. Visits

The members of the committee were invited by Mr. Janet to visit the rooms of the Laboratoire Central d'Electricité, where researches are made on electrical units, and to examine the apparatus in course of construction for the determination of the ohm in absolute measure.

Before concluding, the committee voted its thanks to Mr. Janet for the manner in which he had directed the discussions, and to Mr. Perard for his care in securing the successful operation of the sessions, and especially for assuring the advance distribution of the documents needed in the committee's work. Mr. Jouaust, of the Laboratoire Central d'Electricité, was appointed secretary for the session of 1935.

Resolutions Voted by the Consultative Committee on Electricity in Its Session of September 1935

Resolution 1. For international comparison of electrical standards, the values reported will be those corresponding to a temperature of 20 degrees centigrade, unless an exception is justified.

Resolution 2. The Consultative Committee requests the International Committee to pass a resolution, which should be transmitted to the interested governments, to the end that delicate instruments, and especially electrical standards, may be transported through the medium of the consular bag, (*valise diplomatique*), so as to avoid opening at customhouses, full liberty being, however, allowed to those laboratories that may prefer some other mode of conveyance

Resolution 3. The Consultative Committee decides to fix at first the meeting of the technical subcommittee at the beginning of the year 1937. The Consultative Committee will then meet in the course of that year, a few days before the regular session of the International Committee of Weights and Measures.

Resolution 4. The Consultative Committee on Electricity records with satisfaction the decision taken by the Laboratoire Central d'Electricité, to modify forthwith the magnitude of its unit of electrical resistance, as well as that of its unit of electromotive force, by some few hundred-thousandths, in order to bring them into agreement respectively with the corresponding averages of the values for these units as they are maintained in the 5 other great national laboratories: The Physikalisch Technische Reichsanstalt, the National Physical Laboratory, the National Bureau of Standards, the Electrotechnical Laboratory of Tokyo, and the Metrological Institute of the U.R.S.S.

The Consultative Committee: Considering in that case how very small would be the deviations of the ohm unit and volt unit in each of the 5 laboratories from the respective averages above mentioned, the greatest deviation for either the ohm or volt scarcely reaching 11 millionths; and considering the great importance which would be presented by unification of electrical units in the near future in all countries; suggests to the different laboratories, each acting for itself, and as soon as an opportunity may be offered, to adopt for the magnitude of the ohm and for the magnitude of the volt, respectively, the values defined by the above-mentioned averages.

Resolution 5a. The Consultative Committee on Electricity, upon a question from the International Electrotechnical Commission, relating to the most suitable choice of an electric unit in the mks system, desires first to observe, that according to the Rules of its Constitution, it can only communicate with the International Committee of Weights and Measures. Nevertheless, with the consent of the president of the International Committee, it decided to consider the question presented, the opinion reached being reported to that committee, which alone is competent to make reply.

The Consultative Committee first desires to state that a distinct majority of its members present expressed the opinion that the link between the mechanical and electrical units should be effected by

assigning the value 10^{-7} in an unrationalized mks system, and $4\pi \cdot 10^{-7}$ in a rationalized system, to what is commonly called the permeability of space.

As to the remark that the form in which the question was put limited the choice to the 7 practical units, coulomb, ampere, volt, ohm, henry, farad and weber, the committee unanimously considered that the choice should only fall either on the ampere, defined as 10^{-1} of the cgs electromagnetic unit, or on the ohm, defined as 10^9 cgs electromagnetic units of resistance, these 2 magnitudes, corresponding to the values of 10^{-7} or $4\pi \cdot 10^{-7}$ for space permeability, as above mentioned.

By vote, the committee pronounced in favor of the ohm against the ampere by the small majority of 4 against 3, and 1 abstention.

Resolution 5b. In the following session, Mr. Sears presented to the Consultative Committee the following document:*

Note presented by Mr. Sears:

1. The electrical unit magnitudes of the system sanctioned by the General Conference in 1933, are identical with those of the practical units derived from the classical cgs system of Maxwell.

2. These systems are based essentially on the conception of a constant value for space permeability, this value being in the Maxwell system numerically equal to 1. For the mks system unrationalized, this permeability would have the value 10^{-7}, and for the mks system rationalized, the value $4\pi \cdot 10^{-7}$. In each of these systems the coefficient A^* is taken as a purely numerical constant, to which is assigned the value unity so that it no longer appears in the equations. The principal units of the 2 mks systems would thus be the same as those of the practical system, the adoption of which was sanctioned by the General Conference of 1933.

3. The various electrical units can all be derived from this conception, by means of equations representing physical laws, and with suitably selected constants. In principle, no one of these units has priority over the rest.

4. The definitions adopted for the principal electromagnetic units might be the following:

(*a*) *Ampere.* The ampere is the constant current which, maintained in 2 parallel rectilinear conductors of infinite length, separated by a distance of 1 meter, produces between these conductors a force equal to 2×10^{-7} mks units of force per meter of length.

(*b*) *Coulomb.* The coulomb is the quantity of electricity transported each second by a current of one ampere.

(*c*) *Volt.* The volt is the difference of electrical potential between 2 points of a conducting wire carrying a constant current of one ampere, when the power dissipated between these points is equal to one mks unit of power (watt).

(*d*) *Ohm.* The ohm is the electrical resistance between 2 points of a conductor, when a constant difference of potential of one volt, applied between these points, produces in the conductor a current of one ampere, the conductor not being the seat of an electromotive force.

(*e*) *Weber.* The weber is the magnetic flux which, traversing a circuit of a single turn, would produce an electromotive force of one volt, if brought to zero in one second with uniform diminution.

(*f*) *Henry.* The henry is the inductance of a closed circuit in which an electromotive force of one volt is produced when the electric current traversing the circuit varies uniformly at the rate of one ampere per second.

(*g*) *Farad.* The farad is the electrical capacitance of a capacitor between the armatures of which appears an electrical difference of potential of one volt, when charged with one coulomb of electric quantity.

5. These units may be derived as follows:

Ampere	I	Ampere	I
Coulomb	Q	Ampere-second	IT
Volt	E	Watt per ampere	PI^{-1}
Ohm	R	Volt per ampere	EI^{-1}
Weber		Volt-second	ET
Henry	L	Volt-second per ampere	$EI^{-1}T$
Farad	C	Ampere-second per volt	$E^{-1}IT$

* In the course of the meetings of the International Committee of Weights and Measures, Mr. Sears asked permission to insert certain additions at the head of this note in conformity with suggestions made to him by Sir Richard Glazebrook, these additions not affecting the general meaning of the note. The following paragraph has therefore been added:

Electromagnetic theory leads to the relation

$$A^2 = \mu_0 \times k_0 \times c^2$$

between the 4 quantities there appearing. Of these,

c is the velocity of the propagation of electromagnetic waves in vacuum

μ_0 is the magnetic permeability of a vacuum

k_0 is the permittivity of a vacuum

A is a constant coefficient

In order to have a theoretically complete system of electrical units, it is necessary to assign independent values to 2 of the 3 quantities A, μ_0, and k_0. The third will then be determined by the above relation. In each of these systems the coefficient A is taken as a purely numerical constant to which is assigned the value given above so that it no longer appears in the equations. The principal units of the 2 mks systems would thus be the same as those of the practical system, the adoption of which was sanctioned by the general conference of 1933.

6. For the regular practice of laboratory measurements, at least 2 primary standards of reference are needed and may be conveniently chosen among the various units. The 2 reference standards should be the ohm and volt, the former being produced under the form of coils and the latter under the form of Weston cells.

7. For theoretical questions, such as the dimensional equations connecting the various units, the most convenient unit as a starting point for the derivation of the entire system of electromagnetic units appears to be the ampere, which is directly connected by simple relations not only with the fundamental base of the system; but also with the other electric and magnetic magnitudes, and which, moreover, has the advantage of eliminating fractional powers from the dimensional equations. In this respect, the ampere should be preferred as the fourth unit, in order to complete the mks system of electromagnetic units.

This document met with a unanimously favorable reception in the Consultative Committee, which decided to transmit it to the International Committee without, however, finding it necessary to alter its vote of the previous day.

Appendix II—Intended Substitution of the Practical Absolute System of Electrical Units for the Existing International System

The following information (as translated from the original French text) was approved for general publication by the International Committee of Weights and Measures at its meeting in October 1935, at Sevres, France.

1. In accordance with the authority and responsibility placed upon it by the General Conference of Weights and Measures in 1933, the International Committee of Weights and Measures has decided that the actual substitution of the absolute system of electrical units for the international system shall take place on January 1, 1940.

2. In collaboration with the national physical laboratories, the committee is actively engaged in establishing the ratios between the international units and the corresponding practical absolute units.

3. The committee directs attention to the fact that it is not at all necessary for any existing electrical standard to be altered or modified with a view to making its actual value conform with the new units. For the majority of engineering applications, the old values of the international standards will be sufficiently close to the new for no change, even of a numerical nature, to be required. If for any special reason a higher precision is necessary, numerical corrections can always be applied.

4. The following table gives a provisional list of the ratios of the international units to the corresponding practical absolute units, taken to the fourth decimal place. Since differences affecting the fifth decimal place exist between the standards of the international units held by the various national laboratories and also because all the laboratories which have undertaken determinations of the values of their standards in absolute measure have not yet obtained final results, the committee does not consider it desirable for the present to seek a higher precision. At the same time, it hopes that it will be possible to extend the table of these ratios, with a close approximation to the fifth decimal place, well before the date fixed for the actual substitution of the practical absolute system for the international system.

Table

1	Ampere	international	= 0.999 9	Ampere	absolute
1	Coulomb	international	= 0.999 9	Coulomb	absolute
1	Ohm	international	= 1.000 5	Ohm	absolute
1	Volt	international	= 1.000 4	Volt	absolute
1	Henry	international	= 1.000 5	Henry	absolute
1	Farad	international	= 0.999 5	Farad	absolute
1	Weber	international	= 1.000 4	Weber	absolute
1	Watt	international	= 1.000 3	Watt	absolute
1	Joule	international	= 1.000 3	Joule	absolute

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Pull-In Characteristics of Synchronous Motors

The differential analyzer has proved its worth in solving various types of difficult problems, of which the determination of the pull-in characteristics of salient pole synchronous motors is typical, but even with the aid of this device it has been necessary in solving this problem to make several simplifying assumptions. The differential analyzer recently completed at the University of Pennsylvania, however, is sufficiently comprehensive in design so that few assumptions are necessary, and the major electrical transients and mechanical forces may be taken into account. Typical solutions obtained by means of this analyzer are presented herewith, together with practical pulling-into-step criteria.

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CONSIDERABLE attention has been devoted in recent years to the problem of pulling synchronous motors into step. The difficulties involved in the solution of this problem by past available means have necessitated several simplifying assumptions which have severely limited the application of the results. The recent completion of a large differential analyzer at the University of Pennsylvania has made it possible, for the first time to the authors' knowledge, to obtain solutions of the phenomena of pulling into step, taking into account the major electrical transients and mechanical forces. Typical solutions given by this differential analyzer are presented in this paper, together with practical criteria for predetermining with engineering accuracy whether a given motor will or will not pull into step under specified conditions. The important points brought out in the paper are briefly:

1. A method is outlined whereby specific solutions of the pull-in problem, and similar problems involving the balanced 3 phase characteristics of a machine near synchronism (i. e., synchronizing out of phase, stability, hunting, etc.) may be secured accurately through the use of the differential analyzer.

2. Consideration of the synchronizing performance of motors must be based upon the electrical as well as the mechanical transients.

3. Motors with long time constants are sensitive to the angle of application of excitation, the most favorable angle being that where the field flux linkages are at a positive maximum. This corresponds with the point at which the field current crosses the zero axis, increasing in the positive direction.

4. The pull-in characteristic of a motor when excitation is applied at the most favorable angle is determined largely by the field flux linkages existing at that instant.

5. The average slip from which the motor must pull into step when excitation is applied under the most unfavorable conditions is determined by the net average torque available with the field fully excited and the motor operating out of synchronism.

6. The pull-in performance of motors for the most favorable and unfavorable angles at which the field excitation may be applied, can be calculated with a reasonable degree of accuracy by use of the criteria presented herein.

Nature of Past Investigations

In attacking this problem, other investigators[9,10] have assumed that the synchronous motor might be considered as 2 electrically independent machines: one developing only synchronous and reluctance torques without electrical transients other than that represented by an exponential rate of increase of synchronous torque; the other, an induction motor developing torque as a function of slip and angle. The effect of armature circuit resistance has been neglected, as has also the effect of rate of change of slip upon electrical torque. These investigations resulted in the establishment of empirical factors which were checked by laboratory tests on relatively small machines.

Predictions based upon these factors indicate that the angle at which excitation is applied should make no material difference in the pulling into step performance of a synchronous motor having a long time constant. In actual practice it has been found that the performance of such motors is influenced materially by the angle of application of the excitation.[12]

Approximately 3 years ago, in studying this problem, it was concluded that the synchronous and induction motor components of torque could not be separated entirely, and that it was of importance, in considering the synchronous component of torque, to determine the field linkages at the time the excitation was applied, and not merely assume that the synchronous component built up exponentially from zero. A few step-by-step swing curves were made, taking into account the electrical transients. These calculations indicated that it was, indeed, necessary to consider the linkages in the field circuit that were present at the time of applying excitation. The step-by-step method was so laborious, however, that, beyond proving the importance of considering the major electrical transients, little progress could be made. The nature of the problem was so involved

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9. For all numbered references see list at end of paper.

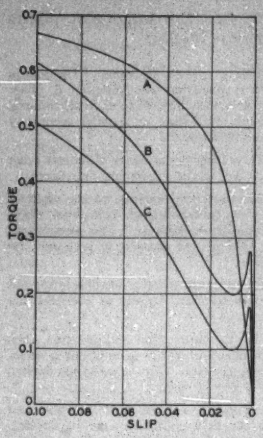

Fig. 1. Average induction motor torque for speeds higher than 90 per cent synchronous speed

Curve *A*—With discharge resistance 8.5 times field resistance
Curve *B*—With field short-circuited
Curve C—With rated field excitation

that the differential analyzers then available could not be used for its solution.

Curve *A* of figure 1 shows the induction motor torque-slip curve of a typical machine for the region near synchronism. It indicates that the relationship between slip and torque is approximately linear at speeds greater than 98 per cent synchronous speed, but departs materially from this for greater values of slip. An examination of curve *B* indicates that it is necessary to consider the modification in the induction motor torque once the discharge resistor is removed from the field circuit. This subject has been discussed in previous literature and needs no further explanation here.[13] The important point is that if the motor does not pull into step immediately but slips several poles, the induction motor torque will be considerably less than that previously developed by the motor with the discharge resistor in the circuit. This will result in an increase in average slip. A third effect is indicated by curve *C* which shows the net average torque developed when the motor is operating at a constant slip with full field excitation. The reduction in torque from curve *B* to curve *C* is caused by the losses in the armature circuit resistance resulting from the applied excitation.

In making the step-by-step calculations it was noted that the induction motor performance was modified when there was a relatively high rate of change of slip. This characteristic has been observed in induction motors that were accelerated on full voltage, without retarding intertia (WR^2) or load, with a rate of acceleration such that the speed of the machines momentarily exceeded synchronous speed. The duration of the electrical transients was greater than the time required for the motor to pass from, say, 5 per cent to zero slip, thus producing a persistence of motor torque above synchronous speed for a short period of time. Identical phenomena were observed in some of the solutions obtained by use of the differential analyzer.

Purpose and Scope of Present Investigation

The purpose of this investigation is to develop and present the results of a more general approach to the synchronizing problem than heretofore has been available. Because of the number of variables involved in such an approach, a tremendous number of solutions would be required to determine families of curves giving the exact characteristics of all synchronous machines. Accordingly, such solutions were secured for particular machines as would provide a basis for the development of suitable criteria for synchronizing under favorable and unfavorable conditions. These solutions encompassed variations in load torque, inertia, excitation, and angle of applying excitation.

Method of Using a Differential Analyzer in Solving the Pull-In Problem

The method of solution was based upon the generalized 2 reaction theory of synchronous machine performance, using equations presented by Park,[4] with such modifications as were expedient to put them in a form suitable for solution by means of the analyzer. The equations, as given in appendix I, are:

$$e \sin \delta = p\psi_d - ri_d - \psi_q - \psi_q \frac{d\delta}{dt} \tag{1}$$

$$e \cos \delta = p\psi_q - ri_q + \psi_d + \psi_d \frac{d\delta}{dt} \tag{2}$$

$$\psi_d = -x_d i_d + \psi_{d1} + \psi_{d2} \tag{9}$$

$$\psi_{d1} = x_d A_{d1} i_d - \alpha_{d1} \int (\psi_{d1} - x_d B_{d1} E_f d1) dt \tag{12}$$

$$\psi_{d2} = x_d A_{d2} i_d - \alpha_{d2} \int (\psi_{d2} - x_d B_{d2} E_f d1) dt \tag{13}$$

$$\psi_q = -x_q'' i_q - x_q \alpha_{q1} \int i_q dt - \alpha_{q1} \int \psi_q dt \tag{22}$$

$$4\pi f H \frac{d\delta}{dt} = -T_L t - \int i_q \psi_d dt + \int i_d \psi_q dt \tag{23}$$

These equations include the effect of armature circuit resistance. Their use assumes that the machine is "ideal" as defined by Park,[4] and that the amortisseur winding can be represented with reasonable accuracy by one short-circuited winding in the direct axis and one in the quadrature axis.

The analyzer was arranged to secure the simultaneous solution of these equations. The set-up is shown in simplified diagrammatic form in figure 2. All factors such as scales, signs, and certain mechanical considerations involved in forcing the solution of the numerous simultaneous equations are omitted from this diagram. It is believed that a complete description of the functioning of the analyzer in solving these equations is unnecessary here as the subject has been covered adequately in previous literature.[8,10,11] It may be well, however, to call attention to several specific features.

The multipliers, which are inherently capable of less accuracy than the integrators, were used only in securing the quantities $\psi_q(d\delta/dt)$ and $\psi_d(d\delta/dt)$, which are small near synchronism.

An interesting feature of the set-up is that in-

volving the quantities $p\psi_d$ and $p\psi_q$, which were secured through the use of 2 integrators. Operators stationed at each of these integrators introduced $p\psi_d$ and $p\psi_q$ into the machine solution. These quantities then were integrated and, when the operators were introducing them correctly into the equations, their integrals were equal to ψ_d and ψ_q, respectively. Comparisons of these equalities were made by means of 2 differential gear units, or adders. The third element of each of the adders merely indicated whether the 2 quantities introduced into the the adder were equal in magnitude and of proper sign. The operators then manipulated the cranks in such a manner that the indicating elements of the adders remained stationary and thus correctly generated $p\psi_d$ and $p\psi_q$. The accuracy of this method may be subject to some question, but here again the quantities introduced were small near synchronism so that errors in them had an insignificant effect on the solution.

Excitation voltage was introduced into the solutions, as a unit function, by adding the quantities $x_d B_{d1} E_{fd} 1$ and $x_d B_{d2} E_{fd} 1$ to the integrands of equations 12 and 13, respectively. At the same time, gear trains were modified to take account of the change in machine constants necessitated by the reduction in field circuit resistance.

It is of interest to note that the free quantity in each equation corresponds to a dependent variable in the actual synchronous machine performance; that is, in equations 1 and 2 all quantities except ψ_d and ψ_q actually are driven either from integrator units, the time motor, or cranks turned by the machine operators.

In equations 9, 12, and 13, the free quantity is i_d, assuming here that ψ_d is driven from equation 2. In a similar manner ψ_q results from equation 1 and i_q from equation 22. Thus, the quantities determined by the foregoing equations are primarily the direct and quadrature axis armature linkages and the corresponding currents. These are used in equation 23 in determining the electrical torque, which, together with an assumed constant load torque, determines the slip, $d\delta/dt$. Integration of this quantity gives the angle δ which in turn is used on the input tables in determining, by the sine and cosine curves, the voltage applied to each axis.

The equations as derived and placed upon the machine take account of armature circuit resistance, a factor that seldom is considered correctly in machine calculations under transient conditions, because of the difficulties involved. Should it be desired to neglect the effect of armature circuit resistance, considerable simplification in analyzer operation may be made. Under this condition $e \sin \delta = -\psi_q$ and $e \cos \delta = \psi_d$, and, accordingly, the operation of 2 integrators and the 2 multipliers will not be required. A few solutions were obtained in this manner to determine whether the amount of resistance included introduced an appreciable effect. When it was found that such was the case, all further solutions were made, including the effect of normal values of armature circuit resistance.

The correctness and accuracy of the solutions obtained were checked in several ways. The average values of slip obtained, on runs corresponding to induction motor operation, agreed closely with the values of slip calculated in the conventional manner

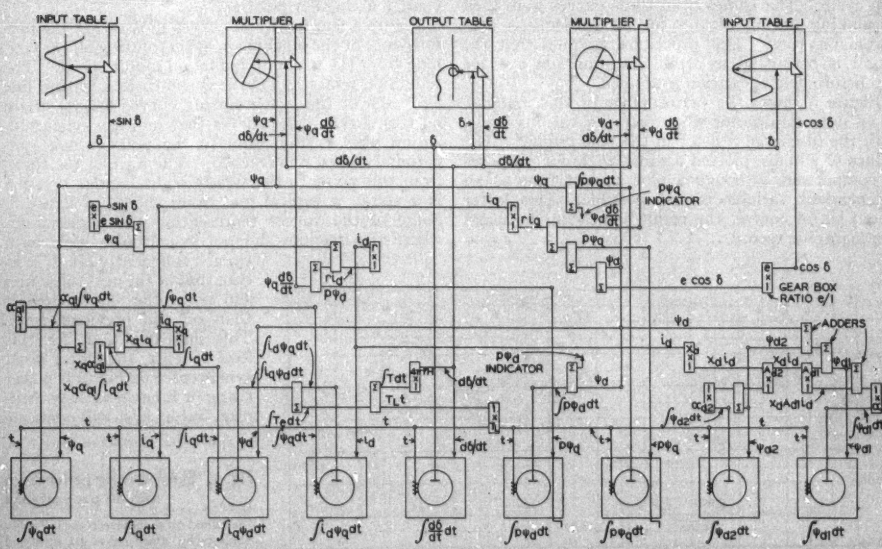

Fig. 2. Schematic diagram of differential analyzer connections for solution of synchronous motor equations

for the loads chosen. The steady state displacement angles corresponding to synchronous operation checked with the calculated values. Several synchronizing runs that were repeated in part or in entirety, showed gratifying correspondence. The most frequent check of solution accuracy consisted of an examination of the equality of equations 1, 2, and 9.

Results of Solutions

The constants of a machine having induction motor characteristics as shown in figure 1, are:

	With Discharge Resistor 8.5 Times Field Resistance	With Discharge Resistor Out
z_d	1.0	1.0
z_q	0.793	0.793
z_q'	0.341	0.341
A_{dn}	0.556	0.521
A_{qn}	0.125	0.160
α_{dn}	0.0087	0.000977
α_{qn}	0.160	0.1405
α_{qi}	0.0469	0.0469
B_{dn}		.681
B_{qn}		−3.43
E_{fd}		0.00312
H	0.898	0.898

The performance of this motor is illustrated in figures 3, 4, and 5.

The first step in determining the characteristics of a particular motor was to make several induction motor runs with selected load conditions. Each of these runs was carried to a point where the slip oscillations were repetitive. The settings of the integrator dials then were plotted for a complete slip cycle. The values from these curves were used in making initial settings for all subsequent synchronizing runs. This procedure assumes that the motor is permitted to attain its minimum average slip before field excitation is applied.

Figure 3 shows the performance of this machine as an induction motor when carrying various loads, with the discharge resistor in the field circuit. The values of slip are plotted against angle for purposes of comparison, although a plot against time as an independent variable is also possible. This latter would be, of course, the result shown on the usual oscillographic record.

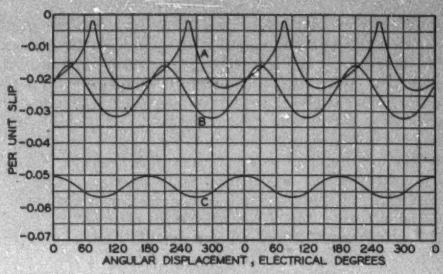

Fig. 3. Slip-angle relationship of induction motor cycle

Curve *A*—Load torque = 38.5 per cent
Curve *B*—Load torque = 50 per cent
Curve C—Load torque = 60 per cent

In accordance with the nomenclature under which the equations were derived, negative displacement angle denotes motor operation. Consequently, all curves in this paper in which angle is the abscissa progress from right to left in the negative slip region corresponding to induction motor operation.

Curve *A* of figure 3 is particularly significant, indicating as it does that the motor almost attains synchronous speed each 180 degrees. This is primarily attributable to the component of torque contributed by the direct axis field winding. The sharpness of the peak in the slip curve is deceptive from the point of view of time, and it should be borne in mind that the slip is plotted against angle and that the smaller the slip the greater the time interval for a given change in angular position.

Figure 4 is a family of curves illustrating the performance of the machine in synchronizing 50 per cent load from the ultimate induction motor speed. The induction motor slip curve is shown as a broken line and each of the synchronizing curves has its origin on this curve. The curves that indicate synchronization were carried only to the point where synchronous speed was reached. The form of the curve from this point to the steady state angular position is a spiral, a typical one being shown in figure 7. Some of the curves representing the performance where the machine did not synchronize have been carried sufficiently far to indicate that at the next minimum slip point the slip is greater than on the previous peak. This indicates that, for this load at least, the motor must synchronize on the first power swing or it never will synchronize, but at best will continue

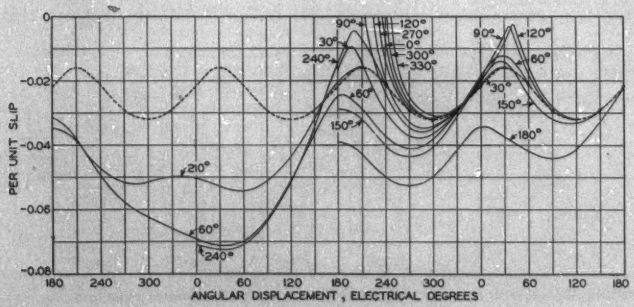

Fig. 4. Synchronizing performance with 50 per cent load

The dotted curve represents the induction motor cycle; other curves are identified by numerals representing the respective angles at which excitation was applied

to operate at some subsynchronous speed.

For 50 per cent load there are 2 angular zones in which excitation may be applied, resulting in synchronization. The most favorable zone is near the zero angle, but slightly in the motor region at an angle of approximately 330 degrees. This is the point at which the induced current in the field winding passes through zero, increasing in the positive direction; here the field flux linkages are a maximum. If at this point the discharge resistor be removed from the circuit and excitation applied, conditions will be most favorable for the motor pull into step. This is indicated by the fact that when synchronous speed is attained, the deviation from the steady state angle is less when excitation is applied here than for the application of excitation at any other point.

A significant factor in the synchronizing of salient pole synchronous motors is that a discharge resistance many times the normal field resistance may be employed in order to bring the machine to the maximum possible speed on its induction motor characteristic. This gives the motor field circuit a relatively short time constant. When, however, the discharge resistor is switched out, the field time constant is greatly increased, thus trapping the flux linking the field circuit at that time. The motor then operates in accordance with its transient rather than its steady state characteristics. The excitation, if applied at the best angle, may have but little effect on the operation of the motor until synchronous speed is reached, except to maintain or slightly increase the initial trapped linkages.

The curves (figure 4) showing performance where excitation was applied at 90 and 120 degrees indicate that the motor almost pulled into step 180 degrees ahead of the normal point, that is, it tended to pull-in under the influence of the trapped negative linkages; but as it did so the combined effect of armature magnetomotive force and applied excitation reduced the negative linkages to a point where the motor could not develop sufficient torque to reach synchronous speed. The time that elapsed while the motor was near synchronous speed was sufficient to enable the armature reaction and applied excitation to reverse the linkages in the field circuit so that the motor then was able to synchronize before the end of the next half slip cycle. The average slip also was favorable because of the small slip attained under the influence of the negative linkages.

Where excitation was applied somewhat later, that is, at 60 or 30 degrees instead of 90 degrees, the motor did not speed up as it had previously but passed through the zero angle in a much shorter time with practically zero linkages in the field. It then was unable to synchronize at the proper angle and, because of the loss of induction motor torque caused by switching out the discharge resistor, slowed down and thereafter was unable to synchronize.

The most unfavorable time for the application of excitation was at an angle of approximately 240 degrees from which point the motor was unable to synchronize within that particular cycle because of the exceedingly short time before reaching the 180 degree point. The field linkages, however, were in the positive direction so that the next part of the swing was in the generator region, which caused the machine to slow down materially. Besides the induction motor torque being lessened, there were additional losses in the armature circuit resistance.

For a given value of field excitation there are combinations of load and inertia (WR^2) that may be synchronized from any angle even though excitation be applied at a slip considerably greater than that at which it normally would be applied. Figure 5 illustrates the action of this motor on synchronizing $38^1/_2$ per cent load where the machine had been operating long enough for the field to have built up to its ultimate value. Each successive cycle shows the slip decreasing slightly until on the last cycle the motor finally synchronized. To indicate that this was the maximum load this motor could synchronize with field applied in this manner, the last cycle of this curve was repeated with a load of $42^1/_2$ per cent. The dotted line at the left side of the chart shows that the minimum slip point, after one cycle, was greater than the value at the beginning. This indicated that the motor never would be able to synchronize a load torque materially greater than $38^1/_2$ per cent if field were applied under the most unfavorable conditions. It also indicates that for loads greater than $38^1/_2$ per cent, if the motor does not synchronize in the first swing it will not syn-

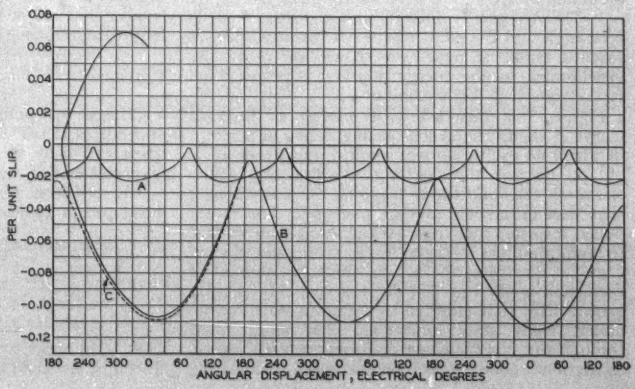

Fig. 5. Synchronizing performance with field excitation fully built up

Curve *A*—Induction motor cycle, 38.5 per cent load torque (Curve *A*, figure 3)

Curve *B*—Synchronizing cycle, 38.5 per cent load torque

Curve *C*—Synchronizing cycle, 42.5 per cent load torque

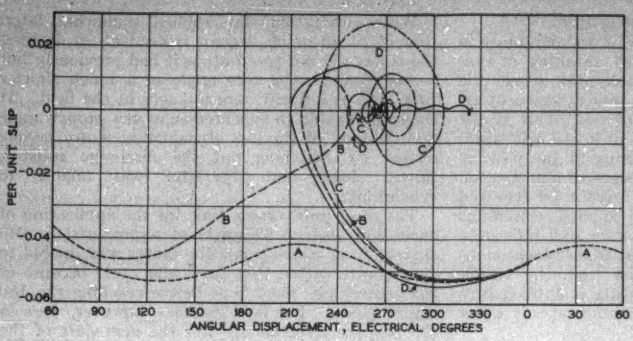

Fig. 6. Synchronizing performance of a machine with $T_d' = 0.33$ second, low excitation applied

Curve *A*—Induction motor cycle
Curve *B*—Zero excitation applied, field short-circuited at 300 degrees
Curve *C*—25 per cent excitation applied at 330 degrees
Curve *D*—40 per cent excitation applied at 0 degrees; steady state load angle 332 degrees

chronize ultimately. Other runs on this particular motor showed that from the most favorable switching angle, the machine could synchronize a maximum of 55 per cent load. A load of 50 per cent may be synchronized with field applied over a considerable range of angles as indicated in figure 4. This indicates a gain of approximately 40 per cent in the amount of load torque that may be synchronized by applying excitation under favorable conditions.

From the user's or operator's point of view, probably the greatest benefit to be obtained by properly applying the field excitation is the reduction of voltage dips. If the motor goes through several power swings in coming into synchronism, it may contribute materially to system disturbances in case its size is comparable with the feeder or system to which it is connected. In any event, the surge transmitted to the system in synchronizing will be a minimum when excitation is applied at the best angle and with the maximum possible average induction motor speed, for under these conditions the minimum amount of energy will be drawn from the system in the synchronizing swing. Following one or more power swings, even with light load, where excitation is applied at too low a speed, the slip at zero angle is greater than it would be if normal induction motor action were taking place (see figure 5). Thus the energy drawn from the system between zero angle and the point where synchronous speed is reached would be great even though the motor did synchronize, as the energy required is proportional to the square of the maximum slip.

Figure 6 is included as a matter of interest. Curve *B* shows the synchronizing action of a motor in which no excitation was applied, but at an angle of 330 degrees the discharge resistor was short-circuited, thus effectively trapping the flux linkages that were in the pole at that moment. The motor pulled into step and then, lacking excitation voltage to maintain these linkages, finally swung out of step. Curve *C* illustrates the action where the amount of excitation applied at 330 degrees was only slightly greater than that required to maintain synchronism under steady state conditions. The motor went through the synchronizing performance with several oscillations about synchronous speed, indicating perhaps that it finally would settle down to some steady operating angle. After a considerable lapse of time in a zone of unfavorable armature reaction, the flux linkages died down and the motor pulled out of step. This illustrates very clearly the fact that the initial performance of the motor is determined by the electrical transients rather than the steady state electrical phenomena.

Curve *D* illustrates the performance of the motor where excitation almost double that necessary to carry the load torque under steady state conditions was applied at an angle of zero degrees. Under these conditions, the pull-in was more difficult because of the less favorable angle. After pull-in, a spiral was generated; but as excitation built up, the motor finally broke from the spiral and moved toward its steady state angle.

A somewhat unique motor performance is indicated in figure 7. The family of curves is similar to that shown in figure 4, but represents the performance of a machine with a higher resistance amortisseur winding and a higher value of discharge resistance. The trapped flux linkage phenomena is illustrated strikingly by the curves beginning at 90 and 120 degrees. In both instances the motor reached synchronous speed under the influence of the trapped negative linkages, but then pulled out as the effect of the applied excitation was realized. The cycle beginning at 90 degrees resulted in ultimate synchronous operation while that from 120 degrees did not, the difference resulting from a smaller amount of trapped negative linkages and a longer elapsed time for the former.

Criteria

Criteria for pulling into step are presented in appendixes II and III for the performance of motors when the field excitation is applied at the most favorable and at the most unfavorable angles.

The criterion for the most favorable angle as developed in appendix II is

$$T_L < \left\{ \frac{2E_d'^{(\max)^2}}{\pi x_d'} + \frac{3}{8} e^2 s_0 \left[\frac{x_d' - x_d''}{x_d' x_d''} T_d'' + \frac{x_q - x_q''}{x_q x_q''} T_q'' \right] - 2fHs_0^2 - \left(\frac{E_d'^{(\max)}}{x_d'} \right)^2 r \right\} \quad (30)$$

That is, in order to synchronize, the load torque T_L should be less than the sum of the other terms. The

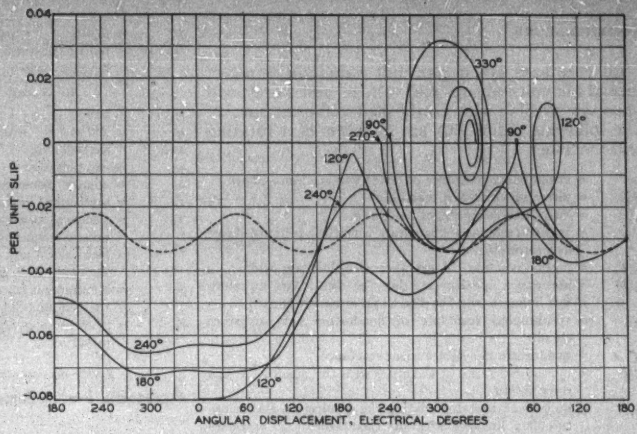

Fig. 7. Synchronizing performance of machine with high resistance amortisseur winding

The dotted curve represents the induction motor cycle; other curves are identified by numerals representing the respective angles at which excitation was applied

first term inside the brackets results from the synchronous component of torque produced by the trapped flux linkages, the second from the amortisseur windings, the third from the inertia load, and the fourth from the primary circuit resistance losses.

Both $E_d'_{(\max)}$ and s_0 can be calculated for practical purposes on the basis of constant slip. The remaining coefficients are constants for any given motor. This formula is adapted particularly to motors having long field time constants, as it assumes constant field flux linkages during the synchronizing period. However, for small machines with short field time constants the terms

$$\frac{2E_d'_{(\max)}}{\pi x_d'} \text{ and } \left(\frac{E_d'_{(\max)}}{x_d'}\right)^2 r$$

can be replaced by

$$\frac{2E_d e}{\pi x_d} \text{ and } \left(\frac{E_d}{x_d}\right)^2 r$$

respectively, in order to show the effect of a very fast time constant, that is,

$$T_L < \left\{\frac{2E_d e}{\pi x_d} + \frac{3}{8} e^2 s_0 \left[\frac{x_d' - x_d''}{x_d' x_d''} T_d'' + \frac{x_q - x_q''}{x_q x_q''} T_q''\right] - 2fHs_0^2 - \left(\frac{E_d}{x_d}\right)^2 r\right\} \quad (30a)$$

If there be an appreciable difference between the load torque that can be pulled into step on the basis of constant field flux linkages (equation 30) as compared with that determined using equation 30*a*, a simple step-by-step calculation can be made to determine the approximate time angle relation for the motor during the synchronizing period and a corresponding correction made as follows:

$$T_L < \left\{k_1 \frac{2E_d'_{(\max)} e}{\pi x_d'} + \frac{3}{8} e^2 s_0 \left[\frac{x_d' - x_d''}{x_d' x_d''} T_d'' + \frac{x_q - x_q''}{x_q x_q''} T_q''\right] - 2fHs_0^2 - \left(k_1 \frac{E_d'_{(\max)}}{x_d'}\right)^2 r\right\} \quad (30b)$$

where k_1 is a correction factor to take into account the increase in the field flux linkages during the synchronizing period.

Figure 8 is a diagram illustrating by means of areas the different components of equation 30 for the machine having the constants tabulated hereinbefore. The load component for the synchronizing period is represented by area A and the inertia component by area B. In order to synchronize, D must be greater than $B + C$. The criterion is slightly pessimistic, for in accordance with equation 30 D must be greater than $B + C + E$, since the components of torque used in deriving the criterion were integrated from 0 to -180 degrees. This discrepancy is not great, as area E is small.

The criteria as given by equations 30, 30*a*, and 30*b* provide a comparatively simple method of predetermining the load that can be pulled into step from the most favorable angle. These criteria checked the results obtained on the differential analyzer with good accuracy.

The criterion for the most unfavorable angle as developed in appendix III is

$$s_{(av)} < k_2 \sqrt{\frac{E_d e}{\pi f H x_d}} \quad (38)$$

That is, $s_{(av)}$ must be less than the right hand term of equation 38. This criterion is based upon the consideration that if the motor is capable of pulling into step from a subsynchronous speed, after the field has been fully built up, it will be able to pull into step if excitation be applied at the most unfavorable angle, even though the motor may slip several poles. In equation 38, $s_{(av)}$ is the average slip resulting from the torque developed by the machine when running out of synchronism with the field fully excited, and k_2 is the ratio between the average slip $s_{(av)}$ and the total slip pulsation s_p. From the differential analyzer results, $k_2 = 0.55$ to 0.60. This value of slip, $s_{(av)}$ is approximated by the average slip during the last slip cycle, for example, curve B, figure 5.

Equation 38 is almost identical with that given in reference 9, equation 5, if $k_2 = 0.50$, except that the average slip is determined by the net average torque available with the field fully excited (curve C, figure 1) and not by the induction motor characteristic with discharge resistor in the circuit (curve A, figure 1).

Nomenclature

All constants are in per unit values in terms of normal kilovolt-amperes and voltage, and correspond wherever possible with established nomenclature.[1,4,6] The following definitions are in terms of a rotating field machine:

x_d = synchronous reactance of direct axis armature circuit
x_d' = direct axis transient reactance
x_d'' = direct axis subtransient reactance
x_{a1d} = mutual reactance of armature with the additional direct axis rotor circuit
x_{afd} = mutual reactance of armature with the main field
$x_d(p)$ = impedance operator relating the direct axis armature flux linkages with the direct axis armature current
x_q = synchronous reactance of quadrature axis armature circuit
x_q'' = quadrature axis subtransient reactance
x_{a1q} = mutual reactance of armature with the quadrature axis rotor circuit
$x_q(p)$ = impedance operator relating the quadrature axis armature flux linkages with the quadrature axis armature current
X_{f1d} = mutual reactance of the main field with the additional direct axis rotor circuit
X_{11d} = self-inductive reactance of additional circuit in the direct axis
= x_{afd} + additional direct axis rotor circuit leakage reactance
X_{ffd} = self-inductive reactance of main field circuit
= x_{afd} + main field leakage reactance
X_{11q} = self-inductive reactance of rotor circuit in the quadrature axis
$G(p)$ = impedance operator relating the direct axis armature flux linkages with the field excitation voltage
r = armature circuit resistance
R_{1d} = resistance of additional direct axis rotor circuit
R_{fd} = field circuit resistance
R_{1q} = resistance of quadrature axis rotor circuit
e = system voltage
E_d = direct axis voltage corresponding to the field excitation
E_d' = voltage back of transient reactance
$= \frac{x_{afd}}{X_{ffd}} \psi_{fd}$
$E_d'(\max)$ = voltage back of transient reactance corresponding to the maximum field flux linkages during the induction motor cycle
E_{fd} = field excitation voltage
ψ_d = direct axis armature winding flux linkages
ψ_{d1} = a component of direct axis armature winding flux linkages (see equation 12, appendix I)
ψ_{d2} = a component of direct axis armature winding flux linkages (see equation 13, appendix I)
ψ_{fd} = main field winding flux linkages
ψ_q = quadrature axis armature winding flux linkages
i_d = direct axis armature current
i_q = quadrature axis armature current
T_d'' = direct axis amortisseur (short circuit) time constant in electrical radians
T_q'' = quadrature axis amortisseur (short circuit) time constant in electrical radians
α_d = root of the denominator of $x_d(p)$
α_q = root of the denominator of $x_q(p)$
A_{d1} = equation 17, appendix I
A_{d2} = equation 18, appendix I
B_{d1} = equation 19, appendix I
B_{d2} = equation 20, appendix I
t = time in electrical radians; unit time is the time required for the rotor to pass one electrical radian at normal frequency
p = d/dt
H = inertia constant
$= \frac{0.231 \times WR^2 \times (RPM)^2}{10^8 \times \text{base kva}}$
s = slip
s_0 = slip at $\delta = 0$ when machine is running out of synchronism
$s_{(av)}$ = average slip
s_p = slip pulsation
δ = angular displacement in electrical radians
T_L = mechanical load torque
T_e = electrical torque
f = normal frequency in cycles per second
1 = Heaviside's unit function used in this paper to indicate the application of voltage to the field circuit
h_1 = a correction factor to take into account the increase in the field flux linkages during the synchronizing period
h_2 = ratio between the average slip $s_{(av)}$ and the total slip pulsation s_p

Appendix I—Fundamental Relations

The following general relations are given by Park[4] for a synchronous machine:

$$e_d = p\psi_d - ri_d - \psi_q p\theta \tag{1}$$

$$e_q = p\psi_q - ri_q + \psi_d p\theta \tag{2}$$

$$\psi_d = G(p)E_{fd} - x_d(p)i_d \tag{3}$$

$$\psi_q = -x_q(p)i_q \tag{4}$$

$$T_e = i_q\psi_d - i_d\psi_q \tag{5}$$

where

$$e_d = e \sin \delta$$

$$e_q = e \cos \delta$$

$$p\theta = 1 + \frac{d\delta}{dt}$$

when the machine is connected directly to an infinite bus.

It is assumed that the amortisseur winding may be represented with reasonable accuracy by 2 closed circuits on the rotor, one in the direct axis, the other in the quadrature axis. On this basis the operators may be evaluated as follows:[2]

$$G(p) = \frac{p(X_{11d}x_{afd} - X_{f1d}x_{a1d}) + x_{afd}R_{1d}}{p^2(X_{11d}X_{ffd} - X^2_{f1d}) + p(X_{11d}R_{fd} + X_{ffd}R_{1d}) + R_{1d}R_{fd}} \tag{6}$$

$$x_d(p) = x_d - \frac{p^2(X_{11d}x^2_{afd} - 2X_{f1d}x_{a1d}x_{afd} + X_{ffd}x^2_{a1d}) + p(x^2_{afd}R_{1d} + x^2_{a1d}R_{fd})}{p^2(X_{11d}X_{ffd} - X^2_{f1d}) + p(X_{11d}R_{fd} + X_{ffd}E_{1d}) + R_{1d}R_{fd}} \tag{7}$$

$$x_q(p) = x_q - \frac{px^2_{a1q}}{pX_{11q} + R_{1q}} \tag{8}$$

Equations 3 and 4, which include the operational impedance operators, were modified in the following manner in order to bring them to a form suitable for solution by means of the differential analyzer:

Let

$$\psi_d = -x_d i_d + \psi_{d1} + \psi_{d2} \tag{9}$$

where

$$\psi_{d1} = \frac{x_d(A_{d1}pi_d + \alpha_{d1}B_{d1}E_{fd})}{p + \alpha_{d1}} \tag{10}$$

$$\psi_{d2} = \frac{x_d(A_{d2}pi_d + \alpha_{d2}B_{d2}E_{fd})}{p + \alpha_{d2}} \tag{11}$$

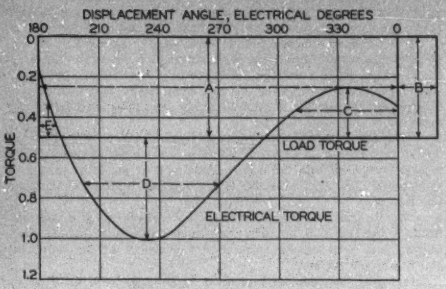

Fig. 8. Energy diagram where excitation is applied at the most favorable angle

A—Load area
B—Kinetic energy area

To synchronize, $D > B + C$
E—Refer to appendix II

From equation 10,

$$\psi_{d1} = x_d A_{d1} i_d + \frac{x_d B_{d1} \alpha_{d1} E_{fd}}{p} - \frac{x_d \alpha_{d1}(A_{d1} p i_d + \alpha_{d1} B_{d1} E_{fd})}{p(p + \alpha_{d1})}$$

Hence,

$$\psi_{d1} = x_d A_{d1} i_d - \alpha_{d1} \int (\psi_{d1} - x_d B_{d1} E_{fd}) dt \tag{12}$$

In a similar manner it may be shown that

$$\psi_{d3} = x_d A_{d3} i_d - \alpha_{d3} \int (\psi_{d3} - x_d B_{d3} E_{fd}) dt \tag{13}$$

From equations 3 and 9,

$$\psi_{d1} + \psi_{d3} = [x_d - x_d(p)] i_d + G(p) E_{fd} \tag{14}$$

The coefficients of equations 12 and 13 may be obtained by substituting equations 6, 7, 10, and 11 in equation 14 and dividing both numerator and denominator of the right hand member by $(X_{11d}X_{ffd} - X^2_{fid})$. The denominator of the resulting expression is

$$p^2 + p\,\frac{X_{11d}R_{fd} + X_{ffd}R_{1d}}{X_{11d}X_{ffd} - X^2_{f1d}} + \frac{R_{1d}R_{fd}}{X_{11d}X_{ffd} - X^2_{f1d}}$$

and may be factored to obtain

$$\alpha_{d1} = \frac{X_{11d}R_{fd} + X_{ffd}R_{1d} - \sqrt{X^2_{11d}R^2_{fd} + X^2_{ffd}R^2_{1d} - 2X_{11d}R_{fd}X_{ffd}R_{1d} + 4X^2_{f1d}R_{1d}R_{fd}}}{2(X_{11d}X_{ffd} - X^2_{f1d})} \tag{15}$$

$$\alpha_{d3} = \frac{X_{11d}R_{fd} + X_{ffd}R_{1d} + \sqrt{X^2_{11d}R^2_{fd} + X^2_{ffd}R^2_{1d} - 2X_{11d}R_{fd}X_{ffd}R_{1d} + 4X^2_{f1d}R_{1d}R_{fd}}}{2(X_{11d}X_{ffd} - X^2_{f1d})} \tag{16}$$

where α_{d1} and α_{d3} represent the open circuit decrement factors of the field and amortisseur windings, respectively.

The constant terms and the coefficients of p and p^2 in the identity resulting from equation 14 may be equated and solved simultaneously with the following results:

$$A_{d1} = \frac{\alpha_{d1}(x_d - x_d'')}{x_d(\alpha_{d1} - \alpha_{d3})} - \frac{x^2_{afd}R_{1d} + x^2_{a1d}R_{fd}}{x_d(\alpha_{d1} - \alpha_{d3})(X_{11d}X_{ffd} - X^2_{f1d})} \tag{17}$$

$$A_{d3} = \frac{x^2_{afd}R_{1d} + x^2_{a1d}R_{fd}}{x_d(\alpha_{d1} - \alpha_{d3})(X_{11d}X_{ffd} - X^2_{f1d})} - \frac{\alpha_{d3}(x_d - x_d'')}{x_d(\alpha_{d1} - \alpha_{d3})} \tag{18}$$

$$B_{d1} = \frac{\alpha_{d1}(X_{11d}x_{afd} - X_{f1d}x_{a1d}) - x_{afd}R_{1d}}{x_d\alpha_{d1}(\alpha_{d1} - \alpha_{d3})(X_{11d}X_{ffd} - X^2_{f1d})} \tag{19}$$

$$B_{d3} = \frac{x_{fd}R_{1d} - \alpha_{d3}(X_{11d}x_{afd} - X_{f1d}x_{a1d})}{x_d\alpha_{d3}(\alpha_{d1} - \alpha_{d3})(X_{11d}X_{ffd} - X^2_{f1d})} \tag{20}$$

From equations 4 and 8,

$$\psi_q = -x_q i_q + \frac{p x^2_{a1q}}{p X_{11q} + R_{1q}} i_q$$

which may be expanded to

$$\psi_q = -i_q\left[x_q - \frac{x^2_{a1q}}{X_{11q}}\right] - \frac{R_{1q}}{p X_{11q}}\left[\frac{p x^2_{a1q} i_q}{p X_{11q} + R_{1q}}\right] \tag{21}$$

Substituting,[8]

$$x_q'' = x_q - \frac{x^2_{a1q}}{X_{11q}} \text{ and } \alpha_{q1} = \frac{R_{1q}}{X_{11q}}$$

there results

$$\psi_q = -x_q'' i_q - \alpha_{q1}\int \psi_q dt - \alpha_{q1} x_q \int i_q dt \tag{22}$$

The summation of instantaneous torques acting upon the mechanical system must be zero. Consequently, accelerating torque = − electrical torque − load torque. Accordingly,

$$4\pi f H \frac{d^2\delta}{dt^2} = i_d\psi_q - i_q\psi_d - T_L \tag{23}$$

where

$$H = \frac{0.231\,WR^2(\text{rpm})^2}{10^6 \text{ base kva}} \tag{24}$$

Equation 23 is given in reference 4, equation 57*A*.

The fundamental equations of a synchronous machine arranged for simultaneous solution on the differential analyzer are therefore equations 1, 2, 9, 12, 13, 22, and 23.

Appendix II—Criterion for Synchronizing at the Most Favorable Switching Angle

The criterion for synchronizing at the most favorable switching angle as derived in this appendix, is based upon the following assumptions and considerations:

1. The most favorable time to apply field excitation is at the instant of maximum main field winding flux linkages when the polarity of these flux linkages corresponds to that resulting from the applied field excitation.
2. The main field winding flux linkages existing at the instant the exciter switch is closed are constant during the synchronizing period, that is, the time from the instant the exciter switch is closed to the instant the slip is zero. This in effect assumes that the applied field excitation is just sufficient to prevent the armature reaction magnetomotive force from decreasing the field flux linkages during the synchronizing period. This is particularly justifiable in the case of large motors, where the synchronizing period from the best angle is relatively short compared with the field time constant when the discharge resistor is not in the field circuit.
3. The synchronizing period is assumed to begin at $\delta = 0$, with field flux linkages corresponding to the maximum obtained during the induction motor cycle. This assumption is justifiable, although the maximum field flux linkages are not obtained at $\delta = 0$ but at about 330 or −30 degrees, since the electrical torque between 0 and −30 degrees is not appreciably different whether the machine is running as an induction motor with the discharge resistance in or with constant maximum induction-motor-cycle flux linkages in the main field circuit.
4. The synchronizing period is assumed to end at $\delta = \pi$. This leads to a slightly pessimistic result. The error is small as the electrical torque is decreasing rapidly as a function of δ, at $\delta = 180$ degrees. This error is shown in figure 8 by the small area *E*.
5. The torque developed by the amortisseur windings during the synchronizing period is assumed equal to the average of that obtained

on the basis of the slip remaining constant from $\delta = 0$ to $\delta = \pi$ and the slip decreasing linearly from $s = s_0$ at $\delta = 0$ to $s = 0$ at $\delta = \pi$. This assumption was considered as a reasonable approximation from an analysis of the differential analyzer results. See figures 4, 6, and 7 for switching at $\delta = 330$ degrees.

6. Normal values of armature circuit resistance have been found to have a negligible effect on the induction motor components of electrical torque, while the effect of the synchronous component is taken into account approximately by adding to the synchronous component of torque determined by neglecting resistance, the term

$$\left(\frac{E_d'(\max)}{x_d'}\right)^2 r.$$

Integrating equation 23 (appendix I),

$$2\pi fH\left(\frac{d\delta}{dt}\right)^2 = \int_0^{-\pi}(-T_L - T_e)d\delta + 2\pi fHs_0^2 \tag{25}$$

For synchronizing, $d\delta/dt$ must equal zero. Letting $d\delta/dt = 0$ in equation 25, and since T_L is a constant

$$\pi T_L = \int_0^{-\pi} T_e d\delta - 2\pi fHs_0^2 \tag{26}$$

where, on the basis of assumptions 2 and 6, equation 14 of reference 3, and equation 61 of reference 5,

$$T_e = \frac{E_d'(\max)e}{x_d'}\sin\delta + \frac{e^2(x_d' - x_q)}{2x_d'x_q}\sin 2\delta + \frac{e^2(x_d' - x_d'')}{x_d'x_d''}sT_d''\sin^2\delta + \frac{e^2(x_q - x_q'')}{x_qx_q''}sT_q''\cos^2\delta + \left(\frac{E_d'(\max)}{x_d'}\right)^2 r \tag{27}$$

In accordance with assumption 5,

$$s = \frac{1}{2}\left[s_0 + \left(1 - \frac{\delta}{\pi}\right)s_0\right] \tag{28}$$

Substituting equation 28 in equation 27 and integrating with respect to δ between 0 and $-\pi$,

$$\int_0^{-\pi} T_e d\delta = \frac{2E_d'(\max)e}{x_d'} + \frac{3}{8}e^2\pi s_0\left[\frac{x_d' - x_d''}{x_d'x_d''}T_d'' + \frac{x_q - x_q''}{x_qx_q''}T_q''\right] - \left(\frac{E_d'(\max)}{x_d'}\right)^2 r\pi \tag{29}$$

Substituting equation 29 in equation 26, the criterion for synchronizing at the most favorable angle is

$$T_L < \left[\frac{2E_d'(\max)e}{\pi x_d'} + \frac{3}{8}e^2s_0\left(\frac{x_d' - x_d''}{x_d'x_d''}T_d'' + \frac{x_q - x_q''}{x_qx_q''}T_q''\right) - 2fHs_0^2 - \left(\frac{E_d'(\max)}{x_d'}\right)^2 r\right. \tag{30}$$

The first term inside the brackets of equation 30 results from the synchronous component of transient torque, the second term from the component of torque contributed by the amortisseur winding, the third term from the kinetic energy component of torque, and the fourth term from the armature circuit resistance losses. In using this criterion it is necessary to make a preliminary set of calculations in order to determine the average slip, s_0, for a given load, and the quantity $E_d'(\max)$ when operating at this slip as an induction motor. These preliminary calculations can be made on the basis of constant slip, with sufficient accuracy for practical purposes.

Appendix III—Criterion for Synchronizing With Excitation Applied at the Most Unfavorable Angle

The criterion for synchronizing with excitation applied at the most unfavorable angle is based on the following assumptions and considerations.

1. It is assumed that the motor will pull into step with excitation applied at the most unfavorable angle if it is capable of pulling into step after slipping several poles with the field excitation fully built up.
2. It is assumed that the fundamental angular component of electrical torque when running out of synchronism is equal to $[(E_de)/x_d]\sin\delta$, where E_d is a voltage corresponding to the field excitation. This is essentially correct for this case since the average field current induced by the motion is approximately zero over a complete slip cycle.
3. Since the pulsating component of synchronous torque produced by the field excitation when the motor is running out of synchronism is large compared with the other components of pulsating torque, it is assumed that minimum slip is 180 degrees from maximum slip (see figure 5).
4. The electrical torque is assumed to be made up of a constant term, a fundamental angular component of torque (synchronous torque), and even angular harmonics of electrical torque (induction and reluctance torques).

Integrating equation 23 (appendix I) from δ_1 to δ_2 in order to find the magnitude of the slip pulsation, $\left[s_p = \frac{d\delta_2}{dt} - \frac{d\delta_1}{dt}\right]$,

$$2\pi fH\left(\frac{d\delta_2}{dt}\right)^2 = -\int_{\delta_1}^{\delta_2}(T_L + T_e)d\delta + 2\pi fH\left(\frac{d\delta_1}{dt}\right)^2 \tag{31}$$

Since at synchronous speed $(d\delta_2)/(dt) = 0$ the magnitude of the slip pulsation, s_p, for the slip cycle before synchronization is equal to $-(d\delta_1)/(dt)$. Accordingly, equation 31 becomes

$$2\pi fHs_p^2 = \int_{\delta_1}^{\delta_2}(T_L + T_e)d\delta \tag{32}$$

In accordance with assumption 3, $\delta_2 = \delta_1 - \pi$, and equation 32 can be expressed as follows

$$2\pi fHs_p^2 = \int_{\delta_1}^{\delta_1-\pi}\frac{E_de}{x_d}\sin\delta d\delta + \int_{\delta_1}^{\delta_1-\pi}(T_1 + T_L)\,d\delta \tag{33}$$

where, in accordance with assumption 4,

$T_1 = T_e - \frac{E_de}{x_d}\sin\delta =$ the constant component plus the even angular harmonic components of the electrical torque.

Since for a complete cycle,

$$\int_{\delta_1}^{\delta_1-2\pi}(T_L + T_e)d\delta = 0 \quad\text{and}\quad \int_{\delta_1}^{\delta_1-2\pi}\frac{E_de}{x_d}\sin\delta d\delta = 0$$

then

$$\int_{\delta_1}^{\delta_1-\pi}(T_1 + T_L)\,d\delta = 0 \tag{34}$$

Substituting equation 34 in equation 33 and integrating,

$$2\pi fH\,s_p^2 = \frac{2E_de}{x_d}\cos\delta_1 \tag{35}$$

or

$$s_p = \sqrt{\frac{E_de}{\pi fH\,x_d}\cos\delta_1} \tag{36}$$

For the magnitude of pulsation to be a maximum, $\delta_1 = 0$ and equation 36 becomes

$$s_p = \sqrt{\frac{E_de}{\pi fH\,x_d}} \tag{37}$$

Assuming the average slip to be k_2s_p, the criterion for synchronizing from the most unfavorable angle is

$$s_{(av)} < k_2\sqrt{\frac{E_de}{\pi fH\,x_d}} \tag{38}$$

where from the differential analyzer solutions $k_2 = 0.55$ to 0.60.

Since the average slip can be determined approximately from calculations based upon constant slip, equation 38 provides a means for determining whether or not a motor will pull in from the most unfavorable angle.

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Discharge Currents in Distribution Arresters

With a view to augmenting the meager data available on the discharge currents through lightning arresters on electric power distribution circuits, the investigation reported in this paper, which covered 4 power systems of various voltages and in different sections of the country, was undertaken. Over the range of circuit voltages involved in this investigation (4 to 24 kv) voltage rating seemed to have no definite influence on the discharges. More negative than positive discharges were recorded, the ratio increasing as the discharge current increased. The maximum current recorded was 17,000 amperes.

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During the summer of 1934, the General Electric Company undertook a co-operative investigation with the Edison Electric Illuminating Company of Boston, the Commonwealth Edison Company of Chicago, the Detroit Edison Company, and the Georgia Power Company, having for its purpose the acquiring of data relative to discharge currents through distribution lightning arresters as the result of lightning. Much valuable work had been done on high voltage transmission lines during the preceding 10 years, leading to a better understanding of what hazards lightning may impose upon insulation and apparatus, both at the point of inception and as the result of wave travel along conductors. With the distribution circuit, however, conditions are frequently less definite, particularly with regard to insulation levels, effects of shielding, and effectiveness of grounding. Considerable data[1] have been published concerning the performance of distribution arresters, particularly as related to the failure of apparatus, but there have been almost no data available with reference to discharge currents through lightning arresters.

In 1934 were published the results of a 4 year study of lightning potentials obtained through the use of the surge voltage recorder[2] on the distribution lines in Chicago, Ill. At 8 locations the lightning discharge current through a special arrester was determined by measuring the potential across "thyrite" disks. Of 32 records obtained, 31 indicated currents of 300 amperes or less, while the remaining record indicated a current of the order of 1,500 amperes. These results were of too limited a character to permit drawing definite conclusions.

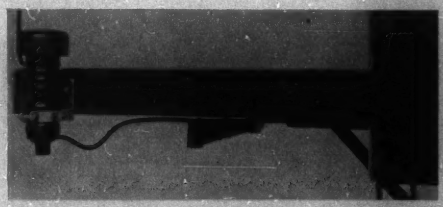

Fig. 1. Typical installation of magnetic links on ground lead of lightning arrester to measure lightning discharge current

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1. For all numbered references see list at end of paper.

Later, currents of the order of 34,000 amperes through the common ground lead of 3 lightning arresters connected to a 24 kv circuit in a "non-shielded" area were reported.[3] In obtaining these results, the size of the hole punctured through paper inserted between 2 electrodes was used to indicate the magnitude of the current, calibration having been obtained through the use of the impulse generator and the cathode ray oscillograph.

The wide difference between the results obtained in these 2 investigations indicated the necessity of obtaining in the present investigation a considerable amount of data over a wide range of circuit voltage ratings and locations. Summarized briefly, the results obtained during the first year of the present investigation are as follows:

1. Circuit voltage rating, which sometimes may imply different line insulation, seems to have no definite influence on the occurrence of a discharge of given magnitude through a lightning arrester. The circuit ratings involved range from 4 kv to 11.95 kv for most of the installations.

2. Lumping all the data together without reference to location, the preponderance of negative records becomes greater at the larger currents. There were about 9 times as many negative as positive records at 5,000 amperes, and 2 times as many at 500 amperes. Apparently, the higher values are attributable to direct strokes, while at low currents an increasing proportion is attributable to induced effects.

3. The highest negative current measured was 17,000 amperes, and the highest positive current 14,000 amperes.

4. On the average, current of a given magnitude will be discharged through a rural arrester 3 $^1/_4$ times as often as through an urban arrester.

5. A lightning arrester installed in a rural area may be expected to discharge a current of 5,000 amperes or more once in 26 years, while the same arrester installed in an urban area would discharge such a current on the average of once in 76 years. The data indicate for 15,000 amperes or more an "expectancy" of 210 years for the rural arrester and 600 years for the urban arrester.

6. In applying these results to predict the number of discharges on any line, considerable variation from the foregoing results may be expected because of variations in the number and severity of storms, the degree of exposure of lines, and density of arresters on the lines.

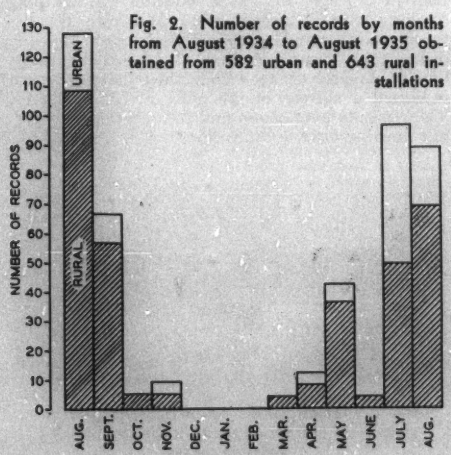

Fig. 2. Number of records by months from August 1934 to August 1935 obtained from 582 urban and 643 rural installations

Surge Crest Ammeter Used

Development of the magnetic link and surge crest ammeter[4] provided a simple and relatively inexpensive means of determining crest current. As used 2 magnetic links are mounted on a triangular wooden bracket as shown in figure 1, the bracket being placed over the arrester ground wire. The 2 links were spaced approximately $^3/_4$ inch and $2^1/_8$ inches from the arrester ground wire for most installations.

Two magnetic links with different spacings were used so that their current ranges would overlap, thus making possible the measurement of a large range of currents. After these installations were made, experience obtained from investigations in the laboratory and on high voltage lines with similar equipment indicated that lightning discharges are not always unidirectional. It was found also that readings obtained on the links, as already installed, would give information regarding any reversals or oscillations of the discharge current as well as the crest amplitude.

Table I—Distribution of Surge Crest Ammeter Installations

Operating Company	Line Kv	Transformer Connection	Rural or Urban	Surge Crest Ammeter Installations: Number	Surge Crest Ammeter Installations: Per Cent on Interconnected Arresters**
Commonwealth Edison Co.	4	Grounded star	Urban	252	72
	4	Grounded star	Rural	69	41
	12	Grounded star	Rural	8	0
	20		Urban	2	
Detroit Edison Co.	4.8	Delta	Urban	30	0
	4.8	Delta	Rural	300	100
	24	Grounded..*	Rural	12	
Edison Elec. Illum. Co. of Boston	4	Ungrounded star	Urban	298	100
Georgia Power Co.	2.3	Delta	Rural	3	0
	6.9	Delta	Rural	74	100
	11.5	Delta	Rural	96	84
	11.95	Grounded star	Rural	81	100

Average length of service, corrected for difference in lightning severity for different months, 1.1 years for urban installations and 1.2 years for rural installations.

* All surge crest ammeter installations on 2,300-volt single-phase circuits.

** Lightning arrester ground and secondary neutral interconnected.

The current measurements obtained in this investigation are based upon laboratory calibration of the magnetic links, using an impulse generator and cathode ray oscillograph.[4] The impulse generator circuit constants were varied to give different degrees of damping, so that calibrations could be obtained for currents with different degrees of reversal.

The range of currents that can be read accurately with the surge crest ammeter, for the link spacings used, is from about 500 up to 5,000 or 7,500 amperes, depending upon the amplitude of reversal. Beyond these limits, knees in both ends of the magnetization curves make interpolation difficult on a scale of suitable length for a field instrument. Also, unless links are selected carefully, the differences between the characteristics of individual links are likely to introduce appreciable errors in readings above the range of the surge crest ammeter.

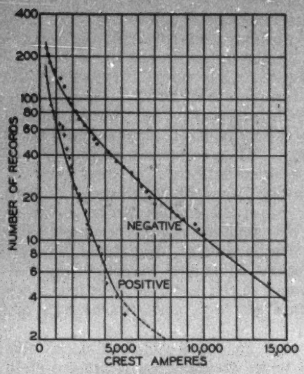

Fig. 3. Relative numbers of positive and negative discharges

Curves show number of discharges whose magnitude was at least as great as shown by the corresponding crest amperes. Based upon a total of 156 positive and 255 negative records from 1,225 installations

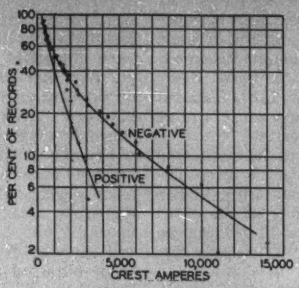

Fig. 4. Summary of 41 positive and 48 negative records obtained from 582 urban installations

Curves in figures 4 and 5 show per cent of discharges whose magnitude was at least as great as shown by the corresponding crest amperes

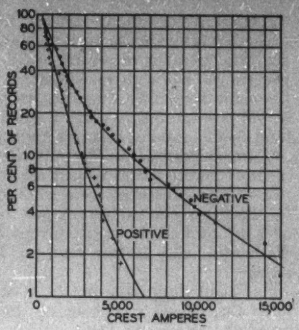

Fig. 5. Summary of 115 positive and 207 negative records obtained from 643 rural installations

In this investigation, readings outside the range mentioned could be made with a fair degree of accuracy, because all links were measured with a ballistic galvanometer, which has a scale length many times that of the surge crest ammeter. Also, links that were found to be strongly magnetized were calibrated individually to eliminate errors from variation in magnetization characteristics.

These measures permitted currents up to a maximum of 17,000 amperes to be measured fairly accurately, and also permitted currents less than 500 amperes, down to about 300 amperes, to be detected and read approximately. It is believed that the accuracy of measurement, except for the smaller currents, is within 10 per cent for single unidirectional waves or for damped oscillations of the type used in the laboratory calibration tests.

It is interesting to note that the smallest currents measured, when considered on a traveling wave basis, would correspond roughly to the lowest surge potentials that would be dangerous to typical distribution circuit insulation. Hence, practically all the current records obtained in the investigation represent surge magnitudes that would have been dangerous to unprotected transformers on the lower voltage circuits.

The procedure with each of the co-operating companies was much the same, in that inspection was made after each storm in so far as conditions would permit. An inspector examined each link using a special magnetic indicator built for the purpose. If magnetism was indicated, the link was enclosed in a special magnetic shield and sent to the laboratory where its magnetization was determined by the use of a ballistic galvanometer. Individual magnetization curves were taken for many links on which records had been obtained outside the normal calibration range. After test, the links were demagnetized and either held as spares or reinstalled.

A total of 1,225 installations have been in service for slightly more than a year, distributed as shown in table I.

Results

It is of interest to note the number of records obtained from the 4 systems for each month of the year. In figure 2, these data are shown divided into rural and urban records. The plot shows clearly the greater number of rural records compared with those from urban areas. Lightning during the months of May and September appears to be about half as severe as it is during July or August.

Polarity of Current. A total of 156 positive and 255 negative records (figure 3) was obtained from all of the 1,225 installations. Of a total of 411 records, 3 or 0.73 per cent were of 15,000 amperes or more, the highest being 17,000 amperes; these were all of negative polarity. The 2 highest positive values recorded were 9,000 and 14,000 amperes, respectively. At 5,000 amperes negative discharges were recorded about 9 times as frequently as were positive discharges. As the current becomes less this ratio decreases, being about 2 at 500 amperes.

It has been well established through the results of studies on high voltage transmission systems that direct strokes to lines are predominantly negative. Induced effects resulting from nearby strokes therefore will be predominantly positive, and of course will be of smaller magnitude. This probably explains the preponderance of negative records at the higher currents obtained in this investigation, and the increasing proportion of positive records at low currents.

Number of Records. With 411 records obtained on the 1,225 installations, approximately one record could be expected per arrester installation once every 3 years on the average. The data, as given in figure 3, show a total of 150 records of 1,500 amperes or more, which means, assuming the season recorded to be average, that an arrester could be expected to

discharge a current of at least 1,500 amperes once every 9 years. On the basis of 5,000 amperes or more, the total number of records is 38, indicating an expectancy of one such discharge every 35 years. Using the same reasoning, 28 arresters per 1,000 installed would be expected to carry a discharge current of at least 5,000 amperes in an average year.

Current Reversals. The majority of the discharges measured were found to contain reversals or oscillations. These reversals were quite consistently smaller for the high current discharges, being of the order of 5 per cent of the crest current for 10,000 ampere discharges, and 40 per cent for 1,000 ampere discharges.

Sufficient data have not been obtained to explain fully the cause or nature of these oscillations or reversals. However, their existence is indicated also by magnetic link records obtained on high voltage lines, and by recent oscillographic studies.[8]

Urban Results Compared With Rural Results. In built-up sections, it is to be expected that the duty on lightning arresters would be less severe because of the shielding effect of nearby buildings and other conducting structures, and also because of the reduced insulation resulting from the presence of grounded conductors on the same pole. In cities also, the density of arresters is likely to be higher, resulting in less current through a given arrester.

In figures 4 and 5, the data presented in figure 3 are segregated according to their sources in urban and rural locations. It is recognized that the division between urban and rural may be on a somewhat different basis in each of the systems studied, yet the great majority of the data so classified do represent comparable conditions. It should be noted that the curves are plotted in terms of per cent of total records rather than number of records as in figures 2 and 3. This allows a direct comparison between the rural and urban data. Plotted on this basis, very little definite difference can be detected between the current to be expected at urban locations and that at rural locations.

From 582 urban installations 41 positive and 48 negative records were obtained, while from 643 rural installations 115 positive and 207 negative records were obtained. In the urban areas there were 17 per cent more negative than positive records, while 79 per cent more negative than positive records were obtained from the rural areas. Of greater significance, however, is the comparison between the number of records obtained. When compared on the basis of an equal number of installations, $3^1/_4$ times as many records were obtained from the rural areas as from the urban areas. Since the shapes of the curves in figures 4 and 5 are similar, about the same ratio will apply to all current values. Additional data yet to be obtained in the continued investigation may show that adjustment of the curve shape is necessary since sufficient data on high positive currents are lacking as yet.

It is believed that the data obtained from this investigation will be of greatest use if presented in the form of expectancy curves, showing the number of years that may be expected to elapse before a current of a certain magnitude or greater passes through a given arrester. These curves will be modified of course as additional data become available, but the results thus far should represent a fair approximation. In figure 6 such expectancy curves are shown for all rural and urban installations, while in the following 3 figures the data are broken down still further with reference to system voltage rating.

Figure 6 indicates that a current of 1,500 amperes or more may be expected through a rural arrester once every 6 years, and once every 20 years through an urban arrester. At 5,000 amperes, the expectancy is respectively 26 and 76 years. Further study of figure 6 shows that a current of 15,000 amperes may be expected once every 210 years through the rural arrester, and once every 600 years through the urban arrester. Expressed in percentages, 0.17 per cent of the urban and 0.48 per cent of the rural arresters would be expected to discharge 15,000 amperes once during each year for which the lightning severity is equal to that covered by this investigation.

Since the time duration of currents could not be measured by the magnetic links, it should be recognized that the current amplitudes alone are not a direct measure of the severity of duty on the arresters. A relatively low current of long duration may represent more severe duty than a very high current of short duration. However, it is significant that distribution arresters are available which appear to have discharge capabilities entirely commensurate with discharge duties on distribution circuits. More than 60 per cent of the field measurements involved a type of arrester with which no recorded discharge resulted in any failure of either the arrester or the protected transformer. This type was subjected to 75 per cent of the recorded discharges of 10,000 amperes or more, including the highest current of 17,000 amperes.

Effect of Interconnection of Arrester Ground and Secondary Neutral. An attempt was made to determine from the data what improvement in the protection of apparatus had been obtained at the locations where arrester grounds were interconnected with secondary neutrals. However, there were so

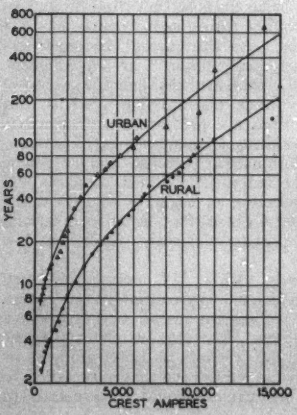

Fig. 6. Expectancy of discharge for urban and rural arresters

Curves show number of years at a given arrester location that may be expected to elapse before a current of at least the magnitude shown by the abscissa will pass through the arrester

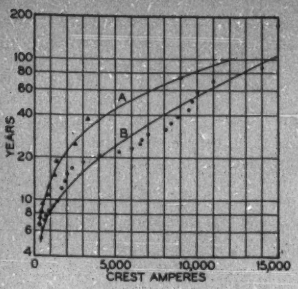

Fig. 7. Comparison of (*A*) 11 records obtained on 69 installations on 4-kv star-connected rural lines of the Commonwealth Edison Company, and (*B*) 71 records obtained from 300 installations on 4.8-kv delta-connected rural lines of the Detroit Edison Company

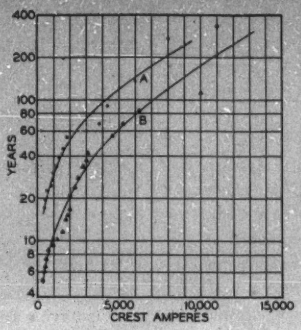

Fig. 8. Comparison of (*A*) 18 records obtained from 252 installations on 4-kv star-connected urban lines of the Commonwealth Edison Company, and (*B*) 67 records obtained from 298 installations on 4-kv star-con ected urban lines of the Edison Electric Illuminating Company of Boston

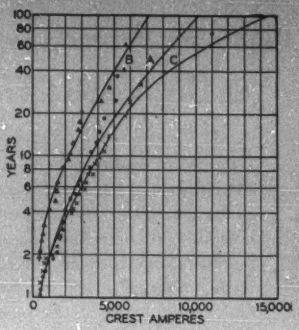

Fig. 9. Comparison of (*A*) 75 records obtained from 74 installations on 6.9-kv delta-connected rural lines, (*B*) 70 records obtained from 96 installations on the 11.5-kv delta-connected rural lines, and (*C*) 86 records obtained from 81 installations on the 11.95-kv star-connected rural lines of the Georgia Power Company

Figs. 7 to 9. Comparison of records obtained on different systems

Curves show number of years at a given arrester location that may be expected to elapse before a current of at least the magnitude shown by the abscissa will pass through the arrester

few installations that were not interconnected, and there were so few cases where protection of apparatus was not obtained, that no conclusions could be drawn. It may be that data to be obtained during the continuation of this investigation will make possible definite conclusions regarding this point.

Effect of System Voltage. Figure 7 compares the results from the 4 kv rural circuits of the Commonwealth Edison Company with those from the 4.8 kv rural circuits of the Detroit Edison Company. Although the Chicago results are from grounded neutral circuits while in Detroit the primary circuit is connected in delta, it is believed that the decreased "expectancy" in Detroit, which means more records per year, is probably attributable to greater exposure rather than the type of circuit employed. The Chicago installations, although they have been classified as rural, are probably in more urban territory than the other installations in this classification. Comparisons of this type between different locations are of very doubtful value at best, because of the great variation that is likely to exist in storm severity and number of storms. The United States Weather Bureau reported 82 thunderstorms in the Chicago area during the period of this investigation, compared with 36 in the Detroit area. The number of thunderstorms of course is not in itself a direct measure of the lightning severity to which distribution lines are subjected.

A similar comparison is made between the urban results from 252 installations on the 4-kv grounded-neutral system of the Commonwealth Edison Company and those from 298 installations on the 4-kv star-connected ungrounded circuits of the Edison Electric Illuminating Company of Boston (figure 8). Here again, there is probably considerable difference in the type of territory. The Boston installations are in suburban districts that are not built up to the same extent as the urban districts in Chicago with which they are compared. There were only 18 thunderstorms in the Boston area compared with the 82 in Chicago.

The results from lines of different voltage ratings in Georgia offer a better comparison, being all on the same system, although a considerable difference in storm severity probably exists because of the large territory covered. The Weather Bureau at Atlanta reported 69 thunderstorms during this investigation. The data, shown in figure 9, are all from rural installations. Since the number of installations were 74, 96, and 81, respectively, for the 6.9, 11.5, and 11.95 kv circuits, the data have about equal weight from the point of view of equality of chance. The 2 11 kv expectancy curves differ by a ratio of approximately 2 to 1 with insulation levels and types of construction approximately the same.

Considering the results of the 3 circuits together, no conclusion can be drawn with reference to circuit voltage. More data over a longer period of time will help to average out the effect of local storms which apparently give one circuit rating a more severe duty than some other.

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Lightning Protection of Distribution Transformers

Data on the results of lightning protection for distribution transformers on the system of the Georgia Power Company have been compiled, to determine the improvement resulting from changes which have been made, particularly the interconnection of the ground leads of the primary arrester with the transformer secondary neutral. The data indicate that such interconnection has not produced all the benefits expected. The experience with lightning protection is presented in an impartial manner, and without attempting to offer a solution of existing problems.

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THE system of the Georgia Power Company covering almost the entire State of Georgia, is exposed to lightning practically every month in the year. Transformer and lightning arrester losses have been higher than reported in other sections of the country, and a careful study is being made in an effort to find out what remedies can be applied.

In 1932, when interconnection of the ground lead of the primary arrester with the transformer secondary neutral came into prominence, it seemed that the answer had been found. Very careful investigations were made, and after full consideration it was decided to interconnect grounds as quickly as possible. However, it was late in 1932 before the work could be started, and comparatively few installations were made before the 1933 lightning season.

The results for 1933 seemed to indicate a marked improvement. There were practically no failures of interconnected transformers, and very few fuses blown. With such encouraging results it was expected that, as further interconnection was made, the good record would continue.

At the beginning of the 1934 season, approximately $^1/_2$ of the transformers were protected by interconnected lightning arresters. The season was one of the worst in many years; not only was there more lightning, but it was more severe. Transformers failed, fuses blew, and arresters were blown off the line. Naturally, an effort was made to investigate each case and determine the cause of failure. In most cases, the reason for the failure could be found, but in too many cases there was no apparent reason.

The work of interconnection was continued, and at the beginning of the 1935 season approximately 80 per cent of the arresters were interconnected. This year there have not been as many failures, but it is felt that there have been too many. This is evident from the curves of figure 3. These curves do not indicate a very marked or definite improvement in the operation of the system as a whole.

Considerable Data Collected

Various studies have been made—weather bureau reports have been carefully analyzed to see if any relation existed between failures; storm days, rainy days, temperature, and even wind conditions were tabulated. There seems to be only one relation, and that is with lightning days. The greater the number of days with lightning the greater the number of failures, and apparently the severity increased with the number of storm days.

There seems to be a slight inverse relation between

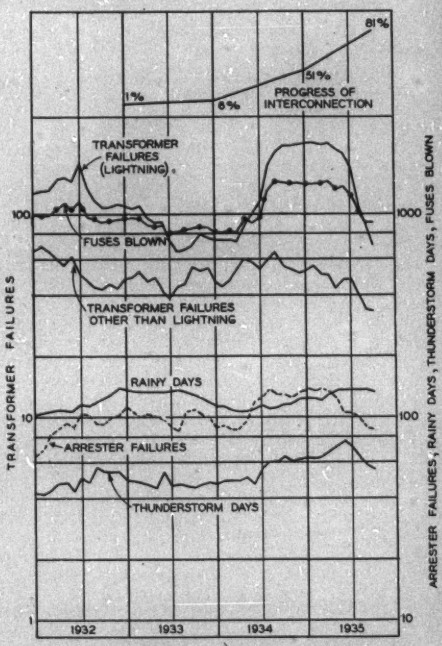

Fig. 1. Relation between weather conditions and lightning troubles

Figures are for the 12 months ending on the dates shown; Atlanta division only

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rainy days and failures, and this is shown by the curves given in figure 1. These curves are made up of a total of 12 months, ending with the month plotted. Therefore, variations from month to month are smoothed out and a much more regular curve obtained.

Referring again to figure 1, it will be noted that in 1933 there were about 130 rainy days, while in 1934 this figure dropped down to 110 to 120, and in 1935 back to over 130. It is an old saying that a thunderstorm coming before a rain will cause a great deal more damage than one following a rain, the explanation being that the rain decreases the resistance of trees, buildings, and other high objects and thus forms a drain to ground lessening the possibility of building up potentials in the clouds, and also the rain in falling transfers part of the cloud mass charge to earth. If this reasoning is true, then a lightning season with very few rainy days might be expected to be more severe than one with a greater number.

Data are given in table I for the entire system and for the Atlanta division for the years 1932 to 1935, inclusive. Except during the 9 months of 1935, data with reference to the performance of interconnected arrester are incomplete. However, for the entire company in 1934, 1.7 per cent of the transformers

Fig. 2. Relation between thunderstorm days and circuit outages

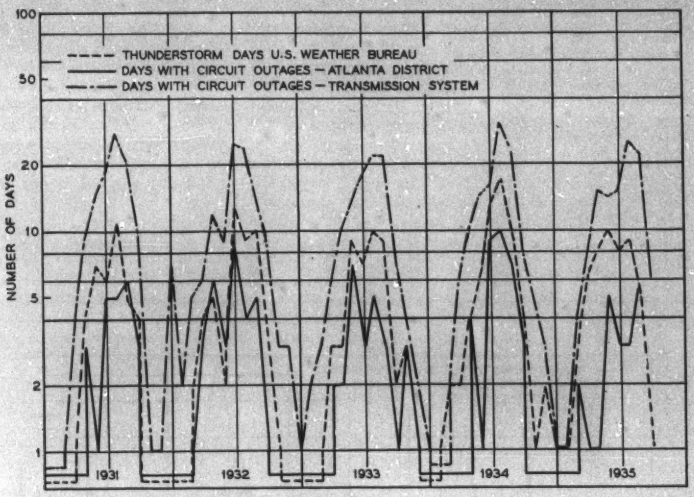

Table I—Lightning Troubles

	Entire Company				Atlanta Division			
	1932	1933	1934	1935	1932	1933	1934	1935
				(9 Mo.)				(9 Mo.)
Days with circuit outages	113	112	116	110	32	27	36	22
Total transformers	18,507	18,628	18,190	18,612	7,516	7,578	7,314	7,600
Total fuses blown (all causes)	4,266	4,092	6,058	3,671	960	819	1,424	818
Per 100 transformers	23.0	21.9	33.3	19.7	12.8	10.8	19.5	10.8
Transformer failures (lightning)	317	205	462	205	108	76	214	61
Per cent	1.71	1.10	2.54	1.10	1.44	1.00	2.93	0.80
Arrester failures	279	267	665	202	111	89	138	70
Per 100 transformers	1.51	1.43	3.66	1.08	1.48	1.18	1.89	0.92
With Interconnection								
No. of transformers *with* interconnected arresters	0	1,000	7,225	14,465	0	500	3,737	6,119
Per cent	0	5.4	39.8	77.8	0	6.6	51.0	80.5
No. of fuses blown (all causes)								529
Per 100 transformers								8.65
Transformer failures (ltg)			123	117			49	29
Per cent			1.70	0.81			1.31	0.47
Arrester failures				129				32
Per 100 transformers				0.89				0.52
Without Interconnection								
No. of transformers *without* interconnected arresters	18,507	17,628	10,965	4,147	7,516	7,078	3,577	1,481
Per cent	100	94.6	60.2	22.2	100	93.4	49.0	19.5
No. of fuses blown (all causes)								289
Per 100 transformers								19.5
Transformer failures (ltg)			339	88			165	32
Per cent			3.09	2.12			4.62	2.15
Arrester failures				73				38
Per 100 transformers				1.76				2.56

Table II—Summary of 1932, 1933, 1934, and 9 Months of 1935—2,300 Volt Overhead Transformer Failures From Lightning

Year	3 Kva	5 Kva	7.5 Kva	10 Kva	15 Kva	25 Kva	37.5 Kva	50 Kva	75 Kva	100 Kva and Over	Total
Entire Company—Number in Service											
1932	3,034	3,916	2,740	2,741	1,818	1,374	427	348	88	66	16,552
1933	2,813	4,114	2,667	2,792	1,915	1,460	468	367	111	98	16,805
1934	2,732	3,965	2,801	2,724	1,815	1,340	437	342	94	73	16,323
1935	2,751	4,088	2,875	2,744	1,852	1,364	437	334	97	80	16,622
Total	11,330	16,083	11,083	11,001	7,400	5,538	1,769	1,391	390	317	66,302
Number of Failures											
1932	85	73	31	33	16	2	0	2	0	1	243
1933	38	43	24	19	13	4	1	1	0	0	143
1934	108	113	49	41	31	14	2	3	0	0	361
1935	54	39	18	24	3	2	0	1	0	0	141
Total	285	268	122	117	63	22	3	7	0	1	888
Failures in Per Cent											
1932	2.47	1.87	1.10	1.20	0.90	0.15	0	0.58	0	0.15	1.47
1933	1.34	1.04	0.90	0.68	0.274	0.214	0.273	0	0	0	0.85
1934	3.95	2.85	1.70	1.50	1.70	1.00	0.50	0.80	0	0	2.21
1935	1.96	0.95	0.63	0.87	0.16	0.15	0	0.30	0	0	0.85
Total	2.52	1.67	1.10	1.06	0.85	0.40	0.17	0.50	0	0.31	1.34
Atlanta Division Only—Number in Service											
1932	1,370	1,468	1,097	1,181	949	793	274	201	38	34	7,516
1933	1,278	1,456	1,084	1,163	908	764	262	193	37	35	7,180
1934	1,192	1,484	1,119	1,170	905	749	267	189	37	38	7,150
1935	1,194	1,601	1,188	1,199	932	763	265	183	37	41	7,403
Total	5,034	6,009	4,488	4,713	3,694	3,069	1,068	766	149	148	29,219
Number of Failures											
1932	27	31	18	17	7	3	0	1	0	0	104
1933	11	22	15	6	10	3	1	1	1	0	70
1934	47	62	30	26	21	9	1	2	0	0	198
1935	18	16	9	13	1	1	0	0	0	0	58
Total	103	131	72	62	39	16	2	4	1	0	430
Failures in Per Cent											
1932	1.96	2.14	1.64	1.43	0.74	0.378	0	0.548	0	0	1.38
1933	0.862	1.51	1.38	0.515	1.10	0.392	0.382	0.52	2.70	0	0.973
1934	3.94	4.17	2.52	2.22	2.32	1.20	0.375	1.06	0	0	2.77
1935	1.50	1.00	0.756	1.08	1.08	0.107	0.131	0	0	0	0.783
Total	2.05	2.18	1.60	1.31	1.05	0.52	0.19	0.52	0.67	0	1.47

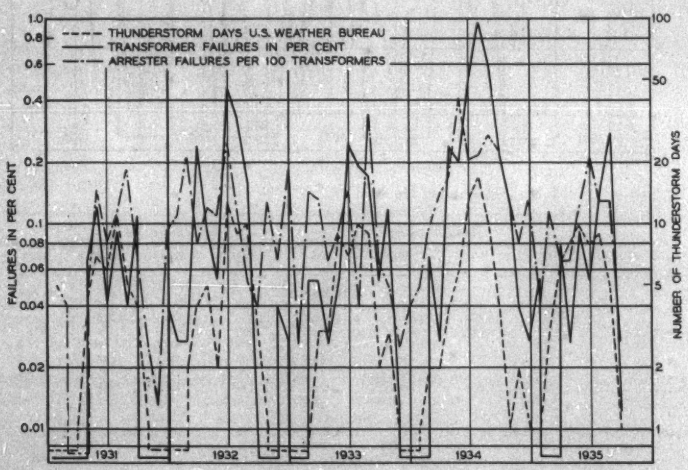

Fig. 3. Relation of thunderstorm days to arrester failures and transformer failures

with interconnected arresters failed, while 3.09 per cent without interconnection failed. For the 9 months of 1935, the percentages were 0.81 and 2.12, respectively. Similar results are obtained for the Atlanta district. These results indicate that the interconnected performance was better by a ratio of somewhat more than 2 to 1. Concerning fuse blowings, a similar result is found for 1935 in the Atlanta district, although fuses blown during lightning storms are not segregated.

Table I also indicates a reduction in the percentage of arrester failures when the arrester is interconnected. Since this represents but 9 months of 1 year, it may not be significant. Of course, with fur-

ther interconnection, the opportunity of further comparison will be lost, it being possible only to compare one year with another, which will be affected by storm severity to a much greater degree.

When making comparisons between interconnected arrester performance and those not interconnected, it is realized that they are not operating under identical storm conditions; in fact, the differences over a state as large as Georgia are likely to be very marked.

Tables II, III, and IV show the record of the past 4 years by voltage class and kilovoltampere rating of transformers. These data show, as shown by other similar tabulations, that in general the smaller transformers in a given voltage class are more susceptible to failure. Presumably, these results are due in part to the age of transformers, their condition, and their size. It is somewhat surprising to note in table II that with the single exception of the 3 kva rating, the percentage of 2,300 volt transformers which failed outside of the Atlanta division is less than inside. When making this comparison attention should be called to the fact that the exposure in the Atlanta district is nearly as bad as in the outlying districts. No explanation has been found for the relatively poorer record in Atlanta.

Attention should also be called to the increase in percentage of troubles with the transformers in the higher voltage ratings, as given in tables III and IV. The data show nearly 5 times as high a percentage failure in 11.5 kv transformers as was found with the 2,300 volt transformers. No good explanation has been found for this as yet, and discussion from others on this point would be helpful.

Lightning Severity

That the severity of lightning increases with the frequency in a given area has been demonstrated by the records obtained from klydonograph records obtained from the Lithonia substation for 1934 and 1935. When the storms were frequent the potentials measured appeared to be greater in magnitude.

Another interesting point on the severity of lightning was brought out by the use of recorders, and that is, the areas high above sea level are more subject to lightning troubles. Although the frequency of storms reported by the U.S. Weather Bureau for the area around Brunswick is higher than for Atlanta, it was found in the studies discussed herein that the mountainous sections have more storms that can be measured than the lowlands of South Georgia. Therefore, the relation between frequency and severity must be confined to a given area.

An interesting comparison of days with lightning

Table III—Summary of 1932, 1933, 1934, and 9 Months of 1935—6,900 Volt Overhead Transformer Failures From Lightning

	3 Kva	5 Kva	7.5 Kva	10 Kva	15 Kva	25 Kva	37.5 Kva	50 Kva	75 Kva	100 Kva and Over	Total
Entire Company—Number in Service											
1932	289	275	108	90	53	55	6	11	14	24	925
1933	344	277	91	73	65	68	13	8	14	24	977
1934	331	322	101	91	65	65	15	8	14	24	1,036
1935	339	340	113	90	76	76	15	10	14	23	1,096
Total	1,303	1,214	413	344	259	264	49	37	56	95	4,034
Number of Failures											
1932	14	18	4	3	2						42
1933	5	10	3	1	1						20
1934	18	22	7			1					48
1935	9	8	3	3		1					24
Total	46	58	17	7	4	2					134
Failures in Per Cent											
1932	4.8	6.5	3.7	3.3	5.7						4.54
1933	1.45	3.62	3.3	1.37	1.54						2.05
1934	5.4	6.7	6.9			1.5					4.64
1935	2.65	2.35	2.65	3.33		1.3					2.20
Total	3.52	4.75	4.1	2.04	1.54	0.75					3.33

Table IV—Summary of 1932, 1933, 1934, and 9 Months of 1935—11,500 Volt Overhead Transformer Failures From Lightning

	2.5 Kva	5 Kva	10 Kva	15 Kva	25 Kva	37.5 Kva	50 Kva	75 Kva	100 Kva and Over	Total
Entire Company—Number in Service										
1932	23	259	46	14	45	11	8	3	10	419
1933		318	53	16	46	16	8	8	7	472
1934	25	337	65	27	55	17	8	7	7	548
1935	24	364	62	28	56	17	8	6	7	572
Total	72	1,278	226	85	202	61	32	24	31	2,011
Number of Failures										
1932	1	25	6							32
1933		34	7							41
1934	3	38	9							50
1935	4	23	8	1						36
Total	8	120	30	1						159
Failures in Per Cent										
1932	4.0	9.8	13.4							7.75
1933		10.8	13.2							8.70
1934	12.0	11.4	14.0							9.00
1935	5.5	6.3	12.9	3.57						6.30
Total	11.1	9.4	13.2	1.17						7.90

is that of circuit outages, shown in figure 2. The thunderstorm days are those reported by the Weather Bureau for Atlanta and naturally there are a great number of storms reported that do not cause outages. The days with outages shown for the transmission system cover the entire state and naturally exceed the storm days reported in Atlanta. In going over these records it is sometimes possible to follow a storm over the state. It may start in North Georgia and continue down the length of the state, taking 2 or 3 days.

Arrester Failure

One of the most difficult problems to solve is that of arrester failure. From the curves and tables it will be noted that failures on this system are high. In checking up on the number of arresters purchased since January 1927 and estimating the number now on the system, it is found that since 1927 almost enough have been purchased to have replaced every arrester. This is certainly true of the 6,900 and 11,500 volt systems.

An old saying of linemen and substation maintenance men is that arresters fail more frequently in areas of high ground resistance. This is contrary to all theory, but a number of cases are known where there was high ground resistance, and where arrester failures have been frequent. The grounds have

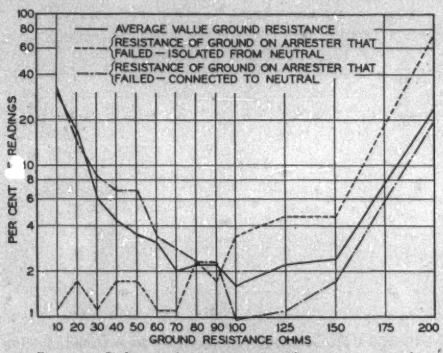

Fig. 4. Relation between ground resistance and arrester failures

been treated to lower the resistance and the number of arresters failing has decreased. These cases are too numerous to pass by lightly, and indicate that something is lacking in the theory of arrester performance.

In an effort to find the answer 176 cases of arrester failure were picked out at random and the resistance of the grounds was measured. The resistance was measured with the arrester ground disconnected from the neutral, and then measured with the ground connected to the neutral. The results are shown in figure 4, and it is apparent that there are very few individual grounds with a resistance under 100 ohms, but this number is materially increased by connecting the arrester ground to the secondary neutral.

On this curve is plotted also an average value of ground resistance, made up from some 800 different tests. While this small number will not reflect the true picture of the entire power system, it should be indicative of what might be expected.

If it is assumed that the arresters are destroyed by surge currents the single electrode resistance would be expected to be the determining factor, as the surge impedance of one span of neutral would be so high that there would be very little benefit from it. Yet it is found that over 70 per cent of these failures have

Table V—Analysis of 176 Cases of Arrester Failure

	3 Kv	6 Kv	9 Kv	12 and 15 Kv	Total
Number of arrester failures	112	2	32	30	176
per 100 transformers	0.67	1.3	2.92	5.25	0.93
Ground resistance—isolated	170	110	178	169	171
Ground resistance—combined	57.50	100	86	72	65

isolated ground resistance of over 200 ohms, and the lineman's argument would be correct.

If on the other hand it is assumed that leakage current and power follow current destroy the arresters, the combined resistance would be the one to consider, and it is found that this curve follows very closely the curve of average values obtained in this study. This would indicate that taken on a percentage basis the failure rate for each value of ground resistance is constant. Further analysis of these 176 failures gives the results shown in table V. From these figures it would seem that ground resistance does not influence arrester failures.

Location of Arrester

On transformers with the neutral interconnected, the arresters have been placed on the load side of the fuse. There were several reasons for doing this, although it was expected that there would be a few more outages. However, the number of fuses blown has been considerably higher than expected, and seems to indicate something lacking in the theory of interconnection.

In view of the voltages that can be expected on distribution lines, it does not seem possible to have frequent fuse blowing from surge currents. The amount of power current flowing through the arrester during discharge should not be enough to cause fuses to blow. Yet they are being blown so frequently that the arresters are being changed so as to be ahead of the fuse, to stop these interruptions.

The arrester was mounted on the transformer "kick" arm as this brought the arrester close to the equipment to be protected. The ground lead was brought across the arm to the pole and then down to the ground. The tie to the neutral was connected just under the arm and run up the pole to the secon-

dary neutral. The neutral lead of the transformer was connected to this secondary neutral about 18 inches from the pole. Thus there was a rather long run from the arrester ground terminal to the neutral lead of the transformer. On 6,900 and 11,500 volt construction this distance was on the order of 12 or 14 feet.

It is impossible to say just what the surge impedance of this lead would be, but it is felt that it is high enough to cause in some cases an impedance drop to build up that will flash over the leads and bushings before the potentials are equalized. Therefore, the specifications are being changed, the arrester being placed on the hanger arm, and the neutral tie being carried directly across the top of the transformer case.

Causes of Transformer Failure

The failures of interconnected transformers have been investigated wherever possible, and a great number of contributory conditions have been found. Most important of these are the following:

1. Transformers having bad leads and bushings.
2. Arresters that looked good on casual inspection but were found to be bad on closer inspection or on breaking.
3. Close clearances in small transformers.
4. Evidence of a direct stroke of lightning in the immediate vicinity of the transformer.
5. The tie between the arrester ground and neutral seemed too long and probably its impedance was of such value that the transformer flashed over before the secondary winding and case were brought up to surge potential. This point has not been proved yet, and some tests under laboratory conditions may be made to determine what effect this will have.
6. The ability of the transformer case to float, especially on a wet pine pole was studied very carefully, and it is believed the case should be tied in to the circuit directly or through a gap. However, this practice has not been started except on 6,900 volts and higher.

Remedies

In order to overcome the above conditions, the following changes in methods have been made:

1. The test voltage has been raised on all transformers, both new and rebuilt, to 75 per cent of the new A.I.E.E. test voltages.
2. When leads and bushings are replaced, the transformer is removed to the shop and new bushing and lead assemblies put in.
3. Small cores and coils have been put in larger cases, i. e., a 5 kva unit put in a 7.5 kva case.
4. New type cases were purchased for 11,500 volt units and the old cases used for lower voltage units.
5. The design of the transformer structure has been changed placing the arrester on the hanger arm and tying the grounds together by a short tie directly across the top of the transformer to the neutral.
6. The arrester ground is being tied to the transformer case, on all 6,900, 11,500 and 13,800 volt transformers, thus making the neutral, case, and arrester ground common.

This paper is written to give others the benefit of experience on one power system, and is not offered with the idea that solutions to existing difficulties have been found. Some gain has been made through interconnection, and some of the changes which are to be made in the transformers and proetctive arrangement will, it is hoped, lead to improvement.

A New Trigger Circuit for Closing a Switch

An electronic device is described for controlling the closing of a relay or switch at a predetermined point on the wave form of an a-c source. Current for closing the relay is controlled by a gas filled triode, the firing of which is obtained by the distorted wave of a multivibrator. The output of the multivibrator is made to change phase with reference to the a-c voltage wave. The device is useful for the study of transients.

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SEVERAL devices have been designed for closing (or opening) a switch or contactor at a predetermined point on the voltage or current wave form. Thus, Kennelly and Nabeshima[1] used a commutator revolved by a synchronous motor, obtaining the phase shift by turning of contactors. H. R. Reed[2] used a similar device. A synchronous motor, however, has inertia and is subject to hunting which may affect the time of closing of the switch by several degrees. W. Orkney[3] used a gas or vapor filled electronic tube, the firing of which was controlled by a sinusoidal wave. In one of Orkney's circuits, the firing was obtained at the peak of the sinusoidal wave where it is changing at its slowest rate; hence the results could not be reproduced closer than a few degrees. The circuit herein described uses an argon-filled 3-element electronic tube and the firing is obtained by superimposing a wave, having a very steep front and well defined peak, on the steady grid bias. The results obtained can be reproduced to within a fraction of a degree in terms of 60 cycle frequency.

Description of Apparatus

The apparatus used consists of 3 principal parts. First, a gas filled triode, whose anode current controls the magnet or solenoid of the relay or contactor. In the present experiments, an argon filled tube was used, but any gas-filled grid-controlled tube will operate as well. Second, a multivibrator is used,

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1. For all numbered references, see list at end of paper.

whose output is controlled by an a-c voltage from the same mains used on the contactor and load. The output of the multivibrator is added in series with the steady grid bias. The peak of the multivibrator wave initiates the discharge. Third, a phase shifter or similar device is used to produce a relative shift in phase between the multivibrator control and the a-c supply to the switch or contactor. The diagram of connections is given in figure 1, but before proceeding with an explanation of the method of operation, it will be best to describe the individual parts more in detail.

The multivibrator[4] is a well known device used in the radio art to obtain a wave form very rich in harmonics, and as such it is used extensively for frequency multiplication. Briefly, it consists of a 2-stage capacity-resistance coupled amplifier, the output of one vacuum tube being fed back to the grid circuit of the other as shown in figure 1. The output of the second tube has the proper phase relation to the input of the first; thus the device will oscillate of its own accord. The wave form obtained has, in general, a very steep front[5] and is more or less rectangular in shape. With the tubes and values shown on figure 1, it was possible to obtain a wave shape with a very sharp peak, although for the purpose on hand, this extreme was not necessary. The period of oscillation is roughly of the order given by the product of the capacity of the capacitor C_1 and the resistance r_1. However, if one of the plate resistances is made very much larger than the other, it is possible, by the introduction of a small controlling voltage into the common plate lead, to bring the natural frequency of the multivibrator into exact synchronism with that of the controlling voltage, provided the natural frequency of the multivibrator is not far from that of the control. It has also been found[6] that the phase relation between the controlling voltage and the output is constant and permanent for a given set up. It is this feature of the multivibrator that makes it useful in the present device. Another advantage is that the wave front of the output is very steep, almost perpendicular. Dye[5] states that even in terms of a frequency of 1,000 cycles per second, the change from zero to maximum takes place almost instantaneously. Figure 2 bears out this statement.

The phase of the multivibrator output with respect to the a-c supply voltage can be changed by various methods. In figure 1, a 3 phase shifter is used, which permits 360 degree change. However, for most purposes, a 90 degree phase shift is perhaps all that is necessary. Changing the grid resistance r_1, figure 1, causes a phase shift of about 45 degrees. Further change can be obtained by use of a capacitor in parallel with a variable resistance in the control circuit; this is a well known device.

Time Delay

The multivibrator output is impressed upon the grid of the argon filled triode as shown in figure 1, and again, diagrammatically, in figure 3. Since the voltage applied to the anode of the triode is direct current the tube should fire whenever the grid potential reaches the critical point, which, for the case shown, is about −4 volts. When the triode fires, the relay or contactor is closed, and the transient is initiated on the load. In order to obtain a photographic record with an ordinary oscillograph, it is necessary to introduce a time delay to give time for the oscillograph shutter to open. This time delay is obtained by the well known device shown on the figures. With the switch S closed, a steady bias of approximately −16 volts is impressed on the grid. As shown on figure 3, the peaks of the multivibrator output (in series with the steady bias) are too low to

Fig. 2. Distorted wave of multivibrator output. Note steep front

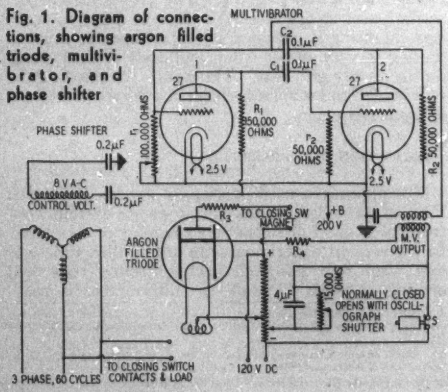

Fig. 1. Diagram of connections, showing argon filled triode, multivibrator, and phase shifter

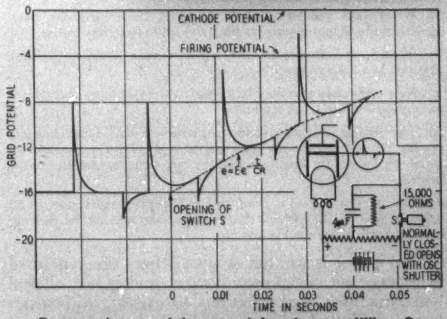

Fig. 3. Action of the time delay device. When S is opened, the steady bias is shifted, but the grid potential does not change until the capacitor has discharged

Fig. 4. Oscillograms of transients on a resistive load using the same setting of apparatus. Note accuracy with which results can be duplicated

Fig. 5. Oscillograms of transients on a resistive load, using 2 different settings, 90 degrees apart

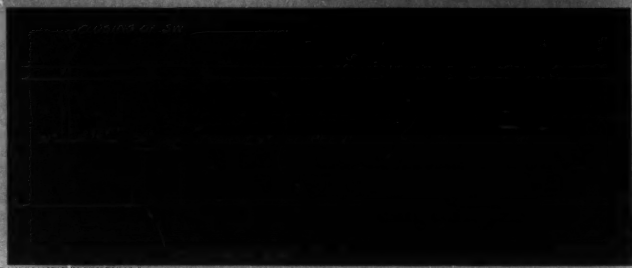

Fig. 6. Oscillograms of transients on an inductive resistance load at 2 preselected points 90 degrees apart. Note the small resistance transient in one case, and large inductive transient in the other

cause firing. When the shutter trigger on the oscillograph is tripped, the switch S is opened, and the bias is changed to the -4 volt point, but before the grid can assume this potential, the capacitor has to discharge through the resistor so that the peaks climb slowly toward the firing potential. As shown on the figure, the first peak after opening of S does not quite reach the firing point, but the second does. Now, due to the very steep wave front, a change in grid bias will not affect the point of firing with reference to the multivibrator wave, although it will change the time delay. The peaks of the multivibrator wave bear a fixed relation to the a-c supply voltage; hence, it is possible to obtain closing of the switch at a given point of the wave. The ionization time of the argon filled triode used is of the order of 10 microseconds, which, in terms of 60 cycle frequency, is only a few tenths of a degree, so that on this score, the error is small. Greater errors are encountered in the constancy of the closing time of the relay or contactor.

Method of Operation, and Results

Referring to figure 1, the solenoid or magnet of the contactor is placed in series with the plate of the triode, and the protective resistor R_3. The phase shifter is set at a given point, and a preliminary oscillogram is taken. The point at which the contactor closes in relation to the voltage wave is determined from the oscillogram and compared to the phase shifter position. Thereafter, if the phase shifter head is calibrated in degrees, it is possible to change the position of closing to any predetermined point.

Some of the oscillograms taken are given. Figure 4 shows 2 oscillograms taken with a resistive load using the same setting of the apparatus, and illustrates the accuracy with which results can be reproduced. Although on this figure time is given in microseconds, it is not claimed that measurements closer than the third significant figure are possible. Many other similar oscillograms show that the time of closing can be duplicated within 20 to 30 microseconds which corresponds to less than a degree at 60 cycle frequency. See also figure 5. Figure 6 shows 2 oscillograms of an inductive resistance, taken at 2 preselected points 90 degrees apart. One shows only the small resistance transient; the other a large inductive transient. The fact that it was possible to take these 2 oscillograms on the same film gives conclusive evidence of the reliability of the apparatus and the accuracy with which results can be predicted.

In addition to the possibility of obtaining transients for subsequent study of switching operations, the device should find useful applications for closing or opening a switch so as to minimize transients or destructive arcing.

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News
Of Institute and Related Activities

Technical Program Announced for the A.I.E.E. Winter Convention

THE TECHNICAL program for the A.I.E.E. winter convention which will be held in the Engineering Societies Building, 33 West 39th Street, New York, N. Y., January 28–31, 1936, is, as usual, of broad scope and timely interest. The convention will convene on a Tuesday and technical sessions will be held both morning and afternoon for the first 3 days. Arrangements are being made for the smoker on Tuesday evening, which is expected to at least duplicate the noteworthy success of the last winter convention smoker. Wednesday evening the Edison Medal presentation will take place and on Thursday evening the dinner-dance will be held at the well-known Hotel Plaza. Friday will be devoted exclusively to inspection trips to interesting places in the city and the vicinity.

The well-balanced program will be interspersed with committee meetings, of importance to many members. Also, arrangements are being made for a luncheon meeting of the committee on education and the Student Branch counselors on Wednesday, January 29. While the daily business programs are quite concentrated, ample opportunities through the days and evenings will occur to renew acquaintanceships and converse with friends. Plan now to attend the convention and keep abreast of the developments in the profession. Details of the various features now being arranged will be announced in the January 1936 issue of ELECTRICAL ENGINEERING. The technical program, however, is given in this article.

TECHNICAL PAPERS

Thirteen technical sessions and one technical conference have been scheduled to bring forth a number of developments in specialized fields. Several of the papers for these sessions are of international importance, particularly the adoption by the International Electrotechnical Commission of the meter-kilogram-second system of units, the story of which will be told by Dr. A. E. Kennelly. Also, 2 papers from France will treat the developments in the electrochemical and electrometallurgical industries in that country. One of these papers will describe the electric furnace with carbon radiator, which has been perfected to a high degree in France.

Another group of papers sure to be of outstanding interest will be presented in the protective devices session. Several of these papers will present data obtained from this year's lightning season in various sections of the country. Data will be included on lightning arrester performance and the protection of distribution transformers, some of it the first presented in respect to the interconnection of the primary and secondary neutrals.

At 1 or 2 other sessions and the conference on electric welding, demonstrations of electrical phenomena by means of high speed motion pictures will play an important part. In each case the technique of obtaining the pictures will be explained. The latest design practices in the development of synchronous machinery as well as recent studies in commutation will be presented at 2 sessions on electrical machinery. Many other papers of interest appear on the program.

The schedule for the 13 sessions and the papers to be presented at each session are given in the accompanying columns. For the papers which have been published, reference to the issue and page is given after each title. Members who wish to follow the presentations in detail and discuss papers should take their issues with them or prepare their discussions in advance. The conference on electric welding will be devoted to demonstrations without publication of papers or the discussions.

RULES ON PRESENTING AND DISCUSSING PAPERS

At some of the technical sessions, a few papers may be presented only by title. This will permit the devotion of more time to discussion. At other sessions, papers will be presented in abstract, 10 minutes being allowed for each paper unless otherwise arranged, or the presiding officer meets with the authors preceding the session to arrange the order of presentation and allotment of time for papers and discussion. Authors will be notified officially in each case about one month in advance.

Any member is free to discuss any paper when the meeting is thrown open for general discussion. Usually 5 minutes are allowed to each discusser for the discussion of a single paper or of several papers on the same general subject. When a member signifies his desire to discuss several papers not dealing with the same general subject, he may be permitted to have a somewhat longer time.

It is preferable that a member who wishes to discuss a paper give his name in advance to the presiding officer of the session at which the paper is to be presented. Each discusser is to step to the front of the room and announce, so that all may hear, his name and professional affiliations. Three typewritten copies of discussion prepared in advance should be left with the presiding officer.

Other discussion to be considered for publication must be submitted, typed double spaced, in triplicate to C. S. Rich, secretary of the technical program committee, A.I.E.E. headquarters, 33 West 39th St., New York, N. Y., on or before Feb. 14, 1936. Discussion received after this date will not be accepted.

New York, busiest port of the United States, offers numerous attractions. Among the many inspection trips which will be made available to Institute members during the forthcoming winter convention in New York, January 28–31, 1936, is a visit to a modern steamship. Shown here is the "S.S. California" of the Panama-Pacific Lines. Details of inspection trips will be announced in the January 1936 issue

Tentative Technical Program

In this program, reference to the issue and, in so far as possible, to the page in ELECTRICAL ENGINEERING, is given for all papers which are being published up to and including this issue.

Tuesday, January 28

9:00 a.m.—Registration

10:00 a.m.—Opening of Convention

10:30 a.m.—Communication

APPLICATIONS OF A PHOTOELECTRIC CELL, A. H. Lamb, Weston Electrical Instrument Corp. Nov. issue, p. 1186–95

ANODE MATERIALS FOR HIGH VACUUM TUBES, E. E. Spitzer, RCA Manufacturing Co., Inc. Nov. issue, p. 1246–51

A CABLE CODE TRANSLATOR SYSTEM, A. F. Connery, The Commercial Cable Co. Nov. issue, p. 1162–6

MEASUREMENT OF TELEPHONE NOISE AND POWER WAVE SHAPE, J. M. Barstow and P. W. Blye, Bell Telephone Laboratories, Inc., and H. E. Kent, Edison Electric Institute. Dec. issue, p. 1307–15

10:30 a.m.—Electrophysics—I

I.E.C. ADOPTS MKS SYSTEM OF UNITS, A. E. Kennelly, Harvard University. Dec. issue, p. 1373–84

PARALLEL INVERTER WITH RESISTANCE LOAD, C. F. Wagner, Westinghouse Electric and Mfg. Co. Nov. issue, p. 1227–35

2:00 p.m.—Instruments and Measurements

HIGH SPEED MOTION PICTURES, H. E. Edgerton, Massachusetts Institute of Technology. Feb. issue, p. 149–53

BRIDGE MEASUREMENT OF ELECTROMAGNETIC FORCES, A. C. Seletzky and G. L. Priday, Case School of Applied Science. Nov. issue, p. 1149–52

POWER AND ENERGY—POSITIVE AND NEGATIVE, L. A. Doggett and H. I. Tarpley, Pennsylvania State College. Nov. issue, p. 1204–9

THE COMPENSATED ELECTROTHERMIC AMMETER, W. N. Goodwin, Jr., Weston Electrical Instrument Corp. Scheduled for Jan. 1936 issue

2:00 p.m.—Electrophysics—II

EARTH RESISTIVITY AND GEOLOGICAL STRUCTURE, R. H. Card, American Telephone and Telegraph Co. Nov. issue, p. 1153–61

CURRENT HARMONICS IN NONLINEAR RESISTANCE CIRCUITS, T. D. Owens, Case School of Applied Science. Oct. issue, p. 1055–7

A GENERALIZED INFINITE INTEGRAL THEOREM, M. G. Malti, Cornell University. Nov. issue, p. 1222–7

EFFECT OF TOTAL VOLTAGE ON BREAKDOWN IN VACUUM, H. W. Anderson, Iowa State College. Dec. issue, p. 1315–20

TWO METHODS OF MAPPING FLUX LINES, F. W. Godsey, Jr., Sprague Specialties Co. Oct. issue, p. 1032–6

* These papers may be presented but they have not been accepted for publication at the time of going to press. Of these papers, those which are accepted will, in so far as is possible, be published in the January 1936 issue.

Wednesday, January 29

10:00 a.m.—Power Transmission

ECONOMICAL LOADING OF UNDERGROUND CABLES, E. A. Church, Edison Electric Illuminating Co. of Boston. Nov. issue, p. 1166–72

THE PYROCHEMICAL BEHAVIOR OF CELLULOSE INSULATION, F. M. Clark, General Electric Co. Oct. issue, p. 1088–94

RESOLUTION OF SURGES INTO MULTIVELOCITY COMPONENTS, L. V. Bewley, General Electric Co. Nov. issue, p. 1199–1203

CORONA LOSSES AT 230 KV WITH ONE CONDUCTOR GROUNDED, J. C. Carroll, Stanford University, and D. M. Simmons, General Cable Corp. Aug. issue, p. 846–7

LIGHTNING CURRENTS IN FIELD AND LABORATORY, P. L. Bellaschi, Westinghouse Electric and Mfg. Co. Aug. issue, p. 837–43

10:00 a.m.—Synchronous and Other Machines

"ANGLE SWITCHING" OF SYNCHRONOUS MOTORS, C. C. Shutt and J. W. Dawson, Westinghouse Electric and Mfg. Co. Nov. issue, p. 1191–5

LOAD LOSSES IN SALIENT POLE SYNCHRONOUS MACHINES, E. I. Pollard, Westinghouse Electric and Mfg. Co. Dec. issue, p. 1332–40

PULL-IN CHARACTERISTICS OF SYNCHRONOUS MOTORS, D. R. Shoults, S. B. Crary, Jr., and A. H. Lauder, General Electric Co. Dec. issue, p. 1385–95

*MECHANICAL AND ELECTRICAL PROBLEMS INVOLVED IN THE DESIGN AND CONSTRUCTION OF LARGE TURBINE GENERATORS, C. M. Laffoon, M. D. Ross, and L. A. Kilgore, Westinghouse Electric and Mfg. Co.

SEGREGATION OF LOSSES IN SINGLE PHASE INDUCTION MOTORS, C. G. Veinott, Westinghouse Electric and Mfg. Co. Dec. issue, p. 1302–6

10:00 a.m.—Electrochemistry and Electrometallurgy

THE ENGINEERING DEVELOPMENT OF ELECTROCHEMISTRY AND ELECTROMETALLURGY, Paul Bunet, Paris, France. Dec. issue, p. 1320–31

INDUCTION HEATING AT LOW TEMPERATURES, B. L. Bailey, Chrysler Motor Corp. Nov. issue, p. 1210–2

ELECTRIC FURNACES WITH CARBON RADIATOR, Henri George, Saint-Gobain Co. Nov. issue, p. 1195–9

POWER COMPANY SERVICE TO ARC FURNACES, L. W. Clark, The Detroit Edison Co. Nov. issue, p. 1173–8

2:00 p.m.—Symposium on Magnetic Materials

PRESENT STATUS OF FERROMAGNETIC THEORY, R. M. Bozorth, Bell Telephone Laboratories, Inc. Nov. issue, p. 1251–61

SILICON STEEL IN COMMUNICATION EQUIPMENT, C. H. Crawford and E. J. Thomas, General Electric Co. Dec. issue, p. 1348–53

CHARACTERISTICS OF PERMANENT MAGNET MATERIALS, C. S. Williams, Westinghouse Electric and Mfg. Co. Scheduled for Jan. 1936 issue

MAGNETIC ALLOYS OF IRON, NICKEL, AND COBALT, G. W. Elmen, Bell Telephone Laboratories, Inc. Dec. issue, p. 1292–9

HIGH POWER AUDIO TRANSFORMER FOR CLASS B AMPLIFICATION, J. F. Peters, Westinghouse Electric and Mfg. Co. Scheduled for Jan. 1936 issue

IMPROVEMENTS IN COMMUNICATION TRANSFORMERS, A. G. Ganz and A. G. Laird, Bell Telephone Laboratories, Inc. Dec. issue, p. 1367–73

2:00 p.m.—Electrical Machinery

FLASHING OF RAILWAY MOTORS CAUSED BY BRUSH JUMPING, R. E. Helmund, Westinghouse Electric and Mfg. Co. Nov. issue, p. 1178–85

ELECTRICAL BRUSH WEAR, V. P. Hessler, Iowa State College. Oct. issue, p. 1050–4

A STATIC THERMIONIC TUBE FREQUENCY CHANGER, A. Schmidt, Jr., and R. C. Griffith, General Electric Co. Oct. issue, p. 1063–7

SELF EXCITATION OF A FREQUENCY CONVERTER, Oscar Hess, Belmont, Mass. Dec. issue, p. 1359–66

VIBRATORILY COMMUTATED STATIONARY CONVERSION, G. T. Southgate, Consulting Engineer. Nov. issue, p. 1213–21

BREAKDOWN CURVE FOR SOLID INSULATION, V. M. Montsinger, General Electric Co. Dec. issue, p. 1300–1

2:00 p.m.—Automatic Stations

SYSTEM POWER DISPATCHING BY REMOTE METERING AND AUTOMATIC LOAD CONTROL, J. T. Logan, Georgia Power Co. Scheduled for Jan. 1936 issue

*SUPERVISORY CONTROL AND REMOTE METERING ON THE PENNSYLVANIA RAILROAD ELECTRIFICATION, J. V. B. Duer, Pennsylvania Railroad.

*AUTOMATIC SWITCHGEAR FOR MERCURY ARC RECTIFIERS, H. Bany, General Electric Co., and M. E. Reagan, Westinghouse Electric and Mfg. Co.

APPLICATION OF SUPERVISORY CONTROL EQUIPMENT, S. A. Canariis, Bureau of Water, City of Pittsburgh. Scheduled for Jan. 1936 issue

Thursday, January 30

10:00 a.m.—Symposium on Modernization of Distribution Systems

MODERNIZATION OF HIGH AND MEDIUM VOLTAGE TRANSMISSION LINES, Lightning and Insulating Subcommittee. Scheduled for Jan. 1936 issue

*MODERNIZATION OF DISTRIBUTION, H. P. Seelye, The Detroit Edison Co.

*MODERNIZATION OF RELAY SYSTEMS ON TRANSMISSION NETWORKS, C. A. Muller and H. E. Turner, American Gas and Electric Co.

*MODERNIZATION OF LIGHTNING PROTECTION EQUIPMENT—TRANSFORMER PROTECTION, Transformer Subcommittee and Lightning Arrester Subcommittee.

10:00 a.m.—Transportation

THE SPEED-TIME ELECTROGRAPH, P. C. Cromwell, New York University. Sept. issue, p. 923–30

THE "COMET"—A DIESEL ELECTRIC UNIT TRAIN, A. H. Candee, Westinghouse Electric and Mfg. Co. Nov. issue, p. 1240–5

THE "BIWAY" SYSTEM OF ELECTRIC PLATFORMS FOR MASS TRANSIT, N. W. Storer, Westinghouse Electric and Mfg. Co. Dec. issue, p. 1340–7

2:00 p.m.—Protective Devices

PILOT WIRE RELAY PROTECTION, E. E. George and W. R. Brownlee, Tennessee Electric Power Co. Nov. issue, p. 1262–9

LIGHTNING PROTECTION OF DISTRIBUTION TRANSFORMERS, L. G. Smith, Consolidated Gas, Lt. and Pwr. Co. Scheduled for Jan. 1936 issue

LIGHTNING PROTECTION OF DISTRIBUTION TRANSFORMERS, J. M. Flanigen, Georgia Power Co. Dec. issue, p. 1400–5

LIGHTNING INVESTIGATIONS IN CHICAGO, Herman Halperin and E. H. Grosser, Commonwealth Edison Co. Scheduled for Jan. 1936 issue

DISCHARGE CURRENTS IN LIGHTNING ARRESTERS, K. B. McEachron and W. A. McMorris, General Electric Co. Dec. issue, p. 1395–9

LIGHTNING ARRESTER ECONOMICS, Philip Sporn and I. W. Gross, American Gas & Electric Co. Scheduled for Jan. 1936 issue

2:00 p.m.—Conference on Electric Welding

DEMONSTRATION—APPLICATION OF HIGH-SPEED PHOTOGRAPHY TO THE STUDY OF WELD PHENOMENA, H. A. Winne, General Electric Co.

Great Lakes District Holds Fifth District Meeting at Purdue University

PURDUE UNIVERSITY, Lafayette, Ind., played host to some 400 members, students, and guests who attended the fifth general meeting of the Great Lakes District, October 24–25, 1935. Traditional Hoosier hospitality was extended by officials and faculty of the university, convenient and comfortable facilities for the technical and other sessions were provided, and generous arrangements made for the entertainment of those in attendance. Each of the 9 Sections in District 5 were well represented, as also were the 16 Student Branches in the District, special emphasis being placed upon the participation of Student groups in the technical sessions and other activities.

Opening Meeting

With Vice President G. G. Post officiating, the opening meeting started promptly on scheduled time at 9:30 Thursday morning, October 24, in the main lecture hall of the electrical engineering building, with an initial attendance in excess of 200. In response to Vice President Post's introduction, A. A. Potter, dean of the schools of engineering of Purdue University, and past-president (1933) of The American Society of Mechanical Engineers, delivered an address of welcome in which he heartily endorsed the idea of holding meetings such as this on University campuses, and stressed the growing importance in modern life of engineering education, outlining some of the leading trends in the development of curricula and teaching methods.

President Meyer in responding to Dean Potter's welcoming remarks, paid tribute to all who had participated in arranging the District meeting. He also took advantage of the opportunity to remind his audience that the institute is a wholly democratic organization of individual members and to emphasize the many opportunities offered for individual participation, pointing out that the return "dividend" to the individual depended quite entirely upon the degree to which the individual participated in Institute affairs.

Technical Sessions

Immediately following the opening meeting, the first of the technical sessions was held. As indicated in the detailed schedule published in the September 1935 issue of Electrical Engineering, pages 1005–7, the 2-day program provided 4 general technical sessions. Presiding officers for the several sessions were: for the general applications session, Vice President G. G. Post, Milwaukee, Wis., and Dr. C. F. Harding, Purdue University; for the session on electron tube theory and practice, Chairman C. A. Cora of the Central Indiana Section, Indianapolis, and Dr. C. B. Aiken of Purdue University; for the Student technical session, Student Counselor B. B. Kurtz of the University of Iowa, Iowa City, and Student Counselor A. N. Topping of Purdue University; and for the high potential measurements session, District Secretary A. G. Dewars of Minneapolis, Minn., Past Chairman O. Kiltie of the Fort Wayne, Ind., Section, and Prof. D. D. Ewing, of Purdue University.

Of the 4 general technical sessions mentioned above, 3 accommodated the presentation and discussion of: 14 formal technical papers, 1 unpublished technical paper, and 2 special addresses; one session was devoted to the presentation and discussion of Student papers, 15 of which were scheduled. With but minor variations, the technical program as carried out was in accord with the published schedule. As all 14 of the formal technical papers were published in Electrical Engineering prior to the meeting, and as most of the discussions thereon will be published in future issues, these technical papers will not be further commented on here.

Analysis of Registration at Meeting

Classification	Location: Central Indiana Section	District No. 5*	Other Districts	Totals
Members	44	89	15	148
Students	170	84		254
Men Guests	15	13	3	31
Women Guests	10	12	2	24
Totals	239	198	20	457

*Outside of Central Indiana Section

Special Addresses

Two addresses of a special nature were presented during the technical sessions: one, "Dare We Become Efficient?" given by J. W. Esterline, president of the Esterline Angus Company of Indianapolis; the other, "Recent Electrical Developments in the Steel Industry," by Ralph H. Wright of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. Mr. Esterline described the development and operation of the unique program of employee relations in vogue at the Esterline Angus plant, and reviewed some of the results of several years of operation with that program. He stated that the program was based upon a definite effort to bring about a fully co-operative working relationship not only between employees and management, but also between departmental groups. He described this plan as being in effect the recognition of each management, design, manufacturing and other working units as a separate, but of course interrelated working unit, each in effect taking a contract to carry on its specialized work, and assuming full responsibility for delivery of goods or services as the case may be. Increased profits resulting from this co-operative-competitive effort are divided equitably between employer and employee with results enthusiastically described by Mr. Esterline as being highly satisfactory to all parties concerned.

As typifying the many important advances made in steel producing equipment Mr. Wright gave a comparison of old and new methods of rolling sheet and tin plate. He pointed out that in the older and common processes the metal is reduced to the desired finished thickness by a slow and laborious hot rolling process involving the passage of small bars of steel back and forth through rolls operating at about 300 feet per minute. In contrast to this, some of the

Taken during the recent meeting of the Institute's Great Lakes District and Student Branch convention held at Purdue University, West Lafayette, Ind., Oct. 24–25, 1935, the photograph reproduced above shows some of those responsible for the success of this meeting

Left to right (both rows) are: Dr. A. A. Potter, dean of engineering schools, Purdue University; National Secretary H. H. Henline; Vice President G. G. Post, chairman of the general committee for this meeting; Dr. C. F. Harding, chairman of the papers committee, member of the general committee, and head of the department of electrical engineering at Purdue; President E. B. Meyer; D. T. Canfield, chairman of the entertainment committee and member of the papers committee; C. A. Cora, chairman of the Central Indiana Section, and member of the general committee and papers committee for this meeting; J. W. Esterline, who presented a special address on the subject "Dare We Become Efficient?" and D. L. Curtner, chairman of the attendance and publicity committee

most recently accepted methods permit the use of heated slabs from 3 to 6 inches thick and weighing several tons which pass first in a continuous process through a preliminary rolling at up to 2,000 feet per minute, and subsequently through cold rolling finishing processes operating on a continuous basis at speeds ranging from 500 to 1,200 feet per minute.

Student Sessions

The Student technical session held Friday morning, October 25, occupied a position of importance on the program paralleling that of the other 3 general technical sessions. Attendance at the Student sessions topped 300, and keen interest was shown in the entire program which was followed through essentially as printed in advance in Electrical Engineering.

Following a Student luncheon meeting Friday noon, which turned out to be so popular that it developed into a general luncheon affair, the regular District conference on Student activities occupied the time of Student Branch chairmen and Branch counselors for the remainder of the afternoon.

Each Branch representative reported briefly concerning his Branch's activities for the past year, and outlined plans now under way for the current year, in most cases guided very constructively by accumulative local experience. Thus there was an effective interchange of experiences and ideas which repeatedly brought forth questions and precipitated spontaneous discussion on questions of more than average interest in connection with the pursuit of Branch affairs. To an observer interested in Institute work, and recognizing the strategic importance of Student Branch work, the general tone of the discussion was inspiring indeed. Most Branches in the District showed conclusively that they were keenly alive and were pursuing Branch organization aggressively, in many cases reporting the actual enrollment of all or of very high percentages of upper class electrical engineering students. Many Branches had segregated their social and technical programs.

Branch counselors present included: S. S. Attwood, University of Michigan; C. Boesewetter (alternate), Milwaukee School of Engineering; E. H. Freeman, Armour Institute of Technology; F. W. Kane, Marquette University; C. C. Knipmeyer, Rose Polytechnic Institute; J. H. Kuhlman, University of Minnesota; E. B. Kurtz, University of Iowa; B. K. Osborn, Michigan State College; F. A. Rogers, Lewis Institute; G. W. Swenson, Michigan College of Mining and Technology; A. N. Topping, Purdue University; G. F. Tracy, University of Wisconsin; H. O. Warner, University of Detroit; K. R. Weigand (alternate), University of Notre Dame; and Benn S. Willis, Iowa State College.

Student Branch chairmen present were: Wendell N. Becker, University of Iowa; Robert Berresford, Iowa State College; W. A. Brastad, University of Minnesota; C. Louis Del Gaizo, University of Notre Dame; Leonard B. Gezon, Michigan State College; Harry Holubow, Lewis Institute; R. B. Immel, Purdue University; Martin Long, Rose Polytechnic Institute; R. L. Oetting, University of Wisconsin; J. D. Scarbrough, Michigan College of Mining and Technology; Ray J. Schmitz, Jr., Marquette University; Curtis G. Talbot, University of Illinois; and Kenneth N. Wilkins, Milwaukee School of Engineering.

Thus, 13 out of the 16 Student Branches in the District were represented by their Branch chairmen, and, including 2 alternates, 15 were represented also by their Student conselors. Other members of the committee present were: District Vice President G. G. Post and District Secretary A. G. Dewars. Others present included: President E. B. Meyer, National Secretary H. H. Henline, Editor G. Ross Henninger, and D. C. Jackson, Jr., of Lewis Institute, Chicago.

Doctor Harding, officiating as toastmaster at the Student luncheon meeting, "summarized" the results of the District meeting as follows:

"Meetings such as this are stepping stones toward (1) better recognition of the electrical engineering profession by the public; (2) extension of geographic activities of the Institute in a manner that constitutes effective decentralization, (3) increasing Institute membership particularly among recent graduates, (4) broadening the technical, economic, and administrative scope of technical papers acceptable for publication, and (5) provision for earlier and less expensive transition and status from Enrolled Student to full membership."

Entertainment and Special Program

Entertainment features of a social nature provided by the local committee included: a dinner tendered Wednesday evening, in advance of the meeting, by Purdue University to the Section, District, and national officers present; the regular District dinner affair held Thursday evening in the ballroom of Purdue Memorial Union Building, and followed by a demonstration rehearsal in the stadium of Purdue's famous electrically illuminated band; and the general luncheon meeting that grew out of the Student luncheon Friday noon. Each of these groups was addressed by President Elliott, Dean Potter, and Doctor Harding of Purdue University, and by Institute President E. B. Meyer. Excellent musical entertainment was provided Thursday evening and Friday noon by Purdue University students.

Entertainment features of a technical nature included a television demonstration, a demonstration of the impulse "lightning" generator in the high voltage laboratory, demonstration of the university's radio station in operation, and visits to and special exhibits in the several engineering laboratories. In addition, inspection trips were arranged to the meter manufacturing plant of the Duncan Electric Manufacturing and to other points of interest according to visitors' choices.

A scene in the lecture hall of the electrical engineering building at Purdue University, where the technical sessions of the recent Great Lakes District meeting were held. One of the student sessions is shown

Future AIEE Meetings

Winter Convention,
New York, N. Y., Jan. 28–31, 1936

North Eastern District Meeting,
New Haven, Conn., May 6–8, 1936

Summer Convention,
Huntington Hotel, Pasadena, Calif., June 22–26, 1936

Middle Eastern District Meeting,
Pittsburgh, Pa., part of week of Oct. 12, 1936

District Executive Committee Meeting

Among the items of business transacted at the luncheon meeting of the executive committee of the Great Lakes District held on October 24, K. A. Auty, Commonwealth Edison Company, Chicago, Ill., was re-elected to the office of treasurer of the District. F. H. Lane, Byllesby Engineering and Management Corporation, Chicago, was elected a member of the Institute's national nominating committee, representing the Great Lakes District. Dr. C. F. Harding, head of the school of electrical engineering at Purdue University, was nominated unanimously as a candidate for the office of vice president of the Institute from the Great Lakes District, for the 2-year term beginning August 1, 1936.

The following members of the executive committee were elected to serve with the vice president, District chairman, and chairman of the District committee on Student activities, as members of the co-ordinating committee for the coming year:

Prof. J. F. H. Douglas	Milwaukee Section
Prof. S. S. Attwood	Detroit-Ann Arbor Section
Prof. F. H. Rogers	Chicago Section
H. P. Seelye	Detroit-Ann Arbor Section

Vice President Post appointed Professor Douglas as chairman of a special committee to determine the desires of the Sections

within the District, as to possible changes in the areas allocated to them. The Milwaukee Section's invitation to the Institute to hold its 1937 summer convention at Milwaukee was endorsed.

PAST-PRESIDENT JOHNSON MEMORIALIZED

A resolution was passed by the Great Lakes District executive meeting at its October 24 meeting, commemorating the recent death of Junior Past President J. Allen Johnson. This resolution in memory of J. Allen Johnson, supplementing that passed by the Institute's board of directors on October 22, 1935 (see ELECTRICAL ENGINEERING for November 1935, page 1274 for this resolution, and pages 1281–2 for an obituary item), is as follows:

WHEREAS: J. Allen Johnson was called from our midst by death on October 4, 1935; and

WHEREAS: Mr. Johnson was not only an engineer distinguished for his accomplishments but was also our friend and an indefatigable worker toward the general advancement of his, and our, profession, and

WHEREAS: Mr Johnson during the 28 years of his membership had served the Institute capably and willingly in both local and national offices, including the presidency which he filled last year; therefore be it

RESOLVED: That the members of the Great Lakes District (No. 5) American Institute of Electrical Engineers, in convention assembled, hereby express their sense of great loss to the Institute in Mr. Johnson's passing and extend to the members of his family deep sympathy in their grievous loss, and be it further

RESOLVED: That copies of this resolution be sent to the Institute and the family.

Among other items at the meeting of the District executive committee, reports of past activities were presented by the delegates, and plans for coming meetings were outlined.

Standards on Letter Symbols and Abbreviations

Preparation of a new dictionary of letter symbols and abbreviations to be used by engineers and scientists is a task to be undertaken by a committee of the American Standards Association. The committee on symbols and abbreviations which has been at work for many years and which has already published several standards, has recently been divided into 2 parts, one covering the letter symbols and abbreviations, and the second covering the graphical symbols. The committee working on letter symbols and abbreviations, which is now beginning its work, has 12 subcommittees covering such broad subjects as mathematics, physics and mechanics, structural analysis, hydraulics, heat and thermodynamics, photometry and illumination, aeronautics, electric and magnetic quantities, radio, astronomy and surveying, geodesy, and scientific and engineering terms.

Any group which has its own standards for symbols, or has comments on standards which have already been approved, or has suggestions for useful new letter symbols and abbreviations, should communicate with Dr. J. Franklin Meyer (A'08, M'13), National Bureau of Standards, Washington, D. C., chairman of the committee.

A.I.E.E. Directors Meet at Institute Headquarters

The regular meetiug of the board of directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, N. Y., on October 22, 1935.

There were present: *President*—E. B. Meyer, Newark, N. J. *Past-President*—J. B. Whitehead, Baltimore, Md. *Vice Presidents*—C. V. Christie, Montreal, Que., Can.; W. H. Harrison, Philadelphia, Pa.; N. B. Hinson, Los Angles, Calif.; F. J. Meyer, Oklahoma City, Okla.; and R. H. Tapscott, New York, N. Y. *Directors*—F. Malcom Farmer, New York, N. Y.; N. E. Funk, Philadelphia, Pa.; H. B. Gear, Chicago, Ill.; C. R. Jones, New York, N. Y.; P. B. Juhnke, Chicago, Ill.; W. B. Kouwenhoven, Baltimore, Md.; Everett S. Lee, Schenectady, N. Y.; A. H. Lovell, Ann Arbor, Mich.; L. W. W. Morrow, New York, N. Y.; G. C. Shaad, Lawrence, Kans.; A. C. Stevens, Schenectady, N. Y. *National Treasurer*—W. I. Slichter, New York, N. Y. *National Secretary*—H. H. Henline, New York, N. Y.

The minutes of the board of directors' meeting of August 6, 1935, were approved.

By rising vote, a resolution was adopted in memory of Past-President J. Allen Johnson, who died on October 4. (The resolution was published in the November issue, page 1274, supplemented by a comprehensive biographical sketch on pages 1281–2.)

Reports were presented and approved of meetings of the board of examiners held September 25 and October 16. Upon the recommendation of the board of examiners, the following actions were taken: 3 applicants were transferred to the grade of Fellow; 14 applicants were elected to the grade of Member, and 67 applicants were elected to the grade of Associate as of November 1, 1935; 27 applicants were transferred to the grade of Member; 445 Students were enrolled.

The finance committee reported monthly disbursements amounting to $15,178.69 in September and $26,839.33 in October. Report approved.

A budget for the appropriation year beginning October 1, 1935, was submitted by the finance committee and adopted.

Upon the recommendation of the executive committee of the Middle Eastern District, approval was given to changing the location of the 1936 District meeting from Akron, Ohio, to Pittsburgh, Pa., to be held in connection with meetings of other engineering societies during the week of October 12.

The board adopted amendments approved at the August board meeting to Sections 22 and 23 of the by-laws, to bring them into conformity with the recently amended sections of the constitution. The amended by-laws read as follows:

SEC. 22. During September of each year, the secretary of the national nominating committee shall notify the chairman of the executive committee of each Geographical District that by December fifteenth of that year the executive committee of each District must select a member of that District to serve as a member of the national nominating committee and shall, by December fifteenth, notify the secretary of the national nominating committee of the name of the member selected.

During September of each year, the secretary of the national nominating committee shall notify the chairman of the executive committee of each Geographical District in which there is or will be during the year a vacancy in the office of vice president, that by December fifteenth of that year a nomination for a vice president from that District, made by the District executive committee, must be in the hands of the secretary of the national nominating committee.

Between October first and December fifteenth of each year, the board of directors shall choose 5 of its members to serve on the national nominating committee and shall notify the secretary of that committee of the names so selected, and shall also notify the 5 members selected.

The secretary of the national nominating committee shall give the 15 members so selected not less than 10 days' notice of the first meeting of the committee, which shall be held not later than January 31. At this meeting, the committee shall elect a chairman and shall proceed to make up a ticket of nominees for the offices to be filled at the next election. All suggestions to be considered by the national nominating committee must be received by the secretary of the committee by December 15. The nominations as made by the national nominating committee shall be published in the March issue of ELECTRICAL ENGINEERING (Journal of A.I.E.E.), or otherwise mailed to the Institute membership not later than the first week in March.

SEC. 23. Petitions proposing the names of candidates as independent nominations for the various offices to be filled at the ensuing election, in accordance with Article VI, Section 31 (Constitution), must be received by the secretary of the national nominating committee not later than March 25 of each year, to be placed before that committee for the inclusion in the ballot of such candidates as are eligible.

On the ballot prepared by the national nominating committee in accordance with Article VI of the constitution and sent by the national secretary to all qualified voters during the first week in April of each year, the names of the candidates shall be grouped alphabetically under the name of the office for which each is a candidate.

The following members of the board were selected to serve on the national nominating committee: F. Malcolm Farmer, W. H. Harrison, W. B. Kouwenhoven, Everett S. Lee, and A. C. Stevens.

A. M. MacCutcheon was reappointed a representative of the Institute on the standards council of the American Standards Association for the 3 year term beginning January 1, 1936, and H. S. Osborne and E. B. Paxton were reappointed alternates for the year 1936.

W. S. Barstow was reappointed an Institute representative on the library board of United Engineering Trustees, Inc., for the 4 year term beginning in October 1935.

A. W. Berresford was appointed to fill the unexpired term, ending in October 1938, of J. Allen Johnson, deceased, on the John Fritz Medal Board of Award.

H. L. Huber was appointed to represent the A.I.E.E. committee on communication, and R. N. Conwell, the committee on power transmission and distribution, upon the American Committee on Marking of Obstructions to Air Navigation.

Chairman Everett S. Lee of the membership committee reported on the state of the Institute membership and the activities of the membership committee, with particular emphasis upon the effective work of the Section membership committees.

Upon the recommendation of the standards committee, the board authorized the submission of a revised report on standards for relays to the American Standards Association, with the endorsement of the Institute, as material for an American standard.

The board accepted, with appreciation, an offer of Past-President Ralph D. Mershon to donate a third golf trophy, to remain permanently in possession of the Institute, and

to take the place of the second golf trophy, which was won by L. R. Keiffer at the 1935 summer convention, at Ithaca, N. Y.

Approval was given to a proposal that the Engineers' Council for Professional Development become incorporated.

Other matters were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.

President Meyer to Serve M.I.T.

Upon invitation of Dr. Karl Taylor Compton (F'31), president of Massachusetts Institute of Technology, President E. B. Meyer of the A.I.E.E. has been appointed to serve as a member of the M.I.T. visiting committee of the department of electrical engineering for the academic year beginning October 1935.

It is the custom of M.I.T. to invite distinguished members of the fields with which its work is concerned to serve with members of its corporation and representatives from its alumni body upon committees which "consider critically and constructively the problems and policies of the various departments and which report their findings and recommendations to the corporation."

Other prominent Institute members serving M.I.T. on this special committee include Dr. Frank B. Jewett (A'03, M'10, F'12, past president), New York, N. Y.; Thomas Spooner (A'12, M'23, F'29), East Pittsburgh, Pa.; and Don L. Galusha (A'05, M'13, F'19), Philadelphia, Pa.

A.I.M.E. Nominates Officers for 1936. Nominations of officers to serve the American Institute of Mining and Metallurgical Engineers for the year 1936, have been made. J. M. Lovejoy, president of the Seaboard Oil Company, has been nominated to serve as president. For 2 vacancies as vice president and director, R. C. Allen and Henry Krumb were nominated. New directors nominated include: S. G. Blaylock, James Douglas, Medalist in 1928 and vice president and general manager of the Consolidated Mining and Smelting Company of Canada; J. L. Christie, metallurgist for the Bridgeport Brass Company; E. T. Conner, Scranton, Pa.; W. B. Heroy, chief geologist, Consolidated Oil Corporation; and F. L. Sizer, San Francisco, Calif. The last 3 were nominated for re-election.

Air Conditioning Standards Adopted. At the October, 1935 meeting of the Air Conditioning Manufacturers' Association held in Chicago, Ill., standards for rating and testing air conditioning equipment were adopted. These standards are the result of many weeks of investigation and study by leading air conditioning engineers, representing not only the manufacturers but also the American Society of Refrigerating Engineers and the American Society of Heating and Ventilating Engineers, which are the leading technical societies in the air conditioning field. Much of the uncertainty which has confronted buyers of air conditioning equipment is said removed by this action of A.C.M.A.

John Fritz Medal Awarded W. F. Durand

At the annual meeting of the John Fritz Medal board of award, the Gold Medal for 1936 was awarded William Frederick Durand for notable achievement "as authority in hydrodynamic and aerodynamic science, and in its practical application; outstanding leader in research and in engineering education." This award was made unanimously by a board having for its members 16 past-presidents of the 4 American societies of civil, mining and metallurgical, mechanical, and electrical engineers.

Doctor Durand is professor emeritus of mechanical engineering, Stanford University, Calif. He was born May 5, 1859, in Bethany, Conn., and graduated from the United States Naval Academy in 1880. He served in the Engineers Corps of the Navy until 1887, and then became professor of mechanical engineering at what is now Michigan State College, Lansing. He went to Cornell University in 1891, and remained there as professor of marine engineering until 1904, when he went to Stanford University to become professor of mechanical engineering.

Early in life Doctor Durand became interested and active in scientific and engineering research. In particular, he devoted his attention to problems of ship propulsion, hydraulics of pipes, and later to aeronautics, being one of the first to engage in scientific research in aeronautics. He has invented precision measuring instruments.

In 1916, he became chairman of the National Advisory Committee for Aeronautics, authorized by Congress, which committee he had assisted in organizing in 1914. During the war, he was in Paris as a representative of the United States government on technical commissions. In 1925, he was appointed by President Coolidge a member and secretary of the aircraft board, and in 1935 he was appointed by President Roosevelt chairman of a committee of review of airship design and construction for the U.S. Navy. He has frequently served as a consultant to the U.S. Bureau of Reclamation.

Doctor Durand was a trustee of the Guggenheim fund for the promotion of aeronautics throughout the life of that organization. In May 1935, Doctor Durand was awarded the Daniel Guggenheim medal for aeronautical achievement. He received the degree of doctor of philosphy from Lafayette College in 1888, and was awarded the honorary degree of doctor of laws by the University of California in 1927. Doctor Durand is a Gold Medalist of the American Society of Naval Engineers, and a past-president of The American Society of Mechanical Engineers. He is general editor for a comprehensive work on aerodynamic theory, now being printed in 6 volumes.

Communication Museum for Canada

While there are rare and valuable collections of telegraph, telephone, and radio historical apparatus in the Smithsonian Institute, Washington, D. C.; Franklin Institute, Philadelphia, Pa.; Science Museum, New York, N. Y.; and the new museum in Chicago, Ill., it was found that no historical museum had been established in Canada. To remedy this situation Donald McNicol (A'05, F'18), past-president of the Institute of Radio Engineers, gathered and procured through purchase several private collections in the United States and Canada. These he has donated to Canadian communication engineers in the form of a museum which is housed in Ottawa. At present the telegraph and telephone items are housed in the Dominion archives department, and the radio items in the National Research Building, but shortly the collections are to be consolidated in the latter building.

The museum consists of more than 100 rare and valuable items.

In arranging for proper housing for the museum Mr. McNicol had the co-operation of Col. W. Arthur Steel, Canadian broadcast commissioner, and John McMillan, late general manager of the Canadian Pacific Railway Telegraphs.

Membership—

Mr. Institute Member:

Next month the membership committee will invite into Associate membership those Students who were graduated last June. There are 1,304 of these young men. Personal letters from Institute headquarters and personal contacts from the Section membership committees will bring the invitation.

The membership committee asks that where you may know any of these young men, you do what you can to acquaint them further of Institute activities.

Ernest F. Fisher

Chairman National Membership Committee

District and National Prizes Available for 1935 Technical Papers

ALL who have presented technical papers before the Institute during the calendar year 1935 are eligible under the A.I.E.E. paper prize regulations for competitive consideration for one or more of the established prizes. Papers are eligible for submission to the prize committees regardless of whether presented before a Branch meeting, a Section meeting, a District meeting, or a national convention, the several classes providing for equitable competition.

Papers Must Be Submitted

Although all 1935 papers are *eligible* for consideration, every paper for which prize consideration is desired, must be *submitted* specifically for that purpose, except as noted below: through the District secretary for consideration for the District prizes, and through the national secretary's office for consideration for the national prizes. There is no provision for automatic consideration of papers, with the exception that those approved by the technical program committee and presented at national conventions or District meetings, will be considered by the national prize committee for the national "best paper" and "initial paper" prizes without being formally offered for competition.

Both District and national prize awards are made each spring for papers presented during the preceding calendar year, provided they are submitted for prize consideration not later than February 15. Prize rules governing 1935 papers were published in full on page 342 of the March 1935 issue of Electrical Engineering. However, inasmuch as these rules contained many changes, they are republished here in full for the convenience of authors, as well as District Section, and Branch officers, and others interested.

National Prizes

The following national prizes may be awarded each year at the discretion of the committee on award of Institute prizes:

1. Prize for best paper in: (1) engineering practice; (2) theory and research; and (3) public relations and education.
2. Prize for initial paper.
3. Prize for Branch paper.

The national prize for best paper in each of the 3 classes, namely, engineering practice, theory and research, and public relations and education, may be awarded for the best original paper presented at any national, District, or Section meeting of the Institute, provided the author, or at least one of co-authors, is a member of the Institute.

The national prize for initial paper may be awarded for the most worthy paper presented at any national, District, Section, or Branch meeting of the Institute, provided the author or authors have never previously presented a paper which has been accepted by the technical program committee, and the author, or at least one of co-authors, is a member of the Institute or is a graduate student enrolled as a Student of the Institute.

The national prize for Branch paper may be awarded for the best paper based upon undergraduate work presented at a Branch or other Student meeting of the Institute, provided the author or authors are Enrolled Students of the Institute.

Only papers presented during the calendar year shall be considered for any of the prizes, except those for the best paper prize in the class of public relations and education. In this class, all papers presented subsequent to those considered at the time of the last previous award in this field will receive consideration. All papers approved by the technical program committee which were presented at the national conventions or District meetings will be considered for the best paper prizes and initial paper prize without being formally offered for competition. All other papers which were presented at Section, Branch, or Student meetings must be submitted in triplicate with written communications to the national secretary on or before February 15 of the following year, stating when and where the papers were presented. This may be done by authors, by officers of the Institute, or by executive committees of Sections or geographical Districts.

Each national prize shall consist of a certificate of award issued by the Institute and $100 (see note below) in cash. When papers are written jointly, the cash awards shall be divided and a certificate shall be issued to each author. The board of directors may, at its discretion, omit the cash awards for any of the prizes.

Committee on Award of Institute Prizes. This committee shall consist of the chairman of the technical program committee, acting as chairman; the chairmen of the publication committee, the committee on research, the technical program committee of the previous year, and the chairmen of such other committees as the board of directors may designate. This committee shall award at its discretion all the national prizes. It may award a single paper more than one of the prizes available and it may make honorable mention of papers which do not receive prize awards. All the national prizes for a given calendar year shall be awarded prior to May 1 of the succeeding year. They shall be presented at the next summer convention of the Institute.

For the national best paper prizes the technical program committee shall indicate to the committee on award of Institute prizes the class under which each paper is to be considered for first prize.

Basis of Grading Papers. The technical committees shall assist the committee on award of Institute prizes by grading papers at the time they are initially reviewed for acceptance. The valuations which shall govern the grading of papers for purposes of making awards shall be as follows:

Analysis of Subject.....10 per cent

The paper shall present a clear outline of the situation out of which arises the need for the preparation of a paper on the particular subject, explaining the point of view assumed in the presentation.

Logical Presentation.....10 per cent

The presentation should include an analysis of the difficulties encountered, the methods of attack and the solution of the problem.

Originality.....10 per cent

Credit should be given to the paper which brings to its subject matter a fresh point of view, a healthy open-mindedness or a discarding of some outworn traditions.

Unity.....10 per cent

While brevity and conciseness are important they should not be attained at the sacrifice of unity and completeness of presentation.

Value in Its Field.....30 per cent

The value of the paper as a contribution to the literature in its own field should receive particular consideration.

Value to Electrical Engineering.....30 per cent

The paper should be considered from the standpoint of the quality of its contribution to the advancement of electrical engineering and its value to civilization.

Publication. Papers awarded prizes shall be published in full or in abstract, in Electrical Engineering, in the Transactions, or in pamphlet form:

District Prizes

The following District prizes may be awarded each year in each geographical District of the Institute:

1. Prize for best paper.
2. Prize for initial paper.
3. Prize for Branch paper.

The District prize for best paper may be awarded for the best paper presented at a national, District, or Section meeting, provided the author, or at least one of co-authors, is a member of the Institute.

The District prize for initial paper may be awarded for the most worthy paper presented at a national, District, Section, or Branch meeting, provided the author or authors have never previously presented a paper before a national, District, Section, or Branch meeting of the Institute, and the author, or at least one of co-authors, is a member of the Institute or is a graduate student enrolled as a Student of the Institute.

The District prize for Branch paper may be awarded for the best paper based upon undergraduate work presented at a Branch or other Student meeting of the Institute, provided the author or authors are Enrolled Students of the Institute.

Each District prize may be awarded only to an author who, or to co-authors of whom at least one, is located within the District, and for a paper presented at a meeting held within, or under the auspices of the District.

Only papers presented during the calendar year shall be considered. They must be

Note—By action of the board of directors, all cash prizes for papers presented during the calendar year 1935, with the exception of the prize for Branch paper in each District, are to be omitted. Certificates, however, will be awarded to all winners as usual.

submitted in duplicate by the authors or by the officers of the Branch, Section, or District concerned to the District secretary, on or before February 15 of the following year.

Each District prize shall consist of a certificate of award issued by the officers of the geographical District and $25 (see note below) in cash. When papers are written jointly, the cash awards shall be divided and a certificate shall be issued to each author. The board of directors may, at its discretion, omit the cash awards for any of the prizes.

Committees on Awards. All the District prizes for a given calendar year shall be awarded prior to May 1 of the succeeding year by the District executive committee or by a committee appointed by the District executive committee and authorized to make such awards.

Basis of Grading Papers. The valuations which shall govern the grading of papers for purposes of making awards shall be the same as those for the national prizes but the papers will not be graded by the technical committees.

Copies of a pamphlet entitled "National and District Prizes" may be secured, without charge, upon application to Institute headquarters. The information given in this pamphlet is identical with that presented above. These rules were originally adopted by the Institute's board of directors June 23, 1927; they were revised December 7, 1928, January 27, 1932, and January 21, 1935. The rules given above include the latest revisions.

Note—By action of the board of directors all cash prizes for papers presented during the calendar year 1935, with the exception of the prize for Branch paper in each District, are to be omitted. Certificates, however, will be awarded to all winners as usual.

New Wood Handbook Considers Utility Needs

A handbook specifically adapted to the principal classes of wood use was published recently by the U.S. Forest Products Laboratory, Madison, Wis., headquarters of wood research for the federal Forest Service. This handbook is reported to be the first publication of its kind to bring the requirements of public utilities and railways to definite focus with the properties and characteristics of American wood species as a whole in their treated and untreated condition.

The selection and use of lumber and timber for general construction are dealt with in respect to grade, defects, strength characteristics, decay resistance, and ability to hold paint, and the effectiveness of various types of paints and finishes is given special attention. Of direct bearing on problems of timbering are the condensed data on mechanical properties of wood and the facts recently established in regard to growth ring placement, fatigue effects, seasoning, and shear relations. The chapter on timber fastenings includes the latest information on nails, screws, bolts, spikes, and the new plate and ring connectors which have greatly enlarged the engineering possibilities of wood in transmission towers, radio masts, bridges, and other heavy construction.

The characteristics of standard wood preservatives are explained and the merits of the various processes set forth in relation to the kind of wood and the type of use. The hazards of decay and of attack by insects, marine borers, birds, and rodent animals are dealt with and corrective measures shown.

Public utility and railway requirements in poles, ties, and piling are taken up in a special section of the handbook. Piling data are presented, and comprehensive information on crossties is given.

Replacing reams of scattered pamphlets, magazine articles, and miscellaneous publications, this handbook is considered to bring within its 306 pages the essential data on wood as a material of construction and use. The new "Wood Handbook" is listed as U.S. Department of Agriculture unnumbered publication and can be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 25 cents per copy, cash or money order.

Washington Award Commission Elects Chairman. For the year 1935–36, the Washington Award Commission has elected Frank D. Chase, member and past president of the Western Society of Engineers, chairman of the commission. This commission annually presents the Washington award, established in 1916 by Past-President Alvord of the Western Society of Engineers "to an engineer whose work in some special instance, or whose services in general, have been noteworthy for their merit in promoting the public good." The Washington Award Commission is composed of: C. A. Morse, F. H. Lane (M'23), D. J. Brumley, Frank D. Chase, M. M. Leighton, L. R. Howson, C. H. MacDowell, W. W. DeBerard, and L. R. Mapes (M'29), all representing the Western Society of Engineers; and the following representatives of the 4 founder societies: E. J. Mehren and Samuel A. Greeley (A.S.C.E.); J. R. Van Pelt and Gustav Egloff (A.I.M.E.); C. B. Nolte and O. A. Leutwiler (A.S.M.E.); and William B. Jackson (A'97, F'13, and past vice-president) and L. A. Ferguson (A'01, F'12, and past-president) (A.I.E.E.).

At the Recent Meeting of the Great Lakes District at Purdue University

ABOUT 170 out of the total of 457 registered for the Institute's Great Lakes District meeting held at Purdue University, West Lafayette, Ind., Oct. 24–25, 1935, are shown here. This group contains many Students, who were given special attention at the meeting, both to their benefit and that of many of the older members present. In the upper central background may be discerned one of the towers of Purdue's high voltage experimental transmission line. In the central foreground appear (left to right) Dr. C. F. Harding of Purdue, Vice President G. G. Post of Milwaukee, President E. B. Meyer, Vice President N. B. Hinson of Los Angeles, National Secretary H. H. Henline, and Director P. B. Juhnke of Chicago. A report of the meeting is given on pages 1410–12 of this issue.

N.R.C. Electrical Insulation Committee Holds Eighth Annual Meeting at Pittsfield

THE eighth annual meeting and conference of the committee on electrical insulation, National Research Council held October 17 and 18, 1935, at Pittsfield, Mass., as guests of the General Electric Company, was unusually successful and interesting. It embraced 3 technical sessions in which 24 papers and progress reports of research were discussed, an evening lecture by Dr. Irving Langmuir, and high voltage demonstrations and inspections in the research laboratories and plants of the General Electric Company. Seventy-six members were registered and a number of local visitors participated. The following news report was prepared by A.I.E.E. Past-President J. B. Whitehead, long-time chairman of the N.R.C. insulation committee.

The normal functions of the committee are the stimulation and co-ordination of research and the gathering, discussion, and publication of its results. The work in these several directions is unified at the annual meeting and conference. The papers presented are largely in the form of progress reports, and finished manuscripts are neither exacted nor expected, nor is there any formal record of the discussions. Most of the papers presented ultimately find publication in current scientific and technical journals. It is believed that the continued success and interest in the work of the committee is largely due to these informal features of its operation. Subcommittees on chemistry and physics are active in following current work in these fields. A subcommittee on monographs has already directed the publication, under the auspices of the committee, of 4 volumes of moderate size by competent authors, on selected subjects in the field of dielectrics and insulation. Several other volumes in the same series are in the process of preparation.

Papers on Basic Chemistry and Physics

A conspicuous aspect of the technical program of the recent meeting was the large number of papers on the basic chemistry and physics of dielectrics. Those in the chemical field indicated a substantial spread in the attack of the problem of instability in high voltage insulation. With the realization of the obscurity of this problem, researches in recent years have been pushed more and more deeply into the study of molecular structure, particularly in its chemical aspect. There were 6 progress reports in this field. They dealt particularly with refinements and extensions in the chemical testing of oils, in the separation of oils into more nearly pure components, with the oxidation of insulating oils, particularly as regards those aspects of oxidation which may be correlated with electrical behavior and the like. The extent of this problem in the important field of insulating oils was indicated in the statement that present methods of refinement permit the segregation of the hydrocarbons in petroleum oils only into certain broad groups such as gasoline, kerosene, lubricants, and the like. Hardly 5 per cent of a crude oil may be recognized as definite hydrocarbons and these are all in the gasoline group. No single definite hydrocarbon has yet been isolated from the viscous fractions of petroleum within which the insulating oils are commonly found. Attention was also called to the fact that no correlation is as yet possible between the dielectric strength of an oil and its chemical or physical structure. Much the same thing may be said as to the several other important electrical properties. It is commonly believed that oxidation is one of the most important causes of deterioration in high voltage insulation. A number of experimental studies of various aspects of the oxidation process as related to deterioration are under way. A paper of special interest reported results from the effects of admixture of anhydrous oxidation products of pure oils as related to their conductivity and to the behavior of paper impregnated with the original oils and as modified. The results were quite definite in segregating certain classes of oxidation product as having little effect on conductivity and loss and others as being markedly harmful. Another striking report was a review of the experimental processes back of the development of "pyranol," a recently developed noninflammable insulating liquid. This report presents a fine example of the advances possible through carefully considered experimental research.

In the field of physics further results were reported of X ray studies on rubber as bearing on changes under electric stress. Further data were presented on the influence of pressure on the breakdown strength of oils. Several papers were devoted to existing theories of dielectric absorption and conduction, with special reference to underlying causes in the light of new experimental data. Simplified methods of computation in practical cases for the avoidance of the inherent complexities of the phenomena themselves were also proposed. Of special interest in this direction was a paper on the distribution of the wide range of value of the relaxation time often encountered in solid dielectrics, the study being an extension of the Maxwell-Wagner analysis with a method for evacuating the Wagner constants from typical experimental studies. A method for studying ionic mobilities in insulating oils was also reported with experiments indicating unexplained high values of such mobilities in liquids of relatively high viscosity.

Papers in Field of Application and Practice

Equally interesting were the papers in the field of application and practice. Several papers reported oscillographic and other studies on the electrical oscillations produced in systems of high voltage conductors by incipient spark discharge and ionization such as mark the beginnings of cable failures. The range of frequency of these oscillations was explored and as related to stress, temperature, pressure, and other factors. The predominance of such oscillations in the parallel connection of test samples was shown and methods proposed for suppressing such oscillations. An extensive series of aging tests through over-voltage and temperature cycles on 66 kv cable was reported with studies of the mechanism of failure. The results of these tests point away from the importance of initial power factor and loss measurements, as well as a radial distribution of the values of these quantities, as dominating factors in the life of cables. More important factors seem to be original care and thoroughness in impregnation. Ultimate failure in these tests was apparently due to a more or less widely distributed process of deterioration rather than to thermal failure arising in a local high conductivity or other imperfection.

A report on progress and research in the field of dielectrics and insulation during the foregoing year was presented by the chairman, Dr. J. B. Whitehead. This report appears in full beginning on page 1288 of this issue of Electrical Engineering.

Dr. Langmuir, under the title "random thoughts on dielectrics," dealt with the atomic aspects of dielectric structure, particularly as regards the significance of electronic energy levels within the atom in their relation to the processes of ionization. The lecture was followed by an interesting and illuminating informal discussion.

A.S.T.M. Standards on Insulating Materials

The "Standards on Electrical Insulating Materials" recently published by the American Society for Testing Materials presents under a single cover A.S.T.M. standards that are in widespread use for testing and evaluating electrical insulating materials. The 1935 edition, 311 pages, gives 25 standardized methods of test and 10 specifications. The method of testing shellac has not been published heretofore. During 1935, revisions were made in a number of the test methods including those covering the following: varnishes, solid filling and treating compounds, molding powders, sheet and plate materials, laminated tubes and round rods, natural mica, and flexible varnished tubing.

Specifications which have been revised cover the following materials: friction tape, rubber insulating tape, and flexible varnished tubing.

The current report of committee *D*-9 outlines the extensive research and standardization work under way, gives a modified Baader saponification test for insulating oils and proposed requirements for rubber insulating blankets.

The following materials are also covered by specifications or tests given in the book: rubber gloves, rubber matting, electrical cotton yarns, silk and cotton tapes, pasted mica, and slate; also, black bias cut varnished tape; asbestos yarns, tape and roving; untreated paper; electrical porcelain; and insulating oils. Other tests which are included cover procedures for thickness

testing, impact, thermal conductivity, resistivity.

Copies, bound in heavy paper cover, can be obtained from A.S.T.M. headquarters, 260 S. Broad St., Philadelphia, at $1.75 per copy. Special prices are in effect on orders for 10 or more copies.

"The Handbook of Chemistry and Physics" (flexible fabrikoid, 4 by 6¼ inches, 1,951 pages, $6) newly revised, enlarged, and otherwise brought up to date, has just been published by the Chemical Rubber Publishing Company of Cleveland, Ohio. For some 22 years, this handbook has served those having need for accurate tables, formulas, and scientific data in a single convenient volume. The current issue is materially more complete than earlier issues. Material prepared for the 20th edition includes the following important features: physical constants of organic compounds, formula index of organic compounds, the pronunciation of chemical words, rules for naming organic compounds, prefix names of organic radicals, properties of the amino acids, X ray spectra, magneto-optic rotation, colorimetry, photometry, and a wealth of other information in tabular form including mathematical tables, properties and physical constants, general chemical tables, heat, hygrometry, sound, electricity, light, and miscellaneous quantities and units, all of which should be invaluable in the commercial, educational, or research laboratory.

Hughes Medal Awarded. The Hughes Medal has recently been awarded by the Royal Society (London, Eng.) to Dr. C. J. Davisson, research physicist of the Bell Telephone Laboratories, Inc., New York, N. Y., for his discovery, jointly with Dr. L. H. Germer, of electron diffraction. The award, established in 1900, has been conferred on such distinguished scientists as Dr. Alexander Graham Bell, Dr. O. W. Richardson, Dr. W. D. Coolidge, Dr. Irving Langmuir, and Mr. E. V. Appleton. Electron diffraction is what takes place when a stream of electrons is shot into a suitable crystal. The atoms, arranged in a regular pattern in the crystal, cause the electrons to emerge in a few sharply defined beams. Occurrence and disposition of the beams can only be explained by the hypothesis that electron streams behave in some respects like trains of wave such as those of light and X rays. Since it was well known that electrons are just as discrete particles as the pellets of lead from a shot gun, the idea that a stream of them could also be treated as a beam of light was a forward step which opened up wide vistas to the atomic physicist.

Radio Data Charts. A second edition of "Radio Data Charts" which contains many new charts added in accordance with modern developments has been issued by Iliffe and Sons Ltd., Dorset House, Stamford Street, London, and is priced at 4s 6d net, or 4s 10d postpaid. The nomographs enable results to be obtained quickly which otherwise require laborious calculation, and are intended to be useful in the design of coils, transformers, etc., and to give other essential data. Explanatory notes are included. R. T. Beatty is the author.

Institute Finances for 1935–36

THE board of directors and the finance committee of the Institute feel that no better opportunity is afforded to inform the membership regarding developments affecting the organization and activities of the Institute than the presentation of the budget of estimated income and expenditures for the appropriation year beginning October first, in conjunction with the report of actual revenue and expenses of the preceding year. While information regarding the finances of the Institute is regularly furnished to the membership in the annual report of the board of directors, it is not feasible on that occasion to furnish a statement of details which would explain the underlying reasons for increases or decreases in expenditures for various activities.

Accordingly, the following comments are given to explain the expenditures authorized in the new budget for those activities considered by the board of directors and finance committee to be of major interest to the greatest number of members, together with a table of expenses and income with comparative figures for the last appropriation year (see table I).

Publications

Electrical Engineering—Transactions. Under the unified publication policy in effect since January 1934, the budget provides for publication in the official monthly journal, Electrical Engineering, of approximately the same amount of technical papers and discussions as printed last year (1,380 pages) and for subsequent publication of identically the same material in the corresponding bound volume of Transactions, which latter publication is distributed to members and others who have duly authorized the subscription charge for such volume. Since the adoption of the budget, it has also been decided to incorporate in the December 1935 issue of Electrical Engineering, the annual reference index to papers and discussions published during the year, rather than to provide this index in separate pamphlet form for distribution only upon request.

Year Book. Last year's appropriation for the Institute Year Book provided funds only to meet the necessary expenses for maintaining the membership and mailing records. The budget for the present year contemplates the publication of a revised edition of the Institute Year Book early in 1936, on the basis of an edition of 4,000 copies, to be sent to members of the Institute upon receipt of request. An announcement will appear in the news columns of Electrical Engineering as soon as the 1936 edition is ready for distribution.

Institute Meetings

The expense for holding the annual winter convention in New York City in January has been provided for on about the same basis as last year; the appropriation for the summer convention at Pasadena, Calif., in June 1936 exceeds the cost of last year's convention by reason of the distant location of the meeting and the consequent increase in traveling expenses.

The appropriation for the Middle Eastern District meeting held last month in West Lafayette, Ind., as well as the North Eastern District meeting to be held in New Haven, Conn., May 6–8, 1936, contemplates the same expenditures as paid for similar meetings in the past.

Institute Sections

After having received the co-operation of all Institute Sections during the past 4 years in the acceptance of a voluntary reduction in the annual appropriation, it is a pleasure to report that the budget provides this year for full payment of the financial support to Sections as specified in Section 48 of the by-laws; i. e., a flat appropriation for each Section of $175, plus an allowance of $1 for each active member located within the territory of the Section on August first.

Institute Branches

Reimbursement of routine expenditures incidental to the holding of meetings at Institute Branches is expected to involve about the same expenditures as last year; other items of expense chargeable to Branch activities have been provided for similarly. Under the paragraph captioned "traveling expenses" will be found an explanation of the allowances authorized for Branch representatives to the District conferences on student activities, and for the Counselor Delegates to the summer convention.

Administration

Almost ¾ of the appropriation for administrative expenses is required for salaries, this appropriation covering 41 per cent of the total salaries paid to 20 members of the headquarters staff, in addition to the full salary of the national secretary and the office manager. In this connection it is pertinent to mention that the Institute maintains the smallest staff per 1,000 members of any of the founder societies. At the recommendation of the finance committee, the board of directors voted to restore the balance of the headquarters staff salary reduction voted in June 1932 to the extent of approximately 3 per cent of the salaries paid.

Other items in this appropriation are provided for to the same extent as last year; expenditures for postage, printing, and mailing of general announcements to the membership, telephone and telegraph service, insurance, office equipment, miscellaneous supplies and services not chargeable to specific appropriations, etc.

Traveling Expenses

With the object of providing reimbursement of substantially all of the expense incurred for railroad fare, Pullman accommodations, and meals en route, the traveling allowance to District, Section, and Branch

Table I—Institute Income and Expenses for Year Ending September 30, 1935, and Budget for Year Ending September 30, 1936

	Actual Income and expenses year ending 9/30/35	Budget for year ending 9/30/36
Income		
Dues	$174,543.17	$175,500.00
Students' fees	9,156.00	9,000.00
Entrance fees	5,161.90	5,000.00
Transfer fees	1,065.00	1,000.00
Advertising	22,514.80	25,000.00
ELEC. ENGG.—non-member subscriptions	12,322.43	12,500.00
TRANS. subscriptions	6,411.15	6,500.00
Miscellaneous sales	6,269.23	5,750.00
Badge sales	1,332.50	1,250.00
Interest on securities	7,546.19	7,425.00
Excess of estimated expenses over est. income		1,132.26
Total	$246,322.37	$250,057.26
Expenses		
Publications		
Text matter	$ 64,638.65	$68,080.00
Advertising section	10,687.54	11,475.00
YEAR BOOK	2,340.14	6,300.00
Institute meetings	10,800.87	11,430.00
Institute Sections		
Appropriations	17,974.45	21,554.00
Trav. exp. convention delegates	2,705.30	7,200.00
Other expenses	4,995.88	5,600.00
Institute Branches		
Meeting expenses	728.32	1,000.00
Trav. exp. District Conferences on Student activities	2,803.30	5,250.00
Trav. exp. Counselor Delegates to convention	536.75	1,100.00
Other expenses	1,832.87	1,910.00
Administration		
Headquarters salaries	31,468.23	32,750.00
Postage	3,228.54	3,300.00
Stationery and printing	3,230.05	3,300.00
Office equipment	424.74	500.00
Trav. exp. nat'l secy.	123.25	1,000.00
Telegraph and telephone, insurance, express, misc. supplies and services	2,491.21	2,350.00
Membership committee	7,315.43	7,125.00
Standards committee	5,394.61	6,775.00
American Standards Assn.	1,000.00	1,000.00
American Engg. Council	9,000.00	10,000.00
Engineering Societies		
Employment Service		
New York Office	3,201.39	3,400.00
Wash. D. C. rep.	333.32	
Traveling exp. general Board of directors	5,045.57	7,000.00
Geographical Dists.	1,100.60	2,250.00
Nat. nominating com.	1,300.67	650.00
President's appropriation	737.30	1,500.00
United Engg. Trustees		
Building assessment	5,153.31	5,882.28
Library assessment	8,586.39	8,759.60
Library equipment	468.75	2,111.38
Other committees and miscellaneous expenses	8,854.84	9,505.00
Total	$218,502.27	
Excess income, applied toward replacement of withdrawals from reserve capital fund, to meet operating deficits years 1930–32	27,820.10	
	$246,322.37	$250,057.26

representatives has been authorized this year as follows:

1. Seven and one-half cents per mile, one way, for each vice president of the Institute to one meeting each year of each Section and each Branch within his Geographical District, it being understood that joint meetings of Sections and Branches will be arranged as far as may be expedient.

2. Seven and one-half cents per mile, one way, for the vice president, the District secretary, the chairman of the District committee on Student activities, and either the chairman or the secretary of each Section within a District (or, if neither can attend, an alternate chosen by the executive committee of the Section) to one meeting each year of the District executive committee *held within the District*.

3. Seven and one-half cents per mile, one way, for the vice president and secretary of each District, and the counselor and the incoming Student chairman of each Branch within the District (alternates not authorized) to one conference on student activities *within the District* each year under the auspices of the committee on Student activities of the District.

4. Five cents per mile, one way, for one delegate from each Section to the annual summer convention.

5. Five cents per mile, one way, for one Student Branch counselor from each District, to represent the committee on Student activities of the District to the annual summer convention.

6. Five cents per mile, one way, to all members of the national nominating committee to the annual meeting of the committee, held during the winter convention.

It will be noted that the rate of 5 cents per mile, one way, has been retained for traveling expenses to meetings which will be held during the winter and summer conventions, when the certificate plan for a reduced return fare, and summer excursion rates, respectively, will be in effect. Similarly, the budget provides for payment of traveling expenses for attendance at the meetings of the board of directors and executive committee at the rate of 5 cents per mile, one way, for the January and June meetings and $7\frac{1}{2}$ cents per mile to all other meetings.

The recommendations of the finance committee with respect to traveling allowance were adopted by the board of directors with the understanding that the entire subject will receive further consideration by the committee, and subsequently by the board of directors at its January meeting.

OTHER ACTIVITIES

The remainder of the budget comprises those items for which further explanations, beyond a statement of the appropriation or activity, the amount expended last year, and the anticipated expense for the present year, probably are unnecessary. It will be noted that an annual contribution of $10,000 is being made to American Engineering Council. Payment of the balance of the Institute's share of the cost of new stacks for the Engineering Societies Library has been decided upon, in place of amortizing this expense over a period of 4 years, opportunity for which was afforded by United Engineering Trustees.

In the above brief presentation it has, of course, been quite impossible to describe the nature and relative importance of the various items which make up the annual budget. From an intimate knowledge of such affairs, however, the board of directors and finance committee have again endeavored to adopt a budget which places the proper emphasis on the different phases of Institute activities, and which limits the annual expenditures to the approximate total of anticipated income for the corresponding period. Obiously, the correctness of the information which has been prepared is largely dependent upon the prompt collection of annual membership dues, the chief source of Institute revenue, but with a knowledge of the excellent record of support contributed by the membership in the past, the board of directors and finance committee enter upon a new administrative year of the Institute confident that its efforts to maintain the Institute's record of services to all members and its substantial progress in the advancement of the electrical engineering profession are assured of success.

Montefiore Award for 1935 Presented

The triennial award of the George Montefiore Foundation of the University of Leeds, Belgium, has been presented for 1935 to Gabriel Kron (A'30), general engineering department, General Electric Company, Schenectady, N. Y. This prize, of 10,000 Belgian francs, was awarded for the best original work on scientific advancement and progress in technical application in any field of electricity submitted to the foundation for consideration.

The award to Mr. Kron was based upon a memoir which he entitled "Non-Riemannian Dynamics of Rotating Electrical Machinery," and submitted some time ago. Announcement of the availability of this prize was given in ELECTRICAL ENGINEERING for June 1934, page 1026. The first prize in this competition, which is international in scope, has not been awarded to an American since 1923 when it was won by Dr. J. B. Whitehead (A'00, M'08, F'12, life member and junior past-president), dean of the school of engineering, Johns Hopkins University, Baltimore, Md.

Heat Transmission Symposium to Be Held. The symposium on heat transmission to be held at Yale University, New Haven, Conn., December 30–31, 1935, under the auspices of the chemical engineering department, continues the policy inaugurated in 1934 by the division of industrial and engineering chemistry of the American Chemical Society, of holding special meetings for chemical engineering symposiums. The subject of heat transmission has been chosen for the forthcoming meeting, because of its wide appeal to chemical engineers, industrial chemists, and engineers in other fields. The tentative program includes 13 papers in the broad field of heat transfer, including heat conduction in solids, heat transfer by convection between fluids and solids, and heat transfer by radiation. Meetings will be held at the Sterling chemistry laboratory of Yale University, on Monday afternoon, December 30, Tuesday morning and afternoon, December 31. Any one interested is invited to attend whether a member of the division or not. There will probably be a small registration fee to cover the cost of preparing, in advance of the meeting, abstracts of the papers to be presented. A brief address of welcome will be given by Prof. R. E. Doherty (A'16, M'27), dean of the Yale engineering school.

American Engineering Council

A.E.C. Committees Meet in Washington

Preliminary to the annual assembly of American Engineering Council which will be held in Washington, D. C., on January 9–11, 1936, meetings of 2 of Council's committees were held in Washington, November 1 and 2, 1935.

The public affairs committee of A.E.C. met on November 1; this committee, made up of representatives of national and local societies, together with chairmen of the major subcommittees of the public affairs committee, discussed several major public policies in which engineers have an opportunity for the expression of opinion. The following subjects were included: administration of public works; development of areonautics; competition of government with engineers in private practice; development of water resources; the trend in patent legislation; and the demand for rural electrification. Approval was given to the development of complete reports on these subjects at the January meeting.

In line with Council's many actions on the basic federal survey and mapping program of the United States, it was voted that Council continue to work for a co-ordination of basic mapping activities and that such a mapping program should not be considered an emergency or relief measure, but a fundamental matter underlying any program of national planning. In the further discussion which developed around the relation of engineers to national planning, it was agreed that engineers, by their training and experience, can make contributions to social and economic as well as to technical features of planning in its national, state, and local phases.

The public affairs committee recorded itself as in complete sympathy with the efforts of the National Civil Service Reform League to establish a wider public understanding of the essential value of the merit system, and further co-operation of Council with other engineering bodies to support the merit system as the only sound basis for improvement in the technical services of the government was recommended. Also, it was proposed to co-ordinate further the work of the national, state, and local public affairs committees in order that Council, in all matters, may be truly representative as a complete cross section of the profession.

At the meeting of the executive committee of A.E.C. held November 2, the nominating committee, consisting of A. W. Berresford (A'94, M'06, F'14, member for life, and past-president) New York, N. Y., *chairman*, H. P. Eddy of Boston, Mass., and Robert W. Yarnall of Philadelphia, Pa., unanimously reported the selection of Dr. A. A. Potter, dean of the school of engineering, Purdue University, West Lafayette, Ind., as nominee for the presidency of Council for 1936–37.

United Engineering Trustees, Inc.

The Joint Engineering Organizations

United Engineering Trustees, Inc., organized in 1904, is now a joint agency of the 4 national societies representing the civil, mining and metallurgical, mechanical, and electrical engineers. It is organized in 3 departments, namely, the administrative department, The Engineering Foundation, and the Engineering Societies Library.

The administrative department manages the Engineering Societies Building and all trust funds placed in the hands of the United Engineering Trustees, Inc. The Engineering Foundation, founded by Ambrose Swasey (HM'28) in 1914, is entrusted with the expenditure of the income from endowments and other funds, its present preferred activity being engineering research. The Engineering Societies Library is a free public library which, with its numerous activities, is operated for users at a distance, as well as for those who visit its rooms in the Engineering Societies Building.

In the accompanying articles will be found announcement of the election recently held by United Engineering Trustees, Inc., and abstracts of the annual reports of this organization and of The Engineering Foundation. The recent election of The Engineering Foundation, held as part of the annual meeting on October 10, 1935, was reported in ELECTRICAL ENGINEERING for November 1935, page 1275.

This year, 1935, marks the advancing of the dates of annual meetings and elections of both these organizations, as a result of the new by-laws, which change the end of the fiscal year from December 31 to September 30. For both of these organizations in 1935, therefore, the fiscal year was only 9 months in length. Changes in the terms of officers and trustees of United Engineering Trustees, Inc., and of officers and directors of The Engineering Foundation, have been made, as announced in ELECTRICAL ENGINEERING for April 1935, page 457.

Election of United Engineering Trustees, Inc., Held

Officers to serve United Engineering Trustees, Inc., for the 1936 year were elected at the annual meeting of that organization held in the Engineering Societies Building, New York, N. Y., October 24, 1935. G. L. Knight (A'11, F'17) vice president in charge of mechanical operations of the Brooklyn Edison Company, Brooklyn, N. Y., was elected president of United Engineering Trustees to serve for the period ending at the annual meeting in October 1936. (A brief sketch of Mr. Knight's career is given in this issue of ELECTRICAL ENGINEERING, page 1423.) H. G. Moulton continues in office as first vice president, having been elected last January to serve for the period ending October 1936. At the recent annual meeting, Otis E. Hovey was elected second vice president, for the term ending October 1937. John Arms was re-elected secretary, and Albert Roberts was elected to serve as assistant treasurer, both for the term ending October 1936. The resignation of C. P. Hunt as treasurer was accepted, and the nominating committee was requested to make further suggestions for the office of treasurer.

The names of all members of the board of trustees of United Engineering Trustees, Inc., including both new members and hold-over members are given in the following tabulation:

Terms expiring October 1936	
John P. Hogan	A.S.C.E. representative
H. G. Moulton	A.I.M.E. representative
D. Robert Yarnall	A.S.M.E. representative
H. R. Woodrow (A'12, F'23)	A.I.E.E. representative
Terms expiring October 1937	
Otis E. Hovey	A.S.C.E. representative
Walter Rautenstrauch	A.S.M.E. representative
Terms expiring October 1938	
J. P. H. Perry	A.S.C.E. representative
A. L. J. Queneau	A.I.M.E. representative
Harold V. Coes	A.S.M.E. representative
George L. Knight (A'11, F'17)	A.I.E.E. representative
Terms expiring October 1939	
Albert Roberts	A.I.M.E. representative
H. P. Charlesworth (M'22, F'28, and past-president)	A.I.E.E. representative

Of these, J. P. H. Perry and Albert Roberts became new members, and H. V. Coes and H. P. Charlesworth became reappointed members, of the board of trustees at the annual meeting on October 24, upon presentation of credentials from the founder societies. All others are hold-over members. Mr. Rautenstrauch is completing the unexpired term of W. L. Batt.

COMMITTEES APPOINTED

The following committees were appointed by the president: finance committee, Otis E. Hovey, *chairman*, H. G. Moulton, Albert Roberts, Walter Rautenstrauch, and George L. Knight (A'13, F'17) *ex-officio;* real estate committee, H. R. Woodrow (A'12, F'23) *chairman*, J. P. H. Perry, A. L. J. Queneau, and H. V. Coes.

Annual Report Issued by United Engineering Trustees, Inc.

The annual report of United Engineering Trustees, Inc., for 1935 has been submitted by Harold V. Coes, president for the term expiring September 30, 1935. The fiscal year of 1935 covered 9 months only, January 1 through September 30; this was the transition period under the new by-laws, which changed the year end from December 31 to

September 30. In consequence, all acts were based upon an apportioned budget, for comparative purposes.

U.E.T. continues as treasurer for the Professional Engineers Committee on Unemployment (of the metropolitan area of New York, N. Y.) and has recently accepted appointment as treasurer for the Engineers' Council for Professional Development.

Improvements have been made to the Engineering Societies Building, particularly to the auditorium. The public address system has been improved, as have the seating arrangements. Obsolete types of lighting fixtures have been removed from the building, and replaced by better and more efficient fixtures.

Operations of U.E.T. have been simplified in several respects under the new by-laws.

The departments of U.E.T. are reported to have remained within their budgets for the year, which are made on a most conservative basis. Changes have been made in mortgages and other investments held, to the advantage of the corporation. A summary of the report of the finance committee of the corporation for 1935 appears in table I. If this tabulation is compared with the similar one for the preceding year which appeared in ELECTRICAL ENGINEERING for April 1935, page 458, it should be noted that the accompanying tabulation for 1935 does not include the founder societies' interest in the library, which, it is reported, was appraised at $480,800 in the year 1933. The aggregate book value of the investments included in the accompanying tabulation is $1,351,380.60 at September 30, 1935, and the aggregate valuation based upon market quotations on that date is $1,283,617.

Annual Report Issued by Engineering Societies Library

The annual report of the Engineering Societies Library for the period January 1 to September 30, 1935 has been submitted by Harrison W. Craver, director. It contains information on the use made of the library, its acquisitions and finances.

The number of users was 30,289, approximately the same as for the first 9 months of 1934. Of these, 22,399 were readers in the library, the remaining 7,890 being nonvisitors who contacted the library by mail or telephone. One hundred and ten searches and 90 translations were made and 128 books were lent to 114 members. There were orders from 1,671 persons for photoprints, requiring the taking of 13,214 photographs. Letters were written answering inquiries from 2,298 persons and 3,606 were assisted by telephone.

An interesting tendency is the increasing use of the library as a general intelligence office, or information bureau. Also, there was a large increase in the number of translations during the year, the number of works translated during the 9 months ending September 30, 1935, being slightly greater than that during the preceding 12 months.

Through purchase and gifts 7,877 items, consisting of books, pamphlets, and maps, were acquired. Of these, 5,180 pieces were not already in the collection. The current numbers of 1,353 periodicals were received, and 273 volumes, worth approximately $1,000, were sent by publishers for review.

Gifts amounted to 6,787 items. Among these were gifts from the estates of Axel O. Ihlseng, Calvin W. Rice, H. de B. Parsons, and John W Lieb. Valuable gifts also were received from R. A. Lesher, George C. Stone, R. W. Seabury, the Huntington Free Library Reading Room, the Parsons Steam Turbine Company, and the Amkniga Company.

On January 1, the library contained 134,344 books, 6,965 maps, and 4,241 manuscript bibliographies, or searches. The corresponding figures on September 20 were 136,464 books, 7,064 maps, and 4,259 searches. In addition 2,741 pamphlets were added to volumes which had been accessioned previously. The loan collection contained 815 volumes on September 30, and there were approximately 11,500 duplicate books on hand. All new material has been cataloged, many improvements in the catalog having been made.

During the 9 months, 17,389 references were added to the classified index to periodical literature, a greater number than in the 12 months of 1934. This was accomplished without any increase in staff. The index now contains about 132,000 cards, and has become a valuable guide to recent literature.

The budget for general operations during the calendar year 1935 as adopted by the trustees and the founder societies, was $42,800. Of this amount $33,300.10 consisted of appropriations by the founder societies, as follows:

American Society of Civil Engineers	$8,725.80
American Institute of Mining and Metallurgical Engineers	6,780.96
American Society of Mechanical Engineers	8,900.04
American Institute of Electrical Engineers	8,893.30

Expenditures for the 9 months amounted to $30,612.71. For work done by the service bureau $5,834.34 were received; the expenses of the bureau were $4,059.85.

Table I—Summary of U.E.T. Finance Committee Report for 1935

Operation of Building			
Operating revenue			$75,845.42
Less operating expenditures			72,635.51
Operating gain 1935			3,209.59
Operating credit previous years			1,667.23
1934 expenditure charged to depreciation and renewal fund in 1935			542.56
Credit balance Sept. 30, 1935			$ 5,419.70
Operation of Library			
Maintenance revenue		$32,194.57	
Maintenance expenditures		31,358.04	
Credit balance for year 1935		836.53	
Credit balance from previous year		$ 3,697.83	
Credit balance Sept. 30, 1935			$ 4,534.36
Service bureau revenue		$ 5,834.34	
Service bureau expenditures and adjustments		4,090.20	
Credit balance Sept. 30, 1935			$ 1,744.14
Total net operating credit balance cumulated to Sept. 30, 1935			$ 6,278.50
Funds and Property			
Funds Included:		**Book Value**	**Market Value**
Engineering Foundation fund		$ 783,132.74	
Edward Dean Adams fund		100,000.00	
Library endowment fund		174,544.32	
Depreciation and renewal fund		336,992.38	
General reserve fund		0.00	
Total		$1,394,669.44	
Less deferred charge—sale of securities		75,095.76	
		$1,319,573.68	
Total investment Sept. 30, 1935	$1,290,277.47		$1,235,215.00
Loans from depreciation and renewal fund	7,516.66		
Cash uninvested	21,779.55		
Total (see above)	$1,319,573.68		
Net loss on sale of securities	75,095 76		
Total (see above)	$1,394,669 44		
Real estate, cost of—Sept. 30, 1935		$1,987,793.92	
Operating cash		13,106.20	
Investments, operating cash		5,000.00	$ 4,978.00
Prepaid fire insurance		3,010.39	
Accounts receivable, gross		1,015.87	
The Engineering Foundation—unexpended income		25,372.17	
The Engineering Foundation—temporary investment		6,180.00	$ 6,300.00
Alloys of iron research—unexpended income		5,118.15	
The Engineering Foundation custodian fund assets		909.51	
Henry R. Towne engineering fund		50,000.43	$ 37,124.00
Total		$3,417,080.32	
Endowment committee (Adams Expense Fund)		$ 702.57	
John Fritz Medal Fund (Custodian)			
Securities held Sept. 30, 1935		$ 3,500.00	$ 3,430.00
Cash on hand Sept. 30, 1935		142.80	

Annual Report Issued by Engineering Foundation

The annual report of The Engineering Foundation for 1935, which this year includes the 9 months ending September 30, has been submitted by H. P. Charlesworth (M'22, F'28, and past-president) chairman of the Foundation, and Dr. Alfred D. Flinn, director.

A summary of the capital funds of The Engineering Foundation is as follows:

Endowments, total book value on September 30, 1935	$882,000
E. H. McHenry bequest, in hands of executors during lives of 2 beneficiaries, as appraised in 1931, approximately	400,000

A condensed financial statement of Foundation for the 9 months ending September 30, 1935, follows:

Resources		
Balance January 1, 1935		$21,781
Receipts		
Income from endowment and temporary investment of income balance	$26,906	
Income from minor items	663	27,569
Total resources		$49,350
Expenditures		
Research projects	$11,300	
Promotion of research and administrative expenses	6,698	
Total for furtherance and support of research		$17,998
Balance October 1, 1935		$31,352

Money contributions from organizations and individuals, for specific activities, passed through the Foundation's accounts from its organization to September 30, 1935, totaled $232,726.

Activities aided by Foundation during the 9 months ending September 30, 1935, included:

1. Continuation of the earths and foundations research, conducted by the American Society of Civil Engineers.

2. Continuation of the alloys of iron research, and the barodynamic research, both sponsored by the American Institute of Mining and Metallurgical Engineers.

3. Experimental studies of critical pressure steam boilers, boiler feed waters, effect of temperature on properties of metals, cottonseed processing, strength of gear teeth, and cutting of metals, conducted by The American Society of Mechanical Engineers.

4. A fundamental study of pure iron electrodes, in connection with welding, sponsored by the American Institute of Electrical Engineers.

5. Organizing and planning a comprehensive program for research in all branches of welding, sponsored by the American Institute of Electrical Engineers and the American Welding Society jointly.

6. Research projects of the Engineers' Council for Professional Development dealing with the accrediting of engineering schools, aptitude tests, self-appraisal methods for junior engineers, and evaluation of professional qualifications.

7. Studies by Personnel Research Federation of conference methods for dealing with employer-employee relations.

8. Research in the plastic behavior of concrete, at the University of California.

9. Investigation of the plasticity of metals, especially creep and relaxation, under the auspices of the University of Pittsburgh.

The policies of Foundation are stated in a platform adopted by its board June 14, 1935, and approved by United Engineering Trustees, Inc., and the founder societies. This platform includes a statement of the general plan and policy to be followed in assisting research projects which it approves. Information on Foundation and its activities can be obtained from its office, 29 West 39th Street, New York, N. Y.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or to reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Registration of Engineers

To the Editor:

In the October 1935 issue of ELECTRICAL ENGINEERING, on page 1129–30, I noted the comments on the registration of engineers by one of our members over at Lynn, Mass.

In the first paragraph of his comments, he speaks about the "intolerable burden on this country" which would be created by the registration of engineers as well as how "unbearably oppressive" as is such a movement. I wonder if this is a local condition or whether it is an individual idea. In this particular write-up he speaks for the whole country. In this State I know that such is not the case.

In his reference to the constant pressure of political influence on the board of examiners, I wonder if the medical, legal, and dental professions didn't encounter the same thoughts in their early stages of organization. Yet today we must admit that political influence doesn't enter into a doctor, dentist, or lawyer getting his license to practice. These professions have made an outstanding success of keeping politics out of their organization. I would hate to think that the engineers couldn't do the same.

There is no percentage in getting into a controversy with anyone on his expression of thoughts, on how he feels in such matters. However, I do feel the licensing of engineers is here. It is here to stay by virtue of the fact that it is a law in the majority of states. Whether engineers like it or not, the thing for us to do is to get in there and do our bit to see that such is taken care of in accordance with our ideas. One must not lose sight of the fact that it is a take and give proposition and you can't be a kid and have your own way all the time. One very obvious fact is that the licensing of the engineers has at least disturbed the slumbering of a large majority of them to the point where they are either talking to or about themselves. The other professions have found it necessary to change their status, codes, and ethics to conform with the present day trend. The engineer must realize that he has got to keep advance of the time or he will be more obsolete than ever. Common sense still plays a very important part in the elevation of any profession. There are too many successful engineers to allow the theory or the narrow paths of some of the few to successfully govern the profession as a whole.

The above are my personal opinions based on my experience gained from contacting engineers in a large portion of the U. S. A. It wasn't necessary for me to consult any members of any organization in making these comments.

Very truly yours,

J. LEO SCANLON (A'28, M'34)
J. Leo Scanlon Co.,
Sales Engineers
Ellicott Sq. Bldg.
Buffalo, N. Y.

Similarity Relations in Electrical Engineering

To the Editor:

There was recently published a paper "Similarity Relations in Electrical Engineering," by J. G. Brainerd and Jacob Neufeld (ELECTRICAL ENGINEERING, March 1935, pages 268–72), and subsequently a letter from Professor Weber (June 1935, pages 683–4) pointing out the necessity for inclusion of the quantities μ and K in any complete discussion of electrical dimensions.

No matter how frequently μ and K may be equated to unity and pushed out of sight, they always seem to bob up again and to inject into the discussion a perpetual query as to their nature.

It has frequently been shown (by equating the electromagnetic and electrostatic dimensional formulas for any one unit), that the quantity $\frac{1}{\sqrt{\mu K}}$ has the dimensions (LT^{-1}) of a velocity, and further that it is numerically equal to the velocity of propagation of light or electromagnetic waves in vacuum.

The dimensional equation

$$\frac{1}{\sqrt{\mu K}} = LT^{-1}$$

or, rearranged,

$$\mu = L^{-2}T^{2}K$$

prohibits the possibility of μ and K being, simultaneously, fundamental quantities, since, if K be taken as fundamental, μ

immediately has dimensions in L and T, and *vice versa*.

While no proof has ever been established, there is thus no prima facie reason why both μ and K should not be translatable in terms of the fundamental dimensions L, M, and T.

The equation for the velocity of propagation of a wave in an elastic medium,

$$V = \sqrt{\frac{E}{\rho}}$$

where E is elasticity and ρ is density, has been used by some writers (*e. g.*, T. F. Wall) to suggest, by analogy with the equation,

$$V = \sqrt{\frac{1}{\mu K}}$$

that μ might possibly be a measure of the density of the universal medium (whether or not modified by the presence of matter), and $1/K$ a measure of its elasticity.

It is interesting to push this suggestion to its logical conclusion by substituting $L^{-3}M$, the dimension of a density, for μ (or $LM^{-1}T^2$ for K) in the usual dimensional formulas.

At once all fractional indices disappear, while certain of the units reduce to dimensions which are, to say the least, suggestive.

Electric strain (D) of EM dimension $L^{-3/2}M^{1/2}\mu^{-1/2}$, reduces to zero dimension, the same as a mechanical strain.

Current (i), $L^{1/2}M^{1/2}T^{-1}\mu^{-1/2}$, resolves into L^2T^{-1}, suggesting diffusion.

Electromotive force (E), $L^{3/2}M^{1/2}T^{-2}\mu^{1/2}$, reduces to MT^{-2}, which may be interpreted as force per unit length.

Electric charge (Q), $L^{1/2}M^{1/2}\mu^{-1/2}$, becomes L^2, the dimension of a surface (electric charge resides *on* the surface of a conductor).

While resistivity (ρ), $L^2T^{-1}\mu$, reappears as $L^{-1}MT^{-1}$, with the same dimension as viscosity.

The foregoing is, of course, purely fanciful, and doubtless the ancient cry will be raised "Don't try to find a mechanical explanation for electrical phenomena."

There is no such intention, except in so far as mechanical, electrical and other phenomena may, at some future date, be found susceptible of a common explanation.

It is quite within the bounds of possibility that, in the working out of such a "common explanation," not only may μ and K be reduced to terms of L, M, and T, but further, the so-called fundamental M may be resolved into still more fundamental terms.

Very truly yours,

ERIC R. COE (A'29)
915 Far Hills Avenue,
Dayton, Ohio

Capacitor Motor With Double Cage Rotor

To the Editor:

The "Letter to the Editor" by A. F. Puchstein in the September 1935 issue of ELECTRICAL ENGINEERING, page 1018, of the possibilities of the double squirrel cage rotor in capacitor motors, involves the reactions of a squirrel cage in a single phase field.

The use of the double squirrel cage or its equivalent in capacitor motors has been proposed by Steinmetz and also Professor Bailey. A practical consideration of the problem indicates the handicaps that have prevented its use in general purpose motors.

The action of a squirrel cage rotor in a single phase field is quite different from its action in a polyphase, or true rotary field. With a single phase field, the squirrel cage in addition to carrying the mechanical load also transforms the alternating field to a rotary field. The effectiveness of this transformation depends upon low resistance and high mutual inductivity of the squirrel cage. With the double squirrel cage neither element is very effective. The high resistance, or starting component, having high resistance is ineffective due to its resistance, and the low resistance, or running component, is also ineffective due to its low mutual induction. Thus, with the double squirrel cage, the transformation of the alternating field into a rotary is imperfect, and as a squirrel cage is efficient only in a substantially rotary field; its efficiency in the single phase field is lower than in a polyphase field.

While the capacitor field has a rotary component independent of the rotor reactions which may be substantially rotary at one particular load condition, in practice, under the varying conditions the squirrel cage is still called upon to stabilize, and in a material measure generate the rotary field.

Further, since the low resistance, or load carrying component of the squirrel cage has high magnetic leakage, the power factor is lowered, thereby nullifying in part the capacitor effect, requiring larger capacitor.

This magnetic leakage also requires a higher primary flux, which in turn, calls for either a higher flux density with increased iron losses, or increased magnetic structure with increased cost. As the double squirrel cage introduces a lagging component, and is also less effective in producing a rotary field, it is antagonistic to best running characteristics.

Where it is required of the capacitor motor to have exceedingly high starting torque and especially if low starting current is desirable, together with low slip at running speed, the most logical solution seems to be the repulsion starting capacitor motor.

The capacitor field with a capacitor suitable for running conditions is predominantly single phase under starting conditions. This makes it possible to utilize the repulsion starting rotor the same as used in repulsion starting induction motors, with the same high torque and low starting current, characteristic of repulsion starting induction motors.

Very truly yours,

EDWARD BRETCH (M'19)
The Advance Electric Co.,
St. Louis, Mo

Personal Items

F. V. MAGALHAES (A'07, F'19) for the past year connected with the inventory of the properties of the Consolidated Gas Company, New York, N. Y., and previously with the General Electric Company at West Lynn, Mass., has been appointed assistant to the executive vice president of the New York (N. Y.) Edison Company, Inc. Mr. Magalhaes, who received the degree of electrical engineer from Brooklyn (N. Y.) Polytechnic Institute in 1906, has already had many years of experience with the New York Edison Company. After several short periods of employment with the company, alternated with school and other work, he entered the meter department in 1907, becoming superintendent 2 years later. In 1917 he was made superintendent of the test department also. From 1926 to 1928 he was general superintendent of distribution and installation, leaving the company to become vice president for engineering of the Hall Electric Heating Company. This company was liquidated voluntarily in 1932, at which time Mr. Magalhaes became commerical representative for the General Electric Company at West Lynn. He is now a member of the Institute's standards committee and of the committee on safety codes, of which he was chairman 1928–29 and 1932–34. He has been a member of the board of examiners since 1931, serving previously 1923–28, since 1928 has been Institute representative on the electrical committee of the National Fire Protection Association, and since 1930 has been representative on the National Fire Waste Council, previously serving for the year 1928–29. Mr. Magalhaes also has been active in the work of other organizations, and for some years was secretary and vice president of the U.S. national committee of the International Electrotechnical Commission.

GABRIEL KRON (A'30) general engineering department, General Electric Company, Schenectady, N. Y., has received the 1935 award of the George Montefiore Foundation of the University of Liege, Belgium, for his

GABRIEL KRON

G. L. KNIGHT

memoir entitled "Non-Riemannian Dynamics of Rotating Electrical Machinery." Mr. Kron, who was born in 1901 at Nagybanya, Hungary, came to the United States after having studied in Europe for several years. In 1924 he received the degree of bachelor of science in electrical engineering from the University of Michigan. Following several months during 1924 in the machine shop of the U.S. Electrical Manufacturing Company, Los Angeles, Calif., he became draftsman for the Jeannin Electric Company, Toledo, Ohio. Between 1925 and 1927, he was designer for the Robbins and Myers Company, Springfield, Ohio. In 1928, he was engaged in research for the Lincoln Electric Company, Cleveland, Ohio, and then became consulting engineer for the United Research Corporation, Long Island City, N. Y. Subsequently, he joined the organization of the General Electric Company, where he is now engaged. Mr. Kron is the author of numerous papers on tensor analysis.

B. W. Kerr (A'12) president and general manager, Railway and Industrial Engineering Company, Greensburg, Pa., was recently elected first vice president of the National Electrical Manufacturers Association. Mr. Kerr, a graduate of Princeton University, was employed by the Westinghouse Electric and Manufacturing Company and the Pittsburgh Railways Company before he came to the Railway and Industrial Engineering Company as assistant manager in 1910. He was vice president and general manager of the company from 1914 until 1918, when he became president. He is also president of the Electrical Development and Machine Company and the Kirk Interlock Company, both of Greensburg.

G. L. Knight (A'11, F'17, and past vice president) vice president in charge of mechanical operations, Brooklyn Edison Company, Inc., Brooklyn, N. Y., has been elected president of United Engineering Trustees, Inc., for the term ending October 1936. He also becomes an *ex-officio* member of the board of The Engineering Foundation. Mr. Knight, who was born at Haddonfield, N. J., graduated from the school of electrical engineering at Drexel Institute in 1900, and came to the Brooklyn Edison Company in 1905 as chief draftsman, having had a similar position previously with the New York Edison Company. In 1908 he was appointed designing engineer, and held this position until his appointment as mechanical engineer in 1924. Since 1932 he has been vice president. Mr. Knight, who has just completed serving as vice president of United Engineering Trustees, Inc., and as chairman of its finance committee, has been a representative of the Institute on the board of U.E.T. since 1933, having had a previous term 1926–31. He has served on many Institute committees, and was a manager 1922–26 and a vice president 1926–28. He is also a member of The American Society of Mechanical Engineers.

M. T. Crawford (A'07, F'22) who has been general superintendent in the central district of the Puget Sound Power and Light Company, Seattle, Wash., has been appointed assistant chief engineer in the newly enlarged engineering department, which will handle engineering for all districts and divisions of the company. Mr. Crawford, who was born at Louisville, Ky., received from the University of Washington the degrees of bachelor of science in electrical engineering in 1907 and master of science in electrical engineering in 1910. From 1906 to 1912 he was connected with the Seattle-Tacoma Power Company, becoming assistant engineer, and in 1912 accepted the position of superintendent in the water power department of the Puget Sound Traction, Light, and Power Company, which later became the Puget Sound Power and Light Company. He held successively the positions of superintendent of transmission and distribution divisions in the former company, and superintendent of distribution and general superintendent in the latter company. Mr. Crawford was a member of the Institute's committee on power transmission and distribution during 4 periods: 1916–17, 1919–20, 1924–26, and 1927–29.

E. W. Schilling (A'29, M'33) assistant professor of electrical engineering at Michigan College of Mining and Technology, Houghton, has been appointed associate professor. Doctor schilling, who received the degree of bachelor of science in electrical engineering from the University of Illinois in 1919, received the degrees of master of science in electrical engineering and doctor of philosophy in 1930 and 1933, respectively, from Iowa State College, where he was a member of the faculty from 1928 to 1931. He had previously been connected with the General Electric Company, Schenectady, N. Y., the B. F. Goodrich Rubber Company, Akron, Ohio, and E. W. Schilling and Company, Brandon, S. D. Doctor Schilling has been at the Michigan College of Mining and Technology since 1931.

H. A. Johnson (M'17) general manager, Chicago Rapid Transit Company, Chicago, Ill., has received the honorary degree of doctor of engineering from Purdue University, where he was graduated in 1905. Mr. Johnson has been employed by the railway company since 1905, and recently served as director of research for the mechanical engineering division of the American Railway Association, supervising tests to develop an improved type of air braking equipment. He is also a member of the Western Society of Engineers, and at one time was a member of the Institute's committee on transportation.

H. P. Charlesworth (M'22, F'28, and past-president) assistant chief engineer, American Telephone and Telegraph Company, New York, N. Y., has been elected chairman of the John Fritz medal board of award. Mr. Charlesworth has been a representative of the Institute on the board since 1932, and is now a member of the Edison medal, code of principles of professional conduct, and Institute policy committees of the Institute, as well as representative of the Institute on the board of trustees of United Engineering Trustees, Inc. In the past he has served on numerous committees and was president of the Institute 1932–33.

E. F. Pearson (M'20) who has been assistant chief engineer of the Northwestern Electric Company and Pacific Power and Light Company, Portland, Ore., has been made chief engineer of the Northwestern Electric Company. Mr. Pearson, a graduate of the University of Nevada, became assistant engineer of this company in 1913, and assistant superintendent of construction the following year. In 1919 he was made electrical engineer. During the year 1933–34 he was a member of the Institute's membership committee.

J. L. Dalton (A'35) has been awarded the A.I.E.E. scholarship for 1935–36, and is now studying at Columbia University, New York, N. Y., as announced in Electrical Engineering for November 1935, page 1274. Mr. Dalton was born at Glenside, Pa., March 19, 1912, and received the degree of bachelor of science at Pennsylvania State College in 1934. He was then employed in the electrical engineering department of the Reading Railway Company until the awarding of the scholarship.

H. E. Boatright (A'12, M'29) former division manager for the Guanajuato Power and Electric Company, Guanajuato, Mexico, has been made superintendent of operation. Mr. Boatright, who received the degree of bachelor of science in electrical engineering at Colorado College in 1907, has been with the company since 1924, when he became meter superintendent, 3 years later being made superintendent of maintenance and operation.

A. W. Berresford (A'94, F'14, member for life, and past-president) has been appointed Institute representative on the John Fritz medal board of award to fill the unexpired term, ending in October 1938, of the late J. Allen Johnson (A'07, F'27, and junior past-president). Mr. Berresford is also a member of the committees on Institute policy and safety codes.

Gerard Swope (A'99, F'22, and member for life) president, General Electric Company, New York, N. Y., has been elected a member of the board of governors of the Na-

tional Electrical Manufacturers Association. Recently he was elected a trustee of the New York Museum of Science and Industry. Mr. Swope was a member of the Institute's Iwadare Foundation committee 1931–35.

W. B. Tuttle (M'30) who has been president of the San Antonio Public Service Company since 1922, is now chairman of the board of directors of the company. Mr. Tuttle has been connected with the company since 1906, serving as vice president and general manager from that year until his appointment as president.

F. S. Benson (A'28) assistant electrical engineer in the department of engineering, Pacific Gas and Electric Company, San Francisco, Calif., received second prize for his paper suggesting standardization in a contest conducted by *Electrical West* on the question of how distribution costs could be lowered.

G. W. McCracken (A'22) who has been electrical engineer with the Birmingham Electric Company, Birmingham, Ala., has been appointed chief engineer. Mr. McCracken is a graduate of Kansas State Agricultural College, and was employed by electric companies in Cuba before coming to the Birmingham Electric Company in 1927.

F. B. Jewett (A'03, F'12, and past-president) vice president, American Telephone and Telegraph Company, and president, Bell Telephone Laboratories, Inc., has been elected president of the New York Museum of Science and Industry. Doctor Jewett is serving on several committees of the Institute.

P. R. Moses (A'94, F'12) electrical engineer, head of the firm of Percival R. Moses, New York, N. Y., is one of the incorporators of Electric Plant Owners Association, Inc., formed to unite the owners and operators of private plants in the city and state of New York.

E. B. Meyer (A'05, F'27, and president) has been appointed to serve as a special representative on the visiting committee of the department of electrical engineering of Massachusetts Institute of Technology for the academic year beginning October 1935.

S. L. Nicholson (A'00, F'13) assistant to vice president and general manager, Westinghouse Electric and Manufacturing Company, New York, N. Y., has been elected a vice president of the National Electrical Manufacturers Association.

W. D. Steele (A'00 and member for life) president, Benjamin Electric Manufacturing Company, Des Plaines, Ill., has been elected a member of the board of governors of the National Electrical Manufacturers Association.

W. J. Kidd (A'24, M'32) is now switchboard design engineer with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. He was formerly assistant system planning engineer for the Pennsylvania Power and Light Company.

C. L. Collens, 2d (A'07) president, Reliance Electric and Engineering Company, Cleveland, Ohio, has been elected a member of the board of governors of the National Electrical Manufacturers Association.

V. G. Dodds (A'26) Aluminum Company of America, is at Los Angeles, Calif., and not at San Francisco as announced in Electrical Engineering for November 1935, page 1281.

E. O. Shreve (A'06) assistant vice president, General Electric Company, Schenectady, N. Y., has been elected a vice president of the National Electrical Manufacturers Association.

H. R. Arnold (A'31) recently in the forestry service of the U.S. Department of Agriculture, is now transformer design engineer with the Westinghouse Electric and Manufacturing Company, Sharon, Pa.

J. F. Imle (A'32) geophysical engineer, has left the Humble Oil and Refining Company, Houston, Tex., and is with Lago Petroleum Corporation, Maracaibo, Venezuela.

P. H. Pierce (A'12, M'27) former engineer with Electrical Research Products, Inc., New York, N. Y., is now an engineer in the Bell Telephone Laboratories, Inc., New York.

A. B. Berresford (A'31) who recently received the degree of doctor of medicine from the Boston University School of Medicine, is now an interne at Waterbury Hospital, Waterbury, Conn.

A. H. Heitzler (M'24) superintendent of electrical department, Public Service Company of Colorado, Denver, has been elected a vice president of the Rocky Mountain Electrical Association.

W. C. Sterne (A'23, M'32) president and general manager, Arvada Electric Company, Denver, Colo., has been elected a vice president of the Rocky Mountain Electrical Association.

J. A. Wood, Jr. (A'30) who recently received the degree of doctor of philosophy from Cornell University, is now an instructor in electrical engineering at Massachusetts Institute of Technology.

W. L. Sullivan (A'34) who has been an instructor in the department of electrical engineering at Massachusetts Institute of Technology at Cambridge, is now at Stevens Institute of Technology, Hoboken, N. J.

S. H. Magruder (A'34) formerly employed by the U.S. Coast and Geodetic Survey, is now in the business training course of the General Electric Company at Schenectady, N. Y.

J. R. Seckman (A'20) former sales engineer for the International Machinery Company at Santiago, Chile, is now senior engineer for the State Road Commission of West Virginia, Clarksburg.

H. M. Platt (A'24) formerly with the National Electrical Manufacturers Association, New York, N. Y., is now secretary and treasurer of the Batavia Times Publishing Company, Batavia, N. Y.

F. H. Collins (M'31) former operations supervisor for the United Power and Light Corporation at Abilene, Kan., is now fire alarm superintendent for the city of Wichita.

T. N. Racheff (A'33) former supervisor for C. F. Burgess Laboratories, Madison, Wis., is now with the Commonwealth Edison Company, Chicago, Ill.

R. E. Thornton (M'32) formerly resident engineer at Sapulpa, Okla., for the Oklahoma Gas and Electric Company is now division engineer at Fort Smith, Ark.

R. H. Croll (A'28) formerly in the industrials division of the Worthington Pump and Machinery Company at Harrison, N. J., has been transferred to Buffalo, N. Y.

Obituary

Edwin Wilbur Rice, Jr. (A'87, F'13, HM'33, past-president and member for life) died November 25, 1935, as this issue of Electrical Engineering was going to press. A biographical sketch of Doctor Rice is scheduled for inclusion in the next issue.

Dudley Hyde Keyes (A'19) structural protection engineer, Bell Telephone Laboratories, Inc., New York, N. Y., died November 9, 1935. He was born December 17, 1883, at Eau Claire, Wis., and was a graduate of the electrical engineering course of the University of Wisconsin. He entered the engineering department of the Chicago Telephone Company in 1906, and in 1912 became an engineer with the Michigan State Telephone Company. Four years later he entered the engineering department of the American Telephone and Telegraph Company at New York, and recently was transferred to the Bell Telephone Laboratories, Inc., as assistant protection engineer. Mr. Keyes was chairman of the structural coordination committee of the Edison Electric Institute, and was the author of a recent A.I.E.E. paper.

Arthur J. Pates (A'25, M'27) telephone engineer, Chesapeake and Potomac Telephone Company, Baltimore, Md., died September 2, 1935. He was born at Boston, Mass., November 5, 1877, and studied electrical engineering at Harvard University. From 1904 to 1913 he was employed in the engineering department of the New York Telephone Company, and since 1913 had been in the engineering department of the Chesapeake and Potomac Telephone Company at Washington, D. C., and Baltimore,

where he was in responsible charge of the engineering of telephone plant equipments.

ALLEN HARWOOD BABCOCK (A'04, F'12, and past vice president) retired, Inverness, Calif., died October 26, 1935. He was born at Buffalo, N. Y., August 12, 1865, and studied at Lehigh University and at the University of California. In 1891 he was employed as draftsman by the Thomson-Houston Electric Company in San Francisco, Calif., and the following year was made assistant engineer; this company was a predecessor of the General Electric Company. In 1898 he took a similar position with the Standard Electric Company of California, becoming superintendent the following year. He then held the position of electrical engineer, successively, with the California Gas and Electric Company, North Shore Railroad, and Southern Pacific Company. During this time he was engaged in electrical traction work, and is credited with making the first installation of third rail electrification in California. He retained his position with the Southern Pacific Company until his retirement in 1932, serving also as consulting engineer for affiliated companies. He was a vice president of the Institute 1918–19, and was a member of the committees on traction and transportation, 1914–22; lighting and illumination 1920–21; and code of principles of professional conduct, 1915–35. He was a member of a number of organizations, and was the author of many professional papers.

Membership

Recommended for Transfer

The board of examiners, at its meeting held November 13, 1935, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Member

Baker, Horatio O., engr., N. Y. State Pub. Serv. Comm., Buffalo, N. Y.
Barr, Rowland W., E.E., Braden Copper Co., Rancagua, Chile, S.A.
Bauer, William M., instr. in E.E., Northwestern Univ., Evanston, Ill.
Brownlie, Wm. N., engr., Mutual Boiler Insurance Co. of Boston, Mass.
Campkin, Wilbert L., equipment supervisor, Saskatchewan Government Telephones, Regina, Sask., Can.
Copeland, Robert M., contracting E.E., Copeland Elec. Co., Jersey City, N. J.
Crawford, Fred D., supervisor, Brooklyn Edison Co., Brooklyn, N. Y.
Devine, Perle A., elec. tester, Public Service Co. of No. Illinois, Chicago.
Esty, Edward S., distrib. supt., Blackstone Valley Gas & Elec. Co., Pawtucket, R. I.
Hallenbeck, C. S., office mgr., long lines engg. dept., Am. Tel. & Tel. Co., New York, N. Y.
Honaman, R. Karl, protection methods engr., Bell Tel. Labs., Inc., New York, N. Y.
Kester, Harold J., sales engr., Westinghouse Elec. Mfg. Co., St. Louis, Mo.
Laidlaw, Hugh A., asst. engr. of operation, Pacific Gas & Elec. Co., San Francisco, Calif.
Ogur, Eugene, cons. E.E. and M.E., Newark, N. J.
Oman, Carl, E.E., Westinghouse Elec. and Mfg. Co., Newark, N. J.
Pfeil, Walter W., engr., Public Service Elec. and Gas Co., Newark, N. J.
Rice, Cortis N., valuation engr., Byllesby Engg. and Mgt. Corp., Chicago, Ill.
Tomlinson, Henry R., engr., New England Power Engg. and Service Corp., Worcester, Mass.

18 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before Dec. 31, 1935, or Feb. 28, 1936, if the applicant resides outside of the United States or Canada.

Anderer, J., N. Y. Hospital, New York, N. Y.
Arthur, R. S., Gen. Elec. Co., Phila., Pa.
Arutunoff, A. (Member), Reda Pump Co., Bartlesville, Okla.
Beatty, R., Union Elec. Lt. & Pwr. Co., St. Louis Mo.
Berry, E. W. (Member), State Trade Sch., Stamford, Conn.
Blackmore, A. H., Westinghouse Elec. & Mfg. Co., Houston, Texas
Brown, H. F., N. Y. Hospital, New York, N. Y.
Bruce, H. W., Dept. of Water & Pwr., City of Los Angeles, Calif.
Bruning, A. C., Columbus Ry. Pwr. & Lt. Co., Ohio.
Buehner, R. O. (Member), Am. Steel & Wire Co., Waukegan, Ill.
Chirgwin, W. C., Pub. Serv. Elec. & Gas Co., Newark, N. J.
Couts, F. H. (Member), Consumers Pwr. Co., Jackson, Mich.
Cramer, H. W., 109 Cumberland St., Brooklyn, N. Y.
Davies, F. H. (Member), Detroit Edison Co., Mich.
Davis, C. R., San Francisco–Oakland Bay Bridge, San Francisco, Calif.
Demmings, H. L., Lynn Gas & Elec. Co., Lynn, Mass.
Diefandahl, W. F., Brooklyn Edison Co., Brooklyn, N. Y.
Dobric, F. S., Reliance Elec. & Engg. Co., Cleveland, Ohio.
Duarte, P. J., Jr., 2a, Chiapas No. 31, Mexico, D. F., Mexico.
Dye, L. E., Los Angeles Railway Corp., Calif.
Eby, J. B. (Member), Am. Tel. & Tel. Co., Phila., Pa.
Ecklea, L. B., Consumers Pwr. Co., Jackson, Mich.
Edwards, F. E. (Member), N.Y. Central R. R. Co., Harmon-on-Hudson, N. Y.
Eighmy, L. W., Jr., Buffalo Gen. Elec. Co., N. Y.
Ellis, S. G., Westinghouse E. & M. Co., Chicopee Falls, Mass.
Endicott, H. S., Gen. Elec. Co., Pittsfield, Mass.
Escobosa, C. W., Pub. Util. Consolidated Corp., Nogales, Ariz.
Finley, K. G., Wash. Water Pwr. Co., Spokane.
Gager, F. M., Boston Col., Chestnut Hill, Mass.
Gallagher, J. P., N. Y. Pwr. & Lt. Corp., Schenectady, N. Y.
Galt, O. P., Ga. Pwr. Co., Canton.
Germeck, C. W., Gen. Elec. Co., Pittsfield, Mass.
Gersoni, H. B., Camp Lower Cispus F-34, Randle, Wash.
Golden, C. H., Texas Elec. Service Co., Ft. Worth.
Haas, H. (Member), Consumers Pwr. Co., Jackson, Mich.
Hahnloser, R. G., Gen. Elec. Co., Lynn, Mass.
Hall, W. G., Una Welding Inc., Cleveland, Ohio.
Hamilton, L. G., Gen. Elec. Co., Pittsfield, Mass.
Hardie, J. B., Jr., Reliance Elec. & Engg. Co., Cleveland, Ohio.
Hartwell, L. M., Jr., Am. Tel. & Tel Co., St. Louis, Mo.
Hedger, G. L., Canadian Gen. Elec., Fraserdale, Ont., Can.
Hissett, W. H. (Member), Sawbrook Steel Castings Co., Lockland, Ohio.
Hoag, S. B. (Member), Titanium Pigment Co., Sayreville, N. J.
Howard, G. A., Consumers Pwr. Co., Jackson, Mich.
Hutson, A. D., City of Gainesville, Fla.
Isom, C. W., Southwestern Bell Tel. Co., Dallas, Texas.
Jamison, W. M. (Member), Am. Tel. & Tel. Co., Chicago, Ill.
Jennings, A. S., Arma Engg. Co., Inc., Brooklyn.
John, G. J., 1549 West St., Utica, N. Y.
Kazmierski, V. C., N. Y. Hospital New York, N. Y.
Kendall, E. H. (Member), Consumers Pwr. Co., Jackson, Mich.
Key, W. A., Box 44, France Field, C. Z.
King, E. D. (Member), Detroit Edison Co., Mich.
King, G. L., Okla. Gas & Elec. Co., Okla. City.
Knox, J. P., N. Y. Hospital, New York, N. Y.
Kornfeld, LeR., Kansas City Pwr. & Lt. Co., Kansas City, Mo.
Lehman, M. L. (Member), Am. Tel. & Tel. Co., Phila., Pa.
Leonardon, E. G., Schlumberger Well Surveying Corp., Houston, Texas.
Le Vesconte, L. B., Westinghouse E. & M. Co., E. Pittsburgh, Pa.
Levine, M., Amdur Leather Co., Danvers, Mass.
Lewis, G. E., Vernon Lt. & Pwr. Co., Vernon, Calif.
McCord, O. P., Westinghouse E. & M. Co., New Orleans, La.
Mehr, C. A., 41 Derby Ave., Seymour, Conn.
Morris, R. C., Union Elec. Lt. & Pwr. Co., St. Louis, Mo.
Morton, A. R., Globe Union Mfg. Co., Milwaukee, Wis.
Muller, C. A. (Member), Am. Gas & Elec. Co., New York, N. Y.
Mullin, G. B., Jr., Gen. Elec. Co., Indianapolis, Ind.
Mullin, LeR. A., Syracuse Univ., Syracuse, N. Y.
Nellis, E. J., Brooklyn Edison Co., Brooklyn, N. Y.
Noell, J. J. (Member), T. V. A., Knoxville, Tenn.
O'Hara, E., Union Gas & Elec. Co., Cincinnati, Ohio.
Pettibone, G. H., Gen. Elec. Co., Schenectady, N. Y.
Phillips, H. H., Osborne Elec. Corp., Niagara Falls, N. Y.
Powers, W. H., 337 So. Main St., Ann Arbor, Mich.
Ranhofer, E. J., N. Y. Hospital, New York, N. Y.
Ransom, C. W., Gen. Elec. Co., Pittsfield, Mass.
Reynolds, F. J., N. Y. Hospital, New York, N. Y.
Rohats, N., Gen. Elec. Co., Schenectady, N. Y.
Sashoff, S. P., Univ. of Fla., Gainesville.
Shaw, O. J. (Member), Municipal Construction & Finance Co., Lincoln, Neb.
Shelby, R. E., Nat. Broadcasting Co., Inc., New York, N. Y.
Sherwood, E. T., Globe Union Mfg. Co., Milwaukee, Wis.
Sinks, A. T., Gen. Elec. Co., Lynn, Mass.
Smith, L. M. (Member), Ala. Pwr. Co., Birmingham.
Snediker, J. B. (Member), Am. Tel. & Tel. Co., New York, N. Y.
Stevenson, G. L., Detroit Edison Co., Mich.
Towers, R. C., Brooklyn Edison Co., Brooklyn, N. Y.
Tulloch, D. F., Edison Elec. Illum. Co. of Boston, Mass.
Underwood, L. T., Elec. Lt. Dept., Little Valley, N. Y.
Van Hamel, T. A., Gibbs & Hill, New York, N. Y.
Watts, T. O., E. L. Ruddy Co. Ltd., Toronto, Ont., Can.
Winther, R. O., Signal Elec. Mfg. Co., Menominee, Mich.
Wood, M. B., Chase Shawmutt Co., Newburyport, Mass.
Wright, C. P., Univ. of Manitoba, Can.
Wright, J. D. (Member), Gen. Elec. Co., Schenectady, N. Y.
Yeary, O. N., Texas Elec. Serv. Co., Ft. Worth.

96 Domestic

Foreign

Mita, N., Electrotechnical Laboratory, Ministry of Comm., Tokyo, Japan.
Romer, M. J., Rochussenstraat 200, Rotterdam, Holland.
Sirajuddin, A. W., Pub. Works Dept., Amritsar, India.

3 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as it now appears on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Chiofalo, J., 203 Graham Ave., Brooklyn, N. Y.
Crite, Mitchel, 32 E. 126th St., New York, N. Y.
Ghosh, K. C., c/o Compagnia Generale Di Elettricita, 34 Via Borgognone, Milan, Italy.
Golikoff, A., Main P. O. Gen. Del., Moscow, U. S. S. R.
Kimball, Gordon S., 154 Elmer Ave., Schenectady, N. Y.
Nelson, Charles J., 1515 N. Lotus Ave., Chicago, Ill.
Rozelle, P. M., 2018 Chestnut St., Harrisburg, Pa.
Soskin, Samuel B., 1141 S. Central Park, Chicago, Ill.
Spiegel, William F., 7 Stegman Court, Jersey City, N. J.
Vance, Paul E., c/o Marietta Mfg. Co., Point Pleasant, W. Va.

10 Addresses Wanted

1935 Index—Electrical Engineering and Transactions

This multientry annual reference index covers comprehensively the entire text content of the 12 issues of ELECTRICAL ENGINEERING published during 1935 and of the identical content of the 1935 A.I.E.E. TRANSACTIONS, volume 54.

Discussions have received particular attention and a special effort has been made to provide effective correlation between references to technical papers and to all published discussions of those papers. In this connection it is of importance to note that discussions of many technical papers published during the latter half of 1934 were published in the early part of 1935, and hence appear in this current index. Likewise, many discussions of the later 1935 papers will be published early in 1936, and consequently will not be found among the references contained in this current index.

For convenience in use, this index is subdivided into the following general divisions:

1. Technical subjects.
2. Authors, including the writers of discussions.
3. News items pertaining to Institute activities.
4. News items of a general nature.
5. Biographical (personal and obituary) items.

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